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PLATE
Product Lifetimes
And The Environment

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Editors

Linda Nhu Laursen & Andreas Kornmaaler Hansen
Aalborg University

DESIGN FOR LONGER LASTING PRODUCTS AND BUILDINGS · ENDURING CONSUMPTION · BUSINESS MODELS FOR LONGEVITY · REPAIR, CARE AND MAINTENANCE · PRODUCT LIFETIME MODELING · POLICIES FOR LONGER LIFETIMES · SUFFICIENCY AND DESIGN FOR LESS · REBOUND EFFECTS AND CRITICAL VIEWS ON PRODUCT DURABILITY · EDUCATION, TOOLS, AND GAMES FOR PRODUCT LIFETIMES · MATERIALS AND LONGEVITY · CLOTHING, FOOTWEAR, AND ACCESSORIES LONGEVITY · DIGITAL LONGEVITY

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Product Lifetimes: The Current Research Landscape

Linda Nhu Laursen[a], Andreas Kornmaaler Hansen[a], Amalia de Götzen[a], Carl Dalhammer[b], Eleonore Maitre-Ekern[c], Harald Wieser[d], Ingun Grimstad Klepp[e], Irene Maldini[f], Isabel Ordóñez[g], Jessika Richter[b], Johannes Roland Scholz[h], Katherine Townsend[i], Katherine Whalen[j], Kirsi Laitala[f], Kirsi Niinimäki[k], Lise Magnier[l], Luca Simeone[a], Mathias Lund[a], Romina Santi[m], Sofia Soledad Duarte Poblete[m], Stefano Salzillo[n]

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Introduction: In recent decades, the average lifespan of consumer goods has declined. This accelerating turnover of material goods is environmentally unsustainable. As researchers, we are uniquely positioned to build knowledge, interrogate and reshape the systems that drive shorter product lifetimes and premature obsolescence. As the Circularity Gap Report 2024 starkly reminds us, the urgency of this work cannot be overstated. Between 2016-2021 – in just six years – we have consumed 78% of the resources consumed in the entire 20th century (Fraser et al., 2024). At the same time, secondary material consumption has decreased from 9,1% in 2018 to 7,2% in 2023, which represents a 21% drop (Fraser et al., 2024). The environmental cost of this trajectory is staggering, and the circularity of material-use cannot keep up with the increase in global consumption.

The Product Lifetimes and the Environment (PLATE) conference brings together some of the leading researchers trying to address ways for us to align our consumption more realistically within our planetary means. Within the PLATE community, there is a shared recognition that the current patterns of production and consumption are unsustainable and that extending product lifetimes is a critical, though complex, strategy for reducing environmental impact. However, the mechanisms behind product lifetime extension may also come into question. Therefore, it is crucial to approach the topic of environmental impact caused by product consumption from different angles.

The tracks of the 6th Product Lifetimes for the Environment conference (PLATE2025), summarised here in this editorial, is indeed an effort to reflect the needed breadth and depth of this research agenda. Rather than isolated domains, these tracks form a dynamic and interconnected landscape of inquiry, each contributing to a more comprehensive understanding of how we can design, use, and govern products within planetary boundaries. In this editorial, we summarise publications from 12 thematic tracks. The contributions to PLATE2025 contribute to the broader trajectory of the field, it is both a reflection of the state of the art and a call to action. As we move forward, the PLATE community must continue to challenge assumptions, bridge disciplines, and imagine alternatives. Only then can we create and sustain products and societies that last.

Design for longer lasting products and buildings

Extending the lifespan of products and buildings is crucial for addressing climate change, reducing resource consumption, and promoting resilience. The contributions in this track examine how design practices, regulatory frameworks, business models, and user engagement can converge to enable more durable and adaptable systems, ranging from toys and packaging to mobility and the built environment.

A central theme is the interplay between design and regulation. Sporchia et al. (2025) highlight how current assumptions in building regulations, particularly those related to service life and end-of-life treatment, limit the climate mitigation potential of engineered timber. By revising these assumptions and enabling the reuse and cascading use of timber elements, design can unlock substantial environmental benefits. Schneider et al. (2025) contribute a methodology to support the selection and evaluation of R-strategies (e.g., reuse, remanufacture, recycle) based on the characteristics of specific product types. Applied to vehicle doors, this approach allows designers to compare design variants and assess circularity readiness at the component level.

Within the built environment, Viljanen et al. (2025) explore how product-service systems can support regenerative and long-lasting buildings by integrating material selection, maintenance services, and business models such as leasing or performance-based procurement. Similarly, Münster & Adriansen (2025) propose design strategies to transform underutilized commercial spaces into modular, multifunctional service hubs. Their work shows how architectural interventions can prolong not only physical lifespan, but also the social and functional relevance of buildings. Gaier & Kramer (2025) adds that circular construction practices must overcome systemic misalignments between project-based logic and long-term sustainability goals, calling for improved collaboration and governance.

Durability also emerges through user-centered design. Avcı (2025) introduces the concept of “Design for Evolving Play” to address premature obsolescence in toys. Through participatory design with children, the study reveals how adaptability, modularity, and emotional attachment can extend product life. This user-centric perspective is echoed by Komlóssy et al. (2025), who explore how co-creation can facilitate the implementation of circular design strategies by actively involving different actors in the repurposing of household goods.

Bradley, Corsini, Baird, et al. (2025) analyze reusable packaging systems, highlighting how factors such as stakeholder alignment, return logistics, and ownership models affect operational success. Dhondt et al. (2025) further investigate the redesign of single-use products for reuse, showing that effective implementation relies on coordinated action across design, infrastructure, and policy. Both studies emphasize that design for reuse is inherently systemic.

Rahman et al. (2025) present a national case of circular bioeconomy in Finland, where long-life wood-based products are embedded in a network of actors supported by public policy, research institutions, and regional cooperation. Finally, Ruggiero et al. (2025) examine the application of ecodesign methodology in the context of luxury yacht design. Their case illustrates how principles of circularity and durability can be balanced with high-end aesthetics and technical complexity, offering a useful reference for other sectors where performance and image are tightly coupled.

Taken together, the papers in this track show that designing for durability is not a singular technical act but a multidimensional effort. From product to policy, from material to meaning, enabling longer-lasting products and buildings requires new ways of thinking, collaborating, and designing across scales.

Enduring consumption

The abundance of products and ease of which consumers have access to a global market from the comfort of their homes has likely contributed to a shift away from enduring consumption.
It is of great importance to better understand the underlying mechanisms that promote enduring consumption of consumer products. The papers in this track focus on the emotional

dimensions and consumer perceptions that affect how products and materials are perceived. It dives into second-hand shopping and the importance of specific knowledge and competences for consumers to find it attractive to shop second-hand.

Özkürkçü & Doğan (2025) investigates ways to prevent plastic waste from the plastic toy market through imbedding emotional durability as a design strategy to promote more sustainable consumption. Most toys are typically discarded within 6 months. Repairability and ways to modify toys could help prevent this early replacement. Similarly, (Sun et al., 2025) identifies design strategies aimed at prolonging the epistemic value of consumer electronics. Consumer electronics is an important topic as e-waste continues to grow globally. To combat this, Zafer et al. (2025) highlights the need for sustainable design practices to reduce e-waste and prolong product use. They explore emotional value retention in consumer electronics, addressing design vulnerabilities that affect consumer emotions over time. Cooper et al. (2025) made a comparative analysis of household appliances and electronic goods over 25 years revealing trends in ownership, lifespan, and consumer attitudes towards acquisition, repair, and disposal. They found that the consumption patterns of household appliances and electronic goods remain environmentally unsustainable. Westervaarder & Mugge (2025) provides insights into consumer perceptions of product lifetimes and replacement behaviours and highlight the influence of societal trends and personal experiences on replacement decisions of electrical appliances. Steiner (2025) explores co-creation experiences in enhancing consumer engagement and product longevity, focusing on how these experiences can empower consumers to maintain, customize, and repair their products.
There are psychological differences between refurbished and new electronic products and Krishnan & Rana (2025) highlights how, with refurbished products, consumers prioritize battery health, service-related aspects, packaging, and hygiene, while new product buyers emphasize features and aesthetic factors. Nilsson et al. (2025) highlights the significant effort required for product circulation among consumers and reuse enablers. They emphasize the need to understand the entire product circulation process and identify three main circulation processes: *Donation*, *Commission Sale*, and *Sell-It-Yourself*. It reveals challenges in circular product transactions and the role of reuse enablers in facilitating recirculation.
Green & Treilhou (2025) identify a high level of invisibility regarding material things in daily interactions, suggesting that individuals often overlook the materiality of objects in their interactions with them. Frahm & Laursen (2025) presents second-hand shopping as a skill to be honed and trained, while (Irving-Munro & James, 2025) highlights consumer values and ethical beliefs regarding purchasing, use, and disposal experienced in C2C sales of second-hand clothing. As highlighted by Iving-Munro & James (2025) with second hand clothing, hygiene is also a perceived barrier in consumers for repurposed furniture (Sumter et al., 2025). Sumter et al. emphasize the importance of storytelling in enhancing the perceived value of repurposed products. Not all turn to repurposed furniture as indicated by the growing 'fast furniture' market. Furmston & Braithwaite (2025) advocates for further exploration of global dynamics in fast furniture consumption and the role of consumer education in sustainability initiatives.
Finally, Amatuni et al. (2025) assess the Total Cost of Ownership (TCO) for various products, integrating price, lifespan, and repair costs. The authors challenge the notion that higher-priced products are always more economical in the long run – in fact – results indicate that cheaper products can offer better long-term cost-efficiency and sustainability.

Business models for longevity

Extending product lifespans is central to advancing a circular and sustainable economy. As linear models driven by rapid consumption and planned obsolescence continue to strain environmental resources, business models that emphasise longevity through reuse, repair, refurbishment, resale, and leasing offer promising alternatives. These approaches reduce waste and emissions and generate new value propositions for consumers and industries alike. The Business Models for Longevity track brings together diverse empirical and conceptual contributions that explore how longevity-oriented models can be effectively implemented across sectors, focusing on real-world challenges, stakeholder dynamics, and design strategies.
The 14 papers in this track - comprising both extended abstracts and full research papers -

address product longevity through varied lenses and contexts, spanning fashion (Whalen, 2025), electronics (Bunodiere & Duflou, 2025; Proske et al., 2025), healthcare (Harding et al., 2025), packaging (Bradley, Corsini, & Ceschin, 2025), and furniture (Italia et al., 2025). Several contributions focus on consumer behaviour and market dynamics, highlighting how perceptions of value, trust in service models, and context-specific preferences influence adoption and effectiveness (Brask et al., 2025; Simmons et al., 2025). Others emphasise organisational and infrastructural enablers, such as the fit between reuse models and institutional settings, the role of supply chains in enabling second-life applications, and the importance of collaboration across value networks (Dokter, Mallalieu, et al., 2025; Suikkanen et al., 2025).

Design emerges as a recurring theme, particularly in strategies for take-back, reuse, and the prevention of product failure before market entry: user-centric product-service models and collaborative ecosystem design illustrate how product and service innovation can support longevity (Choi et al., 2025; Laursen et al., 2025). Governance and policy are also addressed, especially in contexts where coordination across actors, such as in healthcare or end-of-life product repurposing, is essential for system-level change (Ali et al., 2025; van Hees et al., 2025).

Collectively, these papers underscore the necessity of tailoring business models to specific social, cultural, and material contexts. They show that there is no one-size-fits-all solution; rather, effective models account for local behaviours, infrastructure readiness, and stakeholder alignment. They also call for greater experimentation, community participation, and data-driven frameworks to monitor, adapt, and scale longevity initiatives. Future research should deepen comparative analyses of circular models across geographies and industries, assess long-term environmental and economic impacts, and explore digital enablers for transparency and coordination. Expanding interdisciplinary collaboration between designers, technologists, policymakers, and consumers will be key to unlocking the full potential of business models that support sustainable product lifespans.

Repair, Care, and Maintenance

Repair and maintenance of products is a crucial part of what determines a product's lifetime. In most cases, people exhibit a higher willingness to repair products that they care about. As such, this track offers a glimpse into different facets beyond mere material properties and composition.

A large part of the papers highlights the importance of community together with repair, and how the act of repair may have multiple benefits beyond prolonging the life of a product e.g., how transformative repair may aid in situations of bereavement and loss (Keulemans et al., 2025). Community-led repair practices such as repair cafés also extend beyond their immediate environment, creating social bonds and developing skills (Korsunova & Lundberg, 2025; Markussen et al., 2025; Peirson-Smith et al., 2025; van Kaathoven et al., 2025). Such social repair spaces may serve to empower individuals through the act of repair (Hemstock & Herbert, 2025) that appears to have a positive and lasting effect on repair attitudes and behaviour through skill-sharing (Gorniak & Niinimäki, 2025). Taking onset in repair focused social hubs, Kalantidou & Brennan finds that such hubs may also be used for community renewal with a positive effect on a community's social responsibility e.g. indicating increased chances of employability for at risk youths by giving them a sense of belonging and by learning new skills (Kalantidou & Brennan, 2025b, 2025a). However, increased transparency and greater focus on such repair events is needed (Vung et al., 2025). People tend to throw away or store electrical or electronic equipment (EEE) rather than turning to alternatives such as repair cafés (Sahin et al., 2025).

Consumer knowledge plays a large role when it comes to whether products get repaired or not. Upton & James (2025) investigated performance swimwear and found that much swimwear falls victim to premature disposal due to lack of knowledge and maintenance. Similarly, (James et al., 2025) advocates for more responsible wardrobe management, and highlights how a big part of repair efforts currently is related to the level of attachment experienced to a piece of garment. Limited knowledge of repair and maintenance methods, or, perceptions of hygiene and expectation of a chronic "newness" leads to replacement before garments are functionally unusable (Peters,

2025). However, for textiles that are deemed unsuitable for resale, Mak et al. (2025) found that many stains, such as perspiration and oil, could be effectively removed, thus allowing for resale of treated items.

From a professional repairer's perspective, it is found that there is a lack of spare parts while original equipment manufacturers (OEM) often fail to provide important repair support, making it harder for consumers to repair their household appliances (Rovira-Menaya et al., 2025). Across consumer electronics, fashion, and furniture classifications, the price of repair and perceived repairability are significant factors influencing repair decisions for consumers (Hansen et al., 2025). Perceived obsolescence caused by limited skills and resources may be combatted by increased repair accessibility e.g. in the form of mobile repair stations (Çiftçi & Peters, 2025), through repair-focused service design (Apostolova et al., 2025) or using emerging technology to guide the repair process (Jin et al., 2025; Terzioğlu, 2025).

Designing products for repair is investigated from a fashion company's point of view by (Das et al., 2025) and from a problem-based learning perspective (beyond merely assembly and disassembly) by Parmentier et al. (2025) who present redesign of an electrical device where cognitive and physical interactions during repair are taken into account. However, van Dolderen et al. (2025) highlight that while design for repair may increase repairability, it may negatively affect mechanical recyclability, which may be important to consider in one's product design.

Finally, Hirpa et al. (2025) highlight a bigger repair culture of EEE in Ethiopia compared to EU countries, while (Møller et al., 2025) argues how experiences with repair in one's upbringing predicts one's tendency to repair products later in life.

Product lifetime modelling

The ability to model product lifetimes is increasingly critical for enabling sustainable design, policy development, and circular economy strategies. The papers in this track provide both methodological advancements and applied insights into how product lifetime modelling can support repair, reuse, extended use, and informed decision-making across sectors ranging from packaging and furniture to electronics and mobility.

A key theme across contributions is the integration of Life Cycle Assessment (LCA) with lifetime modelling to better account for the environmental impacts of extended use. Audrain & Cuénot (2025) propose an LCA approach to quantify the environmental benefits of repair and reuse in the WEEE sector. By comparing scenarios of replacement versus extension of use for household appliances, their model demonstrates that even moderate lifetime extensions can lead to substantial reductions in climate impact, especially when low-impact spare parts are used. Similarly, Anand et al. (2025) investigate how LCA studies of remanufactured products capture or omit usage-specific parameters. Their systematic literature review reveals a predominance of assumptions and a lack of empirical modelling of user behaviour, suggesting that current LCA practice often fails to reflect actual usage conditions.

Focusing on the textile and footwear sector, Costanzo et al. (2025) analyse how lifespan is modelled within LCA studies for garments and shoes. Their review classifies functional unit definitions into approaches based on care cycles, number of wears, years of use, or durability tests. The authors argue that while diverse modelling approaches exist, a harmonized method is needed to fully capture the interplay between consumer behaviour and product performance.

Clemm et al. (2025) shift the focus to reuse interventions in the smartphone market, using a population-level simulation model informed by consumer survey data. Their analysis shows that extending warranties for second-hand smartphones significantly increases reuse rates and lowers demand for new products, while other interventions (like free data erasure services) have a negligible effect. Their approach demonstrates how behavioural data can inform macro-level modelling to estimate the climate benefits of circular interventions.

Nguyen et al. (2025) provide a conceptual and empirical distinction between individual and cumulative lifespan of products through a study on furniture. They show that while individual ownership is influenced by emotional attachment, it is the accessibility of resale or donation systems that most strongly drives cumulative longevity. This reframes lifetime extension as a systemic property, influenced as much by social and logistical infrastructure as by design.

On the regulatory and reporting side, Nicolajsen et al. (2025) examines how lifetime extension activities are currently underrepresented in national statistics. Using data from Danish

reuse organizations, the study highlights significant discrepancies between actual reuse activities and their categorization in official datasets, calling for improved data infrastructure to support lifetime-based policies. Finally, Pathan & Aurisicchio (2025) assess 21 circularity indicators for packaging to evaluate how well they capture the concept of product lifetime. Their analysis finds that most indicators are biased toward end-of-life management and neglect short use cycles, regulatory conditions, and infrastructure aspects, suggesting a need for more holistic indicators that account for the reality of single-use products.

The contributions in this track explore how product lifetime can be extended through a variety of strategies, ranging from data-informed modelling and circularity indicators to behavioural insights and repair-supportive policy frameworks. Together, they offer a multifaceted look into how the duration of use is shaped not only by product features but also by systemic conditions, assessment methodologies, and user interactions.

Policies for longer lifetimes

Policies aimed at extending product lifetimes are receiving increasing attention as governments and institutions seek to advance circular economy (CE) objectives. There is growing momentum for regulatory frameworks addressing durability, repairability, and obsolescence, but challenges remain in enforcement, scope, and socio-political alignment. The European Union (EU) has emerged as a global leader in developing policies that promote longer product lifespans. This is partly explained by EU Member States' adoption of progressive policies. Dalhammar et al. (2025) highlight France's pioneering measures, including the criminalization of planned obsolescence, mandatory repair indices, and repair vouchers. These national policies have not only influenced EU-wide initiatives, such as the Ecodesign for Sustainable Products Regulation (ESPR), but have also raised concerns about the trade-offs of harmonization potentially diluting progressive standards. Meanwhile, Gulati et al. (2025) critically assess the ESPR's capacity to address premature obsolescence, noting that while it addresses technical and economic factors, it falls short in tackling symbolic obsolescence and consumer culture.

These behavioural dimensions are explored by Bretschneider (2025), who applies an institutional economics lens to show that disposal decisions for electronics are shaped by ownership and disposal costs, highlighting hurdles that cannot be solved by regulation alone. Complementing this, Beigi & Franconi (2025) propose a "Design for Traceability" framework that uses digital passports and smart identification technologies to enhance transparency, accountability, and lifecycle tracking, enabling better enforcement and circular business models.

Globally, regulatory efforts remain inconsistent. Cipriano (2025) contrasts Brazil's statutory ambiguity on spare part availability with the EU's fixed-term requirements, arguing this conflicts with CE objectives. In Australia, O'Neill et al. (2025) analyse the country's "Right to Repair" inquiry and reveal that obsolescence is framed primarily as a matter of consumer choice, thereby shifting responsibility away from producers. Despite stakeholder support for mandatory design interventions, the resulting policy recommendations emphasized product labelling over regulation.

Policy fragmentation is also evident in sector-specific contexts. Bhatnagar et al. (2025) examine textile policy in Europe and find that while regulatory intensity has increased post-2020, many policies still prioritize recycling over durability or reuse. Similarly, Ferrero-Regis & Pushpamali (2025) critique Australia's narrow recycling focus, especially in Queensland, where the lack of a roadmap for textile circularity marginalizes small businesses and higher-order strategies like repair and upcycling.

Policies for longer lifetimes in the built environment reveal similar gaps. Thaher et al. (2025) examine Queensland's construction sector, where policy incentives emphasize recycling over more transformative practices like disassembly, deconstruction, and material reuse. They call for stronger regulatory alignment and infrastructure to promote higher-order circular strategies.

There is also a need for policies to move beyond only focussing on technical efficiency to question the scale and speed of production and consumption. Molnár & Dalhammar (2025) introduce a sufficiency-oriented policy perspective. Arguing that current policies often emphasize doing more with less, while neglecting the need to simply do less. Sufficiency approaches—such as promoting repair, shared ownership, and longer legal guarantee periods—remain underrepresented

in mainstream policy despite their potential for transformative change.

Sufficiency and design for less

The *Sufficiency and Design for Less* track rethinks consumption from a minimalistic, resource-conscious perspective and offers a vision for sustainable futures rooted in frugality, imagination, and responsibility. The four presented papers demonstrate that sufficiency is not about doing without, but about doing differently, rethinking value, redefining waste, and reorienting desire.

One paper by Hansen & Laursen (2025) explores actor constellations that reveal the potential of manufacturing "new waste" through collaborative redesign. By studying real-world cases, the authors show how partnerships among designers, manufacturers, waste processors, and distributors can turn discarded materials into viable products, when aligned business goals and material flows exist. This actor-resource-activity approach presents sufficiency as a systemic challenge, enabling to meet needs within planetary limits by curbing excessive consumption levels.

Granato & Mugge (2025) investigate how combining static and dynamic social norms influences sustainable fashion choices. Across two studies, the authors found that messages highlighting widespread and increasing overconsumption (unsustainable static and dynamic norms) led participants to buy fewer clothing items and support consumption-reduction policies. This effect is explained by social moral cleansing, that is, people's inclination to compensate for others' unsustainable behaviour. The findings offer a novel approach to promoting sufficiency through norm-based communication.

Konovalov & Remm (2025) present six creative research methods that foster engagement with nature, positive activism, and the aesthetics of degrowth. Using gardening as a metaphor, they explore how artistic and design practices can strengthen our response-ability and shift focus from doing more to doing meaningfully.

In their paper, Magnier et al. (2025) investigate how perceived sacrifices shape consumers' willingness to adopt sufficiency behaviours in clothing, such as buying less, choosing second-hand, sharing, or extending garment lifetimes. It identifies seven types of sacrifice, from emotional to financial, and shows how these perceptions can act as barriers to change. By uncovering the subjective and varied nature of what people feel they must give up, the study offers valuable insights for designers, policymakers, and marketers aiming to make sufficiency possible and appealing.

Finally, Vermeyen et al. (2025) explore the potential of adopting smaller wardrobes as a path to sufficiency in fashion. Through wardrobe audits and reduction exercises, the authors reveal how much clothing people really need, challenging the norms of overconsumption. While practical and emotional barriers remain, the study highlights how prioritising versatility and emotional connection to garments can support a shift from excess to essentials, opening up new possibilities for more mindful and sustainable ways of dressing.

Together, these papers show that sufficiency is not about less for the sake of less, but about reimagining systems, behaviours, and desires to align with planetary limits. They offer inspiring pathways toward sustainable futures, where creativity, collaboration, and conscious choices redefine what it means to live well with less.

Rebound effects and critical views on product durability

Research and policy on product lifetime extension (PLE) and durability has traditionally taken for granted that these approaches lead to environmental and social benefits in line with circular economy objectives. These advantages are expected to materialise in lower demand for new products by consumers and reduced volumes of production by industry. However, instead of being 'used up' and turning into waste, many products fall out of use long before they break down. Moreover, products that remain in use do not necessarily prevent the demand and production of additional products (Maldini et al., 2025b), as the volume of materials circulating and stocked in affluent regions is continuously growing (Krausmann et al., 2017; Wiedenhofer et al., 2021). It has been traditionally assumed that PLE leads to delays in product replacement, and accumulation has been ruled out as an equally feasible result of product longevity (Maldini et al., 2025b). Under these conditions, highly durable products may fail to limit overconsumption and even exacerbate the environment impacts of production and end of life of more robust products, and the energy and infrastructure needed to maintain growing volumes of materials in use (Conn, 1977; Wieser et al.,

2023). Durable products and infrastructures can also create lock-in effects that hinder change towards more sustainable practices (Haberl et al., 2017). To account for such important phenomena, more integrative perspectives are needed that consider not just matters of speed and waste, but also how they interact with high volumes and resource intensities in use (Wieser et al., 2023).

Since little attention has been paid to the actual environmental effects of PLE within the growing research community on product lifetimes, this session is an invitation for critical self-reflection: Are we moving in the right direction? Are our efforts really helping to reduce material depletion? Are the material and behavioural conditions needed for PLE to have the desired effect present in our everyday lives? What new ways of thinking can help us in advancing the field for more significant impact?

The contributions that will be presented in this track include assessments of rebound effects associated with PLE efforts (Makov & Meshulam, 2025) and ways to prevent them (Mammen et al., 2025; Mckay et al., 2025). Other studies offer design perspectives (Mammen et al., 2025; Rückschloss & Tochtrop, 2025; van der Loo et al., 2025) or critical perspectives of PLE related policies (Klepp et al., 2025; Richardy et al., 2025). The track includes a combination of conceptual papers building on literature reviews (Klepp et al., 2025; van der Loo et al., 2025) and proposing methods and models (Guzzo & Pigosso, 2025; Mammen et al., 2025; Mckay et al., 2025), and the results of empirical research aimed at understanding the daily and interconnected nature of product use (Hegnes et al., 2025; Makov & Meshulam, 2025; Petersen et al., 2025). Some of the specific product categories studied are clothing (Klepp et al., 2025; Makov & Meshulam, 2025; Richardy et al., 2025), electric appliances (Rückschloss & Tochtrop, 2025), cars (Mckay et al., 2025), and disposable products such as gloves (Hegnes et al., 2025) and diapers (Petersen et al., 2025).

Altogether, these contributions provide a starting point to critically reflect on the relation between PLE and environmental impacts focusing on concrete situations or product categories. What is expected from the discussion and exchange at the conference is a broader discussion about the usefulness of PLE to enable a positive environmental transition. This angle also provides a promising direction for future critical research. Are rebound effects a consequence of imperfect application of circular economy ideas, or the inevitable result of a framework that is unfit to tackle the environmental crisis?

Education, tools, and games for product lifetimes

This track focuses on engaging and informing various stakeholders to foster circularity and extend product lifetimes. The 10 full articles and 3 extended abstracts are informative and practice-oriented, with eight describing digital or physical tools and four incorporating games or gamification strategies. Contributions address different lifecycle stages: design & production (8), use-phase & maintenance (4), and end-of-life (7). They target a diverse range of actors, including designers, manufacturers, and marketers (5), product users (6), and end-of-life stakeholders (3). The work collectively addresses the complexity of circular transitions through inter- and transdisciplinary approaches, combining qualitative and quantitative methods from design, psychology, sociology, engineering, and IT.

Various physical and digital tools developed to educate, guide, and engage stakeholders in circularity are showcased. (Dumon et al., 2025) analyse 10 new circularity tools intended to support companies in circular product design. (Dokter, Silva, et al., 2025) explore the “Social Impact Audit Tool” (SIAT) in a product design project course. (Schoen et al., 2025) develop an indicator to evaluate the environmental benefits of robotic production in manufacturing hotel furniture. (Ko et al., 2025) present a framework for the development of Digital Product Passports (DPPs) in various product categories, testing it with a third-party DPP for iPads in schools. Whalen & Renström (2025) test the “Collaborative Circular Value Creation Canvas,” a tool developed to enhance communication between companies and identify circular collaboration opportunities.

Games and gamification, as standalone tools or as parts of physical or digital tools for communicating circularity, are increasingly being researched and applied to engage new groups and simplify complex systems. Reinhard & Schmidt (2025) offer a smart city App containing an AI-driven circular consumption and a gamification-driven biowaste tool. Scholz et al. (2025) develop a collaborative card game to communicate circularity principles from the perspective of

material recovery initiatives that recirculate items from existing waste streams.
Three articles educate product designers and users. Lewe & de Lamballerie (2025) test citizen engagement activities for sustainable clothing consumption. Barrios-O'Neill et al. (2025) aim to "translate" the process of biobased textile recycling by using interdisciplinary, multisensory, and speculative design. Hall et al. (2025) explore, via interviews, how sustainability information about circularly designed garments is communicated to users, noting frequent information loss in the supply chain. The two remaining articles describe innovative pedagogical approaches addressing design students. Flipsen & Persaud (2025) describe the experience of using productive failure theory in an elective on "repair." Patnaik & Isaacs (2025) present a multidimensional pedagogical approach that applies waste management knowledge for a combination of entrepreneurship and sustainability.

The development and application of tools, gamification and games, and educational approaches appear to support circularity and the transition toward longer product lifecycles. However, research and evidence on the long-term effects of such interventions on actual product circularity and lifecycle stakeholders remain notably scarce.

Materials and longevity

Materials durability is today a critical issue for addressing environmental sustainability in a profound and systemic way. Rethinking materials' longevity and temporality requires questioning durability in relation to technical, expressive and sensorial qualities, aesthetic transformation, socio-cultural meanings and their role in shaping more equitable, circular and responsible futures.
From fashion to furniture, and from reclaimed to bio-based materials, the contributions in this track reflect the complexity of reconciling durability with environmental sustainability. While several authors present material innovations and circular strategies with strong applicative potential — including bio-based composites for indoor use (Turhan-Haskara, 2025), man-made cellulosic fibres for textiles (Durán-Rubí & Vence, 2025), blended recycled fabrics for circular systems (Forst & Goldsworthy, 2025), and the integration of technical, aesthetic and emotional dimensions in textile design (Andersen et al., 2025) — these approaches also bring to light critical tensions like the systemic risks of overproduction in the fashion sector (Durán-Rubí & Vence, 2025) and the fragile perception of reused materials in specific social contexts (Behal et al., 2025).
At the same time, these tensions invite a broader reading of materials as active agents embedded in cultural, ecological, and affective contexts, whose evolution and perceived value are shaped by time and use as illustrated by Ramage & Bassereau (2025), who reinterpret discoloration as a meaningful trace of ageing, and by Briones Castro & Schmidt (2025) who explore the expressive and performative complexity of upcycled textiles. The affective and perceptual dimensions of design are further investigated by (Guarino et al., 2025), exploring emotional and relational durability through care by the integration of living organisms in wearables, and by Bahrudin et al. (2025), who address the human 'sense of order' by combining biomaterials with a formal 'mechanical aesthetic'.
The topics of circularity and material reuse are widely discussed. Addressing pre-consumer industrial waste, Lund & Laursen (2025) present a model for integrating upcycling into ongoing business practices. In parallel, Sander & Laursen (2025a) introduce the "Reshape" strategy, aimed at preserving the functional and aesthetic integrity of materials, and propose to overturn dominant paradigms by embracing imperfection as an integral part of material experience, consciously designing for change over time Sander & Laursen (2025b). Moreover, as shown by (Sumter et al., 2025) in the context of repurposed furniture, strategies that aim to foster durability must carefully balance functionality with identity, symbolic coherence, and perceived quality. In a similar direction, Alan et al. (2025) propose a narrative-based design approach, employing material journey mapping and anthropomorphism, to reveal the transformation of discarded materials and strengthen material–user relationships.
The challenge of material longevity calls for interconnected disciplines and coordinated approaches. Escande & Shea (2025) argue for the development of circular computational methods that are applicable at an industrial scale. Eheliyagoda et al. (2025) show that improving the recyclability of critical elements requires supportive policies and infrastructures. Goeppel et al. (2025) emphasize the socio-economic dimensions of lithium battery recycling, while Ferraresi & Curto (2025) highlight the persistent gap between ecodesign

principles and material selection in industrial practice.
Looking ahead, several key research directions emerge across the different thematic trajectories addressed in this track. These include the systemic integration of ecodesign with materials development and selection; a deeper investigation into user-material relationships to support behavioural change; and an expanded exploration of criteria and methods for assessing material sustainability and circularity — including social and economic dimensions. Altogether, this collection of contributions invites a critical and creative rethinking of materiality, longevity, and temporality — toward the design of systems capable of lasting through change.

Clothing, footwear, and accessories longevity

Several papers in this track highlight the important aspect of attachment to products we own and wear. Attachment process strongly connects to formation of our self-identity through appearance, abstract symbols but also through wear experience. The self-identity can be connected to the image of garments or shoes (Lombard et al., 2025), use practices (Matthews, 2025) or changes on our body (Gal, 2025). Researchers navigate a circular fashion future through concepts of attachment and detachment, focusing on personal fashion practices related to modifying, auditing and tracking well-loved clothing items (Matthews, 2025) including casual, formal, and velskoene footwear (Lombard et al., 2025). The role of spirituality (Martinez, 2025), and mindfulness (Huang et al., 2025) are emerging themes in attachment discourse. Research shows that spiritual mindset can even reduce consumers' need for external approval for their appearance (Martinez, 2025). Oppositional contexts of luxury fashion (McNeill & Ibrahim, 2025) and even the interest to use repair services (Karell & Niinimäki, 2025) are also explored as responsible behavioural catalysts. Different methods for measuring durability are proposed by researchers assessing the use, failure and disposal of everyday items such as T-shirts (Morris et al., 2025), and workwear (Hall, Taudal, et al., 2025; Thiyagarajan et al., 2025). Upcycling is envisioned as a creative and social practice that is essential for testing and upscaling pre-consumer textiles (Child, 2025) and post-consumer clothing waste streams (Vanacker et al., 2025). Remanufacturing is perceived as an opportunity for the empowering Township elderly women (Khumalo et al., 2025), while the hyper-local recirculation of secondhand clothing is supporting sustainable innovation through donation-thrift networks (Kozlowski et al., 2025).
In transiting from linear economy model to circular one, designers need help and tools to implement this change. An advisory tool for circular material selection offers fashion designers a route to extending clothing longevity (Thiyagarajan et al., 2025). Fashion hacking and zero waste fashion (Salomè, 2025), as well as modular fashion (Zhang et al., 2025) and remaking approaches (English, 2025) challenge the design practices even at the industrial level (Borcherdt & Child, 2025).
LCA Lifecycle analysis are needed to assess the environmental impacts (Dahan et al., 2025) e.g. in laundry (Zuin et al., 2025) and it can be done by using open-source tool (Makov & Vivanco, 2025). It is also worthwhile to raise critiques towards assessment methods and tools that are used as well as towards ecolabels and their content. Researchers propose e.g. adopting a system-based lifecycle approach to improve the current ecolabels (Kesidou & Palm, 2025).
Even while we are researching the sustainable practices and strategies in design or manufacturing, consumers still play an important role in longevity of product lifetimes. Accordingly, it is important to research garment lifetimes from the angle of consumers and through the aspect of active garment use (Kuzmycz & McCorkill, 2025), reuse and garment lifetime expectations (Payne et al., 2025) and even explore the potential of clothing swaps to enable the reactivation of passive garments (Vermeyen & Germeys, 2025).

Digital longevity

The emergence of digitalisation across various practices and industries is inevitably changing the world and hereby has an impact on the environment. This paper track addresses both the opportunities presented by digital tools across sectors and the need for critical reflection on their broader implications.
Corsini & Terzioğlu (2025) explores how digital technologies like IoT, AI, and digital twins can support a circular economy in the Electrical and Electronic Equipment (EEE) sector. Through a horizon scan and case study analysis, the study identifies opportunities to extend product lifecycles and improve resource use, while also addressing risks such as increased e-

waste. The findings highlight both the potential and challenges of building a digitally enabled circular economy for EEE.

Similarly, another study by Lange et al. (2025) identifies business opportunities for high-tech SMEs adopting Digital Product Passports (DPPs). The study presents a roadmap that highlights benefits such as extended product lifecycles, improved supply chain transparency, and hands-on learning, using literature reviews, stakeholder interviews, and four co-creation workshops with engineers, service teams, business developers, and managers from six companies. Adu et al. (2025) emphasise five key areas for circularity and ecological sustainability in Germany and Europe's information and communication technology sector. These were identified through a systematic approach involving surveys, expert interviews, roadmap analysis, literature review, and market research. The study highlights the need for green data centers, power electronics, quantum technologies, circular microelectronics, and sustainable supply chains.

Wetherell et al. (2025) provide a more specific example of use of digital tools, by exploring how digital 3D tools and archived design patterns support the redesign and remanufacturing of deadstock garments. Two case studies assessed the impact of CLO3D on product longevity: one focused on historical garment archives and the other on a contemporary collection of 30 deadstock sportswear garments. The study shows potential in how digital tools can help expand the use and value of existing garments.

Finally, van der Velden (2025) introduces the concept of "digital degrowth," which calls for realigning digital technologies to be regenerative, ecologically sound, and socially just. Her work reflects on the rebound effects of digitalisation and emphasises the need for resource efficiency in digital efforts.

Together this paper track explores the sustainable possibilities of digitalisation while also highlighting the importance of critically reflecting on its unintended consequences.

Concluding remarks

The PLATE2025 contributions underscore the urgent need to extend product lifetimes as a multifaceted strategy for environmental sustainability. It highlights how design, consumer behaviour, business models, policy, education, and digital tools must align to reduce material throughput and foster circularity. While promoting durability, repair, reuse, and sufficiency, the PLATE community also critically examines potential rebound effects and systemic barriers that may undermine these efforts. Ultimately, it calls for interdisciplinary collaboration and reflective practice to ensure that longevity truly contributes to sustainable and equitable futures.

References

Adu, L., Aslan, T., Gorlova, K., & Thesen, M. (2025). Navigating Trends and Ecological Sustainability Needs in Germany and Europe's ICT Industry. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment, Aalborg.

Alan, A. C., Gelmez, K., Efilti, P., Yılmaz, O., Sezgin, H., Yalçın, İ., Öztemur, J., & Özdemir, S. (2025). Exploring Material Potentials for Product Design: In Pursuit of a Narrative-Based Approach. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Ali, M., Andersen, P. H., Anvari-Moghaddam, A., Nielsen, R. P., & Eng, M. (2025). Re-purposing Wind Turbine Blades: Matching Strategies and Inno- vation Governance Forms. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Amatuni, L., Faludi, J., & Sprecher, B. (2025). The Hidden Cost of Cheap: Are We Paying More for Short-Lived Goods? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE).

Anand, K., Ryan-Fogarty, Y., & Fitzpatrick, C. (2025). Life cycle assessment (LCA) of remanufactured electrical and electronic products; a review of methodological choices. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Andersen, K. R., Skjold, E., Nyvang, L., Bang, A. L., Tolnov, A., Harsaae, M. P., & Jørgensen, P.-E. (2025). Design-ability in the Circular Economy of Textiles. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Apostolova, V. Y., Simeone, L., & Laursen, L. N. (2025). A Preliminary Review of Service Design for Repair Practices. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Audrain, G., & Cuénot, L. (2025). Coupling LCA and product lifetime modeling to support repair & reuse: A case study in the WEEE sector—Plate Conference 2025. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Avcı, E. O. (2025). Design for Evolving Play: Exploring Levels of Adaptability in Toy Design. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Bahrudin, F. I., Kian, L. Y., Zakariya, K., Daud, N., & Dong, P. (2025). Sense of Order: The Effects of Machine Aesthetic on Biomaterials Favourability. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Barrios-O'Neill, D., Ribul, M., Pisapia, C. T., Yan, Y., Rungta, D., Selby, L., Ren, X., Quintana, C., Morrow, R., Lanot, A., McQueen-Mason, S., & Baurley, S. (2025). Learning by Transforming: Widening Access to Complex Circular Economy Science using Experimental Design. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Behal, A., Islam, S., & Tan, C. S. L. (2025). Exploring Parental Engagement in Sustainable Practices for School Uniforms: A Circular Economy Perspective. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Beigi, H., & Franconi, A. (2025). Design for Traceability (DfT): How to enhance transparency and accountability by designing products and materials with features that allow their entire lifecycle to be tracked and documented? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Bhatnagar, A., Manivannan, A. C., & Niinimäki, K. (2025). European Policy Strategies for Textile Product Life Extension: Current Implementation and Challenges. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Borcherdt, M., & Child, E. (2025). A Shared Vision: The importance of Knowledge Exchange through Co- design in Scaling Circular Strategies for Fashion Remanufacture – Case studies from global perspectives. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Bradley, C. G., Corsini, L., Baird, H. M., & Ceschin, F. (2025). Reusable Packaging Systems: Design recommendations for fostering and sustaining consumer adoption. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Bradley, C. G., Corsini, L., & Ceschin, F. (2025). Implementing reusable packaging systems: Lessons from industry. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Brask, L. G., Greve, N.-P., & Hansen, A. K. (2025). Exploring Consumer Behavior on Product Longevity as a Pathway to Product-Service System Adaptation. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Bretschneider, W. (2025). Getting rid of electrical and electronic equipment. Disposal decision and service life in the light of institutional economics. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Briones Castro, Y., & Schmidt, S. M. (2025). Circular fashion and new materialities from repurposing waste: A discussion on the opportunities for the valorisation of material design from and for wearable garments. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Bunodiere, A., & Duflou, J. R. (2025). Enhancing Critical Raw Material Usage through Battery Cell Extraction and Reuse. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Child, E. (2025). Testing methods of remanufacture of pre-consumer textiles in scalable environments. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Choi, Y. J., Dong, J., & Pyon, J. (2025). Exploring take-back recovery strategies in the Circular Economy: A Multiple Case Study Analysis. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Çiftçi, G., & Peters, G. (2025). Mobile Fixer Studio: How to repair one item at a time on campus. *Proceedings of the 6th Product Lifetimes*

and the Environment Conference. Product Lifetimes and the Environment (PLATE), Aalborg.

Cipriano, T. A. R. P. (2025). Availability of spare parts and product lifetime in Brazilian law. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Clemm, C., Amatuni, L., Chun, Y.-Y., & Moon, D. (2025). Measuring the Impact of Smartphone Reuse Interventions on Consumer Choice and Product Lifetime – Preliminary Findings. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Conn, W. D. (1977). Consumer product life extension in the context of materials and energy flows. *Resource Conservation: Social and Economic Dimensions of Recycling*, 127–143.

Cooper, T., Watkins, M., Javareshk, M. B., & Baguley, T. (2025). Have prospects for product life-spans improved? A comparison of trends in household appliances and electronic goods over 25 years. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE).

Corsini, L., & Terzioğlu, N. (2025). Building a Digital Circular Economy for Electrical and Electronic Equipment. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment, Aalborg.

Costanzo, A., Frey, M., & Niero, M. (2025). Exploring Lifetime Modeling Approaches in Life Cycle Assessment of Textiles and Footwear. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Dahan, A., Benkirane, R., Scaglia, T., & Thomassey, S. (2025). Test less, better, faster, cheaper. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Dalhammar, C., Vonderscher, F., Leonet, S., & Richter, J. L. (2025). National leadership for legislating longer product lifetimes: French policies and their interaction with European Union policies. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Das, M., Ahsan, N., & Rooy, D. V. (2025). Unveiling the Power of Repair Services in Enhancing Consumer Repair Behaviour in the Fashion Industry: A Crucial Step Towards a Circular Economy. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Dhondt, K., Harding, C., & Watts, R. (2025). Redesigning single use to reuse: Identifying opportunities for surgical instrument sets. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Dokter, G., Mallalieu, A., Hallstedt, S. I., & Isaksson, O. (2025). Collaboration towards the design of sustainable and circular value chains: Reviewing the state-of-the-art in literature and practice. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Dokter, G., Silva, P. F. B., Tuveson, J., & Hammersberg, P. (2025). Navigating social sustainability in engineering education: Student experiences and challenges of using a social impact audit tool in a product design project. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Dumon, L., Parmentier, D., Hoveskog, M., & Ostuzzi, F. (2025). Examining longevity in tools for a circular economy. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Durán-Rubí, E., & Vence, X. (2025). Regenerated cellulose fibers synthesized with recycled textiles: A circular bioeconomy milestone for material longevity or another fiber overproduction escalation? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Eheliyagoda, D., Veluri, B., Liu, G., & Ramanujan, D. (2025). Can Circular Economy Strategies Limit the Prospective Dysprosium Demand in the European Union? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

English, J. (2025). Categorising Remaking Methods for Fashion Practitioners. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Escande, M., & Shea, K. (2025). Computational Circular Design of Planar Linkage Mechanisms Using Available Standard Parts. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Ferraresi, S., & Curto, B. D. (2025). Towards an integrative approach for ecodesign

principles and sustainable material selection. A systematic literature review to explore scholarly contributions at the intersection of materials, sustainable design and household appliances. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Ferrero-Regis, T., & Pushpamali, C. N. N. (2025). Gendered threads: Policy barriers to sustainable textile lifecycles. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Flipsen, B., & Persaud, S. M. (2025). Experiencing Design for Repair, educating circular practitioners. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Forst, D. L., & Goldsworthy, K. (2025). Compatible blending for circular textiles with next-gen materials. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Frahm, L. B., & Laursen, L. N. (2025). Not Just Luck: Uncovering the Secret Skills and Expertise of Second-hand Shoppers. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Fraser, M., Conde, Á., & Haigh, L. (2024). *Circularity Gap Report 2024*. https://policycommons.net/artifacts/11317813/cgr-global-2024/12203525/

Furmston, K., & Braithwaite, N. (2025). How "Fast" is Fast Furniture? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Gaier, J., & Kramer, S. (2025). Design for Circularity (DfCE) – How to Align Product Requirements With R-Strategies to Enhance Circular Economy on an Operational Level. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Gal, A. (2025). Design for Sustainability: A Multi-level Framework from Products to Socio-technical Systems. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Goeppel, P., Ott, J., Zimek, M., & Baumgartner, R. J. (2025). Assessing socio-economic impacts of Lithium-Ion Battery recycling through Multi-Regional Input-Output Analysis. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Gorniak, K., & Niinimäki, K. (2025). "Spring Cleaning": Skill-sharing towards conscious clothing consumption. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Granato, G., & Mugge, R. (2025). Leveraging social norms for sustainable behaviour: How the exposure to static-and-dynamic-norm communications encourage sustainable behaviour towards reduction of fashion consumption. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Green, C., & Treilhou, S. (2025). Guilty (or invisible) materiality in everyday object relations? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Guarino, N., Ferraro, V., & Rognoli, V. (2025). Designing materials with living organisms for care-based practices: An analysis of case studies within the wearables domain. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Gulati, B., Dillenseger, L., Cresci, I., & Luzzati, T. (2025). Does the EU Eco-design for Sustainable Product Regulation Address Premature Obsolescence? A Systemic Perspective on Barriers to Longer Product Lifetime. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Guzzo, D., & Pigosso, D. C. A. (2025). The rebound mechanisms identification tool: Finding rebound effects in circular economy business models. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Haberl, H., Wiedenhofer, D., Erb, K.-H., Görg, C., & Krausmann, F. (2017). The Material Stock–Flow–Service Nexus: A New Approach for Tackling the Decoupling Conundrum. *Sustainability*, *9*(7), Article 7. https://doi.org/10.3390/su9071049

Hall, C. A., Ravnbøl, K., & Pedersen, J. (2025). Communicating Circular Design: A ReSuit case study of embedding knowledge of circularity from design to wholesale to shop assistant. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Hall, C. A., Taudal, S. L., & Bundgaard-Nielsen, M. J. (2025). Defining Worn Out Workwear: Exploring how to assess garments for reuse within a laundry system. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Hansen, A. K., & Laursen, L. N. (2025). One man's trash is another man's treasure: Actor constellations to prolong the life of 'new waste' resources. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Hansen, A. K., Laursen, L. N., & Jørgensen, M. S. (2025). Worthy or not worthy? Repair motivations and barriers from consumers across fashion, furniture, and consumer electronics in Denmark. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE).

Harding, C., Watts, R., & Travella, P. (2025). Matching reuse models to hospitals: Reframing value-chains for reusable medical products. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Hegnes, A. W., Heidenstrøm, N., & Laitala, K. (2025). Hygiene practices in everyday Life: Exploring the adoption and environmental implications of disposable gloves. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Hemstock, O., & Herbert, D. (2025). Repair as a vehicle for grassroots leadership in transition towards circular economy. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Hirpa, H. K., Desissa, T. D., & Duflou, J. R. (2025). E-Waste Management Trend in Ethiopia: Strategies for Extending Electronics Lifecycles. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Huang, S., Bakker, S., & Xue, H. (2025). Why Do You Buy? Introducing a Reflective Café Approach to Foster Mindful Clothing Purchases in Generation Z. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Irving-Munro, A., & James, A. (2025). The Consumption Economy – Finding Value in Our Clothing. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Italia, M., Pei, X., & Migliozzi, S. (2025). Designing a collaborative ecosystem for sustainability transition in the furniture industry: The Opendesk case. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

James, A., Peirson-Smith, A., Mutambo, N., Nicolson, S., & Irving-Munro, A. (2025). The Care and Repair Guide: Reducing Environmental Impact and Addressing Skills Gaps in Responsible Wardrobe Management. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Jin, Y., Mugge, R., Balkenende, R., & de Hooge, I. (2025). The Value of Emerging Technologies for Enhancing Consumer Trust and Adoption of Repair Electronics. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Kalantidou, E., & Brennan, T. (2025a). Repair as a driver of community-led behavioural change. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Kalantidou, E., & Brennan, T. (2025b). Repair-focused social enterprises for environmental and social resilience. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Karell, E., & Niinimäki, K. (2025). Consumers' interest in using clothing repair services in Finland. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Kesidou, E., & Palm, C. (2025). Ecolabels in the Textile and Fashion Industry: Strengths, Weaknesses, and Recommendations for Improvement. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Keulemans, G., Gaughwin, M., Jansen, T., & Parkes, B. (2025). Transformative repair beyond materiality: Care, bereavement and loss. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Khumalo, M., Patnaik, S., & Chisin, A. (2025). Empowering Township Elderly Women: Upcycling Post-Consumer Waste Clothes into Sustainable Livelihoods. *Proceedings*

of the 6th Product Lifetimes and the Environment Conference. Product Lifetimes and the Environment (PLATE), Aalborg.

Klepp, I. G., Maldini, I., & Laitala, K. (2025). The limitations of product longevity: Are longer product lifetimes really better for the environment? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment, Aalborg.

Ko, J., Okafor, N., Badurdeen, F., & Wang, P. (2025). Development of a Digital Product Passport for iPads to Enhance Student Sustainability Practices. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Komlóssy, T., van Dam, S., & Bakker, C. (2025). Implementing circular design strategies through co-creation: An action-research case in the household goods sector. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Konovalov, M., & Remm, J. (2025). Creative research methods for engagement with nature, positive activism and the aesthetics of degrowth. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Korsunova, A., & Lundberg, P. (2025). The ReMake Cafes as a source of well-being: Being, doing and interacting as motivations to participate. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Kozlowski, A., McQueen, R., Roy, L., & Little, C. (2025). Hyper-Local Recirculation of Second-hand Clothing Through Donation-Thrift Networks. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Krausmann, F., Schandl, H., Eisenmenger, N., Giljum, S., & Jackson, T. (2017). Material Flow Accounting: Measuring Global Material Use for Sustainable Development. *Annual Review of Environment and Resources*, *42*(Volume 42, 2017), 647–675. https://doi.org/10.1146/annurev-environ-102016-060726

Krishnan, K., & Rana, A. (2025). Behind the Stars: Consumer Personality and Review Composition for New and Refurbished Products. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Kuzmycz, A., & McCorkill, G. (2025). Idle and Active Dresses: Design Briefings from the Wardrobe. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Lange, K., Helmus, J., Boermans, D., & Oskam, I. (2025). Accelerating Circularity in High-Tech Manufacturing: Towards a Roadmap for Implementing Digital Product Passports (DPPs) at SMEs. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment, Aalborg.

Laursen, L. N., Barros, M., Nielsen, C., Nøkleby, C., & Nielsen, K. (2025). No Product Lifetime! Why products fail pre-consumer. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Lewe, E., & de Lamballerie, E. (2025). Citizen Engagement Activities: Applying Behaviour Change Techniques in Sustainable Clothing Consumption. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Lombard, E., Taljaard-Swart, H., & Jacobs, B. (2025). I feel more like myself when I wear my velskoene: Exploring South African male millennial consumers' attachment to their velskoene. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Lund, M., & Laursen, L. N. (2025). Upcycling from 'One-of-a-Kind' to Industry Scale: Leveraging Strategies to Prolong the Life of Industrial Waste Materials. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Magnier, L., Kobus, C., & Tunn, V. (2025). Perceptions of sacrifice in the pursuit of sufficient consumption. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Mak, W. S., McQueen, R., & Kozlowski, A. (2025). Treat and Clean: A pilot study in stain removal and mending of substandard thrift store donations. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE).

Makov, T., & Meshulam, T. (2025). Recommerce Rebound Effects- The Case of Second-hand Apparel. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment, Aalborg.

Makov, T., & Vivanco, D. F. (2025). Environmental Impact factors for Apparel Products: Generalizing LCAs with Statistical "Market-mix" Modeling. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Maldini, I., Klepp, I. G., & Laitala, K. (2025a). The environmental impact of product lifetime extension: A literature review and research agenda. *Sustainable Production and Consumption*, *56*, 561–578. https://doi.org/10.1016/j.spc.2025.04.020

Maldini, I., Klepp, I. G., & Laitala, K. (2025b). The environmental impact of product lifetime extension: A literature review and research agenda. *Sustainable Production and Consumption*, *56*, 561–578. https://doi.org/10.1016/j.spc.2025.04.020

Mammen, A. L., Hartvigsen, E. M. D., Pigosso, D. C. A., & Van der Loo, I. (2025). Nudging as a strategy to prevent behavioural rebound effects in the early phases of design. *Proceedings of the 6th Product Lifetimes and the Environment Conference*, 277301 Bytes.

Markussen, T., Jørgensen, M. S., Dorland, J., Laursen, L. N., & Hansen, K. (2025). Repair Cafés as Circular Economy Enablers: Exploring Participants Practices through Social Practice Theory. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE).

Martinez, C. M. J. (2025). Exploring spirituality's location in sustainable clothing consumption through "Black Swan" narratives. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Matthews, R. (2025). Wearing and sharing #wardrobechallenges: Finding inspiration when you have nothing to wear. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Mckay, L., Meneguim, L., & Pigosso, D. C. A. (2025). Leverage Points as an Analytical Framework for Preventing Rebound Effects: An Exploratory Study. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

McNeill, L. S., & Ibrahim, K. (2025). Can Promoting Fashion Innovativeness Move Traditional Luxury Consumers Toward More Sustainable Fashion Behaviours? - Plate Conference Proceedings Template 2025. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Møller, S. R., Schmidt, K. S.-H., & Laursen, L. N. (2025). Repairing the upbringing: Socialization and product repair behavior. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Molnár, M., & Dalhammar, C. (2025). Sufficiency in European Product Policies: Status Quo and Future Potentials. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Morris, K., Joynes, A., Sumner, M., Scott, E., & Taylor, M. (2025). Measuring physical garment durability: An assessment of 47 T-shirts. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Münster, M. B., & Adriansen, H. K. (2025). From Empty Shops to Vibrant Communities: Adaptive Reuse as a Sustainable Response to Retail Decline. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Nguyen, A. K., Birkek, C. O., & Hansen, A. K. (2025). Convenience as a Key Driver in Extending the Cumulative Lifespan of Furniture. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Nicolajsen, A. B., Bjørn, A., McAloone, T. C., & Pigosso, D. C. A. (2025). Mind the gap: To what extent are Danish early adopters of science- based targets addressing impacts across their products´ life cycles? *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Nilsson, K., Frahm, L. B., Rexfelt, O., Strömberg, H., & Laursen, L. N. (2025). Turning Trash into Treasure is Hard Work! How the Activities of Consumers and Reuse Enablers Extend Product Lifetimes. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

O'Neill, M., Maguire, R., Hurst, B., & Walton, A. (2025). What's the Problem with Product Obsolescence? Critical Policy Perspectives from Australia's Right to Repair Inquiry. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Özkürkçü, E., & Doğan, Ç. (2025). Exploring Emotional Attachments in Children's Toy Relationships: A Generative Co-Design Approach to Design for Sustainability. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Parmentier, D., Dumon, L., & Detand, J. (2025). Designing products that facilitate easy and intuitive repair, an implementation in product design education. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Pathan, R. K., & Aurisicchio, M. (2025). Circularity Indicators for Packaging: A Literature Review and System-Based Classification. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Patnaik, S., & Isaacs, S. (2025). Entrepreneurship and Waste Management: Cultivating Sustainable Solutions Through Education. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Payne, A., Jiang, X., Street, P., Leenders, M., Nguyen, N., Pervan, S., & Tan, S. L. (2025). The influence of age, gender and income on Australians' expectations of clothing lifespan. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Peirson-Smith, A., Wetherell, S. V., Singer, E., James, A., Irving-Munro, A., Mutambo, N., & Nicolson, S. (2025). Repairing and regenerating the community: A study in activating. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Peters, E. (2025). Reviving Bedlinen: User Expectations, Use-Life, and Repair Practices in Australia. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Petersen, M. K., Ankerstjerne, V., Bubinek, R., & Cimpan, C. (2025). No Product is an Island: The Case of Incontinence Pads in a Nursing Home. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Proske, M., Morozov, A., Poppe, E., & Nissen, N. F. (2025). Beyond Ownership: The Environmental Impact of Rent, Repair and Refurbishment of ICT devices. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Rahman, R., Korsunova, A., Dmitrijeva, A., & Toppinen, A. (2025). Circular bioeconomy business ecosystem in Finland: From barriers to solutions for wood reuse in construction. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Ramage, L., & Bassereau, J.-F. (2025). Lightfastness Natural Color Database: A tool for designing evolving effects on textile surface through sunlight exposure. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Reinhard, J. B., & Schmidt, I. (2025). From Clicks to Circular Behavior: A Smart City Mobile Application Leveraging AI and Gamification. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Richardy, J., Skjold, E., & Skødt, T. (2025). The Wicked Problems of Durability: Rebound Effects and Textile Illiteracy in Circular Policy. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Rovira-Menaya, P., Pina, C., & Sierra-Pérez, J. (2025). Existing barriers to consumer repair of small household appliances from a product design approach: A scoping review. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Rückschloss, J., & Tochtrop, C. (2025). "Oh no, it's broken!" – How product functionality limits lifespan. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Ruggiero, L., Piccioni, M., & Ratti, A. (2025). Evaluating Ecodesign Methodology in Yacht Design: A Professional Workshop Case Study. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Sahin, B., Clark, N., & Lilley, D. (2025). Is This the End? - Lifetime of Electrical and Electronic Equipment. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE).

Salomè, M. A. (2025). Re-Imagining Garment Cutting Waste: Fashion Hacking, Zero-

Waste, and the Power of Negative Spaces. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Sander, N., & Laursen, L. N. (2025a). Introducing the Reshape strategy: Preserving material integrity. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Sander, N., & Laursen, L. N. (2025b). Material discard reasons: Categorising and characterising industrial waste materials. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Schneider, F., Hansen, S., Redeker, J., Klose, G. I., Strube, M., Mennenga, M., Vietor, T., Völkerink, O., Herrmann, C., & Müller, M. (2025). Novel methodology for the selection and evaluation of R-strategies to support product design for circular economy. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Schoen, T., Griffioen, S., Malé-Alemany, M., Rodrigues, M., & Kiestra, M. (2025). Impact of Robotic Circular Wood Processing: Lessons from the “One Plank” Challenge – using the AUAS Circular Wood KPI Framework. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Scholz, J. R., Ordonez, I., & Rotter, V. S. (2025). Waste What? —A game to communicate about local circular economy practices. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Simmons, C., McQueen, R., Kozlowski, A., & McNeill, L. (2025). Will it Make it to the Rack? An Investigation of Perceived Retail Value in Second-hand Clothing. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Sporchia, F., Patrizi, N., Ruini, A., & Bastianoni, S. (2025). Revising regulations unleashes engineered timber buildings potential for climate mitigation. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Steiner, R. (2025). Employing Pedagogy in the Experience Economy to Extend Product Lifetimes. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Suikkanen, J., Heinonen, T., Horn, S., Judl, J., Räikkönen, M., & Sokka, L. (2025). Second-hand smartphones in Finland: Key actors, barriers and enablers. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Sumter, D. X., Snäll, B., & Oskam, I. F. (2025). Selling repurposed furniture: An exploratory study into consumer perception. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Sun, H., Granato, G., & Mugge, R. (2025). Design Strategies to Strengthen Epistemic Value in Consumer Electronics and Prolong Product Lifetime. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Terzioğlu, N. (2025). AI-Powered Consumer Electronics Repair towards a Digital Circular Economy. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Thaher, Y. A. Y., Schork, T., Pushpamali, N., Cowled, C., & Crowther, P. (2025). Towards Building Circularity in Queensland: Policy Gaps in the Built Environment. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Thiyagarajan, J., Bäckström, M., & Waller, J. H. (2025). Analyzing Durability and Failures of Workwear Rain Jackets. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Turhan-Haskara, G. D. (2025). Longevity and Biodegradability Assessment of Biobased Lighting Fixture Design for Interiors. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Upton, B., & James, A. (2025). Improving the sustainability and durability of performance swimwear through consumer knowledge and usage habits. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

van der Loo, I. G. H., Mammen, Anna Lodberg, Hartvigsen, E. M. D., & Pigosso, D. C. A. (2025). Behavioural rebound effects and secondary benefits of sustainability-oriented design: Two sides of the same coin? *Proceedings of the 6th Product*

Lifetimes and the Environment Conference. Product Lifetimes and the Environment (PLATE), Aalborg.

van der Velden, M. (2025). Digital Degrowth – From Rebound to Regeneration. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment, Aalborg.

van Dolderen, D. C., Versloot, D. L., Aghaeian, S., Bakker, C. A., & Balkenende, R. (2025). Designing Electronics for a Circular Economy: How to balance Repair and Recycling. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

van Hees, M., Oskam, I., & Bocken, N. (2025). Transformative and community-based participation in collaborative business model experimentation for urban upcycling. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

van Kaathoven, D., Huffman, E., & Mizuno, D. (2025). Making Mends: Visibly Mending the Circular Economy. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Vanacker, H., Lemieux, A.-A., Laitala, K., Dindi, M., Lamouri, S., & Bonnier, S. (2025). Extending the Lifespan of Garments Globally through Local Upcycling: A Multimethod Approach. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Vermeyen, V., Duyvejonck, M., & Germeys, F. (2025). From excess to essential – Exploring the Potential of Adopting Smaller Wardrobes. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Vermeyen, V., & Germeys, F. (2025). Garment Reuse in Practice—Insights from a Clothing Swap. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Viljanen, A. M. K., Korsunova-Tsaruk, A., Oijala, S., & Toppinen, A. (2025). Product-service Systems for Regenerative and Long-lasting Buildings: Case of Wood in Finland. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Vung, C., MacDonald, M. J., McQueen, R., & Kozlowski, A. (2025). The Importance of Reuse and Repair– A Call for Canadian Municipal Action to Promote Clothing Repair Events. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Westervaarder, J. T. E., & Mugge, R. (2025). Understanding Mental Book Value: Exploring Replacement Decisions and Lifetime Expectations. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Wetherell, S. V., Shilton, L., & James, A. (2025). Utilising Digital Technology for Garment Longevity. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment, Aalborg.

Whalen, K. A. (2025). Circular Fashion Success: Cross-Country Insights on Adoption of Circular Business Model Offerings. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Whalen, K. A., & Renström, S. (2025). From Matching to Making: A Canvas for Collaborative Circular Value Creation. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Wiedenhofer, D., Fishman, T., Plank, B., Miatto, A., Lauk, C., Haas, W., Haberl, H., & Krausmann, F. (2021). Prospects for a saturation of humanity's resource use? An analysis of material stocks and flows in nine world regions from 1900 to 2035. *Global Environmental Change*, *71*, 102410. https://doi.org/10.1016/j.gloenvcha.2021.102410

Wieser, H., Hofmann, F., Jaeger-Erben, M., & Marwede, M. (2023). 1. Durable economies: Towards a new research programme. In M. Jaeger-Erben, H. Wieser, M. Marwede, & F. Hofmann (Eds.), *Arbeit und Organisation* (1st ed., Vol. 10, pp. 7–48). transcript Verlag. https://doi.org/10.14361/9783839463963-002

Zafer, O. B., Mugge, R., & Magnier, L. (2025). Vulnerabilities of Design Strategies for Retaining Emotional Value in Consumer Electronics. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Zhang, X., Normand, A. L., Wood, D. J., & Henninger, D. C. E. (2025). Modular Fashion: Sustainable Potential and Challenges for the Industry. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product

Lifetimes and the Environment (PLATE), Aalborg.

Zuin, S., Dengin, V., Perzolla, V., Bisaro, F., Pipita, M. M., Azzano, A., Garzena, F., & Stabon, E. (2025). The Laundry Care LCA project. *Proceedings of the 6th Product Lifetimes and the Environment Conference*. Product Lifetimes and the Environment (PLATE), Aalborg.

Design for Longer Lasting Products and Buildings



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Redesigning single use to reuse: identifying opportunities for surgical instrument sets

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Keywords: reuse in healthcare; circular economy; waste reduction; surgical instrument sets; design of reuse context; willingness to reuse

Abstract: Hospitals have a significant impact on the environment due to their size, energy-intensive processes, consumption of resources and waste generation. A trend of increased reusable products usage and so re-sterilized products is becoming visible. Nevertheless, reusable products have to compete with the added values of single use regarding convenience, effort and costs. Although the concept of reusable sterile surgical instrument sets seems valuable to reduce resource consumption compared to single-use instruments, their use is threatened by multiple inefficiencies. This case study aims to understand why the sterile sets usage is not optimal, what the consequences are for the various departments, what journey they take within the hospital, and how communication occurs regarding these sets. Observations and in-depth interviews were conducted in operation rooms, central sterilization department and the healthcare logistics department of a large sized university hospital. This led to a roadmap of the sterile surgical instrument sets within the hospital through each department involved. Using the roadmap, several critical points are discussed to design optimal reuse contexts in hospitals. In sum, we found that sets are often incomplete due to (i) a lack of turnover time for checking completeness, (ii) difficulty of recognizing specific instruments based on their name, (iii) lack of a good communication system to communicate incompleteness. Additional unwanted waste is created due to (iv) extra sets that are opened as a precaution for missing instruments, (v) unused instruments are thrown away or re-sterilized, (vi) broken sterility due to storage problems, which requires repackaging and re-sterilization.

Introduction

Hospitals have a significant impact on the environment due to their size, energy-intensive processes, consumption of resources and waste generation (Hunfeld et al., 2023; Pencheon, 2009). The increasing amount of medical waste, most of it coming from the operating rooms, is a growing concern. This escalation is linked to the aging population requiring more care, the extensive use of disposable products and sterilized products and their packaging used in surgical procedures (Conrardy et al., 2010; Ertz & Patrick, 2020; Harding et al., 2021; World Health Organisation, 2024). Despite a trend towards increased use of reusable products due to rising awareness and willingness among healthcare workers to reduce waste, reusable products must compete with single-use items in terms of convenience, effort, and cost.

In this research, we focus on reusable surgical instrument sets, which combine medical devices (MD) into one sterile package per specific surgical procedure shown in (Figure 1 (a). The sets are organized based on specific rules related to operation sequence and user requirements and are organized per medical procedure. The MD are packed together in net baskets made of stainless steel and another packaging layer, as shown in Figure 1 (b), to ensure sterility up to the moment of use and should allow for an aseptic presentation (FPS Public Health, 2017) Based on previous research , (Ahmadi et al., 2019; Nast & Swords, 2019; Van De Klundert et al., 2008) the following problems are indicated that hinder efficient usage of reusable surgical instrument sets and could limit further usage and extension: (i) Surgical instrument sets are often

incomplete (Thomasson et al., 2016). As a result, additional sets must be opened regularly. (ii) Even when only one instrument is used from the set, the entire set is unsterile and must go through the sterilization process again in its entirety. (iii) Re-sterilization requires a lot of water, energy, and packaging materials. Moreover, (iv) it is costly. In addition to the cost of sterilization itself, the cost of transportation, storage, and instrument use also increases. Furthermore, an investigation of intraoperative equipment failure reports that (v) issues with surgical instruments occur unacceptably high (Efthymiou & Cale, 2022).



Figure 1 (a) Surgical instrument set with MD and (b) packaging layer.

In the University Hospital Antwerp (UZA), Belgium, the tertiary referral hospital for this study, an average of 250 sets are re-used and sterilized daily. This means that about 90,000 sets must be packed every year. Each set requires a polypropylene cloth, protective liners and indicator tape. These packaging materials are not reusable, creating 2.6 tons of waste per year for only UZA. Knowing that Belgium has 103 hospitals (of varying size), an impression can be created on the total amount of waste. We argue that a significant part of this could be avoided if the reuse system of these surgical instrument sets were optimized.

The objective of this case study is to examine the practical challenges that impede the effective use and management of reusable sterile surgical instrument sets, further referred to as ‘sets’. This study aims to pinpoint opportunities for enhancing and optimizing the usage cycles of these sets. By combining sustainability and convenience, this research seeks to propose solutions to mitigate current issues with reusable surgical sets and to increase their adoption.

Materials and Method

This study utilized a qualitative approach to examine the reuse cycles of surgical instrument sets at the University Hospital of Antwerp (UZA). Three stakeholder groups were included: (i) operating room (OR) staff, (ii) Central Sterilization Department (CSD) staff, and (iii) logistics personnel. These groups provided insight into the processes, challenges, and opportunities associated with set management.

The research was conducted sequentially across departments, beginning with the OR, followed by the CSD, and concluding with logistics. This order allowed findings from each department to inform subsequent observations and interviews. A convenience sampling technique was used to select surgeries and staff based on their availability and relevance to set management issues. Surgeries involving urology and gynecology were chosen because these specialties frequently encounter problems with surgical sets, and their personnel were motivated to participate in improvement efforts.

Operating Room (OR):
In the OR, four surgeries (totaling 10 hours of observation) in the urology and gynecology department were observed. Observations were structured to record detailed information on instrument use, waste disposal, and the management of incomplete or missing instruments. The researcher mapped the OR layout, documented workflows, and recorded each action in a standardized template. During surgeries, two main aspects were observed: (i) instrument and product usage, including instances of incorrect disposal, and (ii) unused instruments. In later observations, specific questions were posed to OR staff to clarify their handling of set-related issues and communication methods.

Between surgeries, brief, focused discussions were conducted with three OR nurses to gather their perspectives on set usage challenges. Key questions addressed (i) common issues with sets, (ii) primary difficulties encountered, (iii) current problem-solving methods, and (iv) inter-departmental communication practices.

Central Sterilization Department (CSD): Here, data collection began with an in-depth interview and facility tour led by the head nurse, who provided background on CSD tasks, challenges, training, and inter-departmental

communication. The observation day (totaling 8 hours of observation) was divided into sessions within each of the CSD's three zones, where staff were shadowed and asked to explain each task's purpose, key challenges, and details regarding the handling and processing of sterile sets. Special attention was given to differences in set contents and technical specifications. Observations were documented using a template, and photographs were taken to capture specific processes.

Healthcare Logistics Department:
The logistics study consisted of a structured interview and tour with the head coordinator. Questions focused on logistical processes, communication with the OR and CSD, and inventory management challenges. A step-by-step tour provided insight into the storage systems, transport, and workflow.

All observations and interview notes were transcribed and coded to identify recurring themes, patterns, and discrepancies between departments. Data were analyzed to pinpoint specific procedural inefficiencies, communication gaps, and opportunities for improvement in set reuse. Findings were organized by stakeholder group to facilitate comparisons and identify overarching issues affecting the instrument management cycle across departments.

Results

The results describe the workflow analysis and critical issues that were identified for each researched department. These formulated critical issues directly or indirectly affect the optimal usage and consequently the ecological impact of the sets.

Results of the Operating Room

During the observation in the operating room, the following workflow analysis was conducted, as shown in Figure 2:
Before patient entry:

1. all necessary sets (both reusable and disposable) are taken from the storage cabinets and put on a transportation cart.
2. Sets are scanned at the computer.
3. Set is opened and placed ready on a wheeled cart.

During surgery:

4. The instrumenting nurse hands the instruments to the surgeon
5. The PP cloth is either discarded in the green trash or used as a table cover for the wheeled cart.

After surgery:

6. Set is taken to a secondary room of the OR, and the instrumenting nurse checks that the set is complete.
7. Set is taken to a CSD transport cart in the hallway.

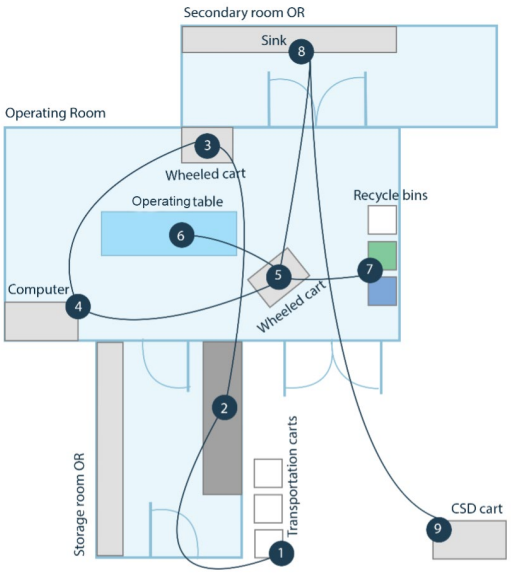


Figure 2. Workflow analysis of the OR.

The observations and group discussion with the OR nurses and surgeon resulted in critical points being identified in the OR contributing to the inefficient use of sets: (i) A primary issue was identified in OR storage, where sets can be misplaced or out of stock. When this occurs, nurses may use sets from different specializations or procedures, which are then by default not consisting of the right instruments, requiring them to open additional sets or individually packaged instruments to complete the necessary items. (ii) Missing instruments within sets are also common. Both surgeons and nurses repeatedly noted this in interviews, and during observations at least one instrument was found to be missing per surgery. Nurses often notice this before surgery begins and proactively bring a backup set or additional instruments as a precaution. This often leads again to requiring them to open additional sets or individually packaged instruments to complete the necessary items. (iii) Communication between departments regarding missing or incomplete sets is inadequate. The current system relies on

scanning comments in the computer, which is rarely performed due to system complexity and time constraints. Instead, nurses write missing items on a card placed within the set, hoping it reaches the CSD, though no feedback is provided. This approach is unreliable, especially in the busy OR environment, where limited turnover times between surgeries often prevents thorough instrument checks. (iv) Frequent shift rotations among nurses can result in lapses in communication regarding missing instruments, as outgoing staff may forget to update incoming colleagues. (v) Another recurrent is the preference for Custom Procedure Trays (CPT) containing single-use instruments (e.g., scissors, knives, clamps), even though reusable versions are available. This preference dates back to a shift toward disposables, largely driven by infection control, convenience, cost considerations, and efficiency.

Results of the Central Sterilization Department (CSD)

Based on the observation, the following workflow analysis, as shown in Figure 3, could be detailed:

Unclean area:

1. CSD staff will pick up the cart with dirty sets and instruments from the OR hallways and bring them to the CSD.
2. Sets are scanned at the computer. In each zone, staff members not only scan the sets they handle but also scan every action performed, listed below.
3. Instruments are unloaded, opened and divided into two or more net baskets (depending on the size of the set).
4. The loaded net baskets are put into the ultrasonic machine for pretreatment.
5. The loaded net baskets are prepared on a loading cart.
6. When this cart is full, the net baskets are loaded into the washing machine.

Clean area:

7. The net baskets are taken from the washing machine and scanned again.
8. Instruments are unloaded, checked, and put back together based on a list of the original set. Missing instruments are supplemented here. Sets are packed using PP cloths and sealed with indicator tape.
9. The packed sets are prepared on the loading cart.
10. When the cart is full, the sets are loaded into the autoclave.

Sterile area

11. The sets are taken out of the autoclave.
12. Staff checks the indicator tape to ensure validity of the sterilization process.
13. The sets are placed in cluster bins in the transport cart and are ready to be picked up by the internal transport and taken to the sterile or OR storage area.

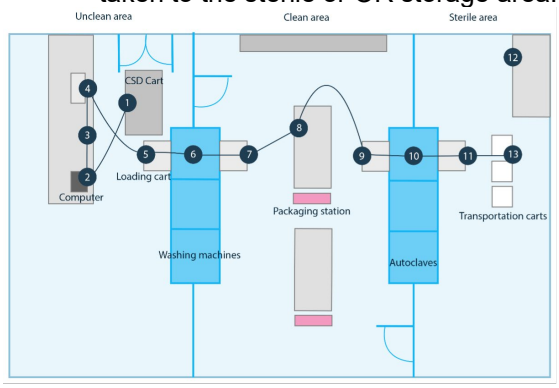


Figure 3. Workflow analysis of the CSD showing unclean, clean and sterile areas.

Based on the observation and in-depth interview, the following critical points could be identified in the CSD:

Related to the design of sets itself: (i) ergonomic challenges; several staff members reported back problems due to lifting heavy sets (up to 12 kg) in awkward positions. Additionally, (ii) the handles on the surgical instrument sets lack ergonomic design, being thin with poor grip and can only be used when the set is unwrapped, despite most handling occurring while wrapped. A third point (iii) involves material degradation, as aging stainless steel trays damage instruments and packaging, compromising sterility and necessitating re-sterilization.

Furthermore, (iv) knowledge support is missing during the set assembly process in the clean area. Staff rely on lists that only name instruments without visuals, making identification difficult for both new employees (with only three months training) and for experienced staff's routine-based inattention. (v) Storage and restocking challenges arise when specific instruments are missing. No effective communication with the OR alerts them to shortages, creating operational delays. An in-depth interview with the CSD head nurse

highlighted further issues: (vi) Missing instruments are attributed to accidental disposal in the OR. (vii) Although a traceability system exists, it is underused in the OR, where sets are often unchecked. (viii) Effective communication between OR and CSD is hindered by procedural misunderstandings and long communication chains, with the interviewee suggesting any initiative for improvement should come from the OR staff.

Results of the logistics department

Based on the tour given by the head of logistics the following workflow could be analyzed, as shown in Figure 4:

1. Before surgery, all necessary reusable instruments and sets are sterilized in the CSD and placed in the correct storage area by the logistics department.
2. On the day of surgery, the pick list (detailed by the surgeon while planning the surgery) is prepared in the sterile storage room. A logistics worker takes all supplies (surgical sets (reusable and disposable), separate sterile-packed instruments and other necessary tools). These are placed in a cluster box. All cluster boxes are put into a cluster cart in the hallway. Per operating theater, there is one cart per day that contains all necessary materials for that day's operations.
3. The cluster cart is taken to appropriate OR storage area and cluster boxes are unloaded there.
4. During surgical preparation, if instruments or sets are missing in the storage area, the OR nurses can contact logistics personnel to request missing instruments be delivered.

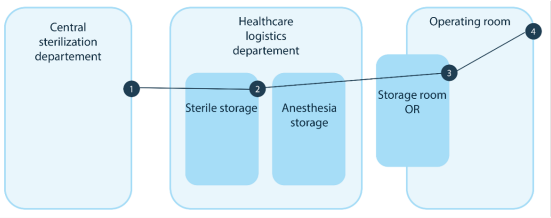


Figure 4. Workflow analysis of the logistics department.

Healthcare logistics is essential for maintaining an uninterrupted supply of materials between the OR and the CSD, ensuring 24-hour support for surgical operations. Three storerooms; sterile, OR, and anesthesia must remain stocked. In the logistics department, key challenges include (i) insufficient storage capacity, with growing demand outpacing infrastructure, leading to storage overflow into corridors and misplacement of sets. This spatial limitation frequently disrupts the "first-in, first-out" (FIFO) inventory method and increases retrieval time. Additionally, (ii) the computerized inventory system lacks logical organization, causing frequent errors in supply preparation and contributing to operational delays and workflow tensions. (iii) The current tracking software, Steriline, does not provide real-time updates, allowing only retrospective tracking of instruments' locations.

Discussion

Reorganizing the critical findings revealed three main problem clusters, which form the foundation for new design opportunities:

1. Communication-related issues: limitations of the electronic health record system, limited time for checking instrument completeness, the lack of visual identifiers on instrument lists, and reliance on an unreliable physical card system to track missing instruments. Additionally, the need to search for sets stored in different locations and the precautionary use of extra sets exacerbate these issues. Inter-departmental tensions originate due to a lack of understanding of each department's procedures.
2. Set-related problems: excess waste from unused single-use and sterile packaging, non-ergonomic set handles and heavy weights of sets, and the presence of both unused and missing instruments. Prior research also highlights that sets frequently contain surplus instruments for precautionary use, adding to waste.
3. Organizational challenges: misplaced sets, inadequate storage space, and stockouts of sets or spare instruments.

Based on these identified problem clusters, we propose the following high-level design drivers to guide innovation and enhance the efficient use of reusable surgical instrument sets:

1. Ensuring set completeness and accuracy

2. Facilitating interactive communication on set status, location, and sterility
3. Improving ease of use and reducing workload for stakeholders
4. Promoting sustainability by achieving full reusability and minimizing unnecessary waste
5. Enhancing cost-effectiveness by reducing losses

After conducting a brainstorming session with the observed personnel to generate potential solutions for the identified problems, five concepts were developed. These concepts were then evaluated by operating room and central sterilization department personnel, who scored them based on the design drivers to facilitate a trade-off analysis. As a result, the following potential design opportunities were identified:

1. Communication tool: A physical or digital tool could standardize inter-departmental communication, reducing confusion about tool completeness, location, and identification. Technologies such as AI, machine learning, and intelligent systems could assist staff in identifying and detecting missing instruments. Communication between the tool and staff should allow the set composition to stay up to date.
2. Surgical instrument set redesign: Redesigning the reusable surgical instrument basket and packaging could eliminate disposable packaging, enhance ergonomics, and ensure set completeness.
3. Storage system optimization: Improving the storage system to maximize limited space and introducing automation could reduce staff workload.

Research Limitations

This case study was conducted in one university hospital, limiting generalizability. To verify these conclusions, further studies should include various hospital settings, including public and private hospitals. The study focused on urology and gynecology, which use smaller instruments; further research should examine whether similar issues arise in other specialties with larger or robotic instruments.

Conclusions

This paper presents a case study examining the challenges associated with reusable sterile instrument sets for surgeries. Inefficiencies in the current system have contributed to a trend toward reintroducing single-use sets, which undermines efforts to promote circularity in healthcare systems. Consequently, merely developing reusable medical products does not guarantee effective usage or replacement of single-use alternatives. To identify critical issues, we observed and interviewed key stakeholders involved in managing reusable surgical instrument sets: (i) operating room staff and surgeon, (ii) central sterilization department personnel, and (iii) logistics staff.

Key obstacles for efficient use of reusable surgical instruments identified include communication-related issues, set-related issues, and organizational issues. To address these, three design oportunities are proposed based on high-level design drivers: redesigning reusable surgical sets and their packaging, optimizing storage systems, and implementing a structured communication tool.

Further innovation should focus on understanding and optimizing the broader context of reuse. Future research should examine how hospital contexts, including the entire value chain, and including production, can be holistically adapted to support reuse. By following research through design principles, we should focus on developing intelligent systems for detecting missing instruments, efficient communication frameworks, and sustainable, waste-free packaging solutions to minimize medical waste.

Acknowledgments

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References

Ahmadi, E., Masel, D. T., Metcalf, A. Y., & Schuller, K. (2019). Inventory management of surgical supplies and sterile instruments in hospitals: A literature review. *Health Systems*, *8*(2), 134–151.

https://doi.org/10.1080/20476965.2018.1496875

Conrardy, J., Hillanbrand, M., Myers, S., & Nussbaum, G. F. (2010). Reducing Medical Waste. *AORN Journal*, *91*(6), 711–721. https://doi.org/10.1016/j.aorn.2009.12.029

Efthymiou, C., & Cale, A. (2022). Implications of equipment failure occurring during surgery. *The Annals of The Royal College of Surgeons of England*, *104*(9), 678–684. https://doi.org/10.1308/rcsann.2021.0345

Ertz, M., & Patrick, K. (2020). The future of sustainable healthcare: Extending product lifecycles. *Resources, Conservation and Recycling*, *153*, 104589. https://doi.org/10.1016/j.resconrec.2019.104589

FPS Public Health. (2017, May). *GOOD PRACTICES VOOR STERILISATIE VAN MEDISCHE HULPMIDDELEN*. https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/170912_good_practices_for_the_sterilisationa5.pdf

Harding, C., Van Loon, J., Moons, I., De Win, G., & Du Bois, E. (2021). Design Opportunities to Reduce Waste in Operating Rooms. *Sustainability*, *13*(4), 2207. https://doi.org/10.3390/su13042207

Hunfeld, N., Diehl, J. C., Timmermann, M., Van Exter, P., Bouwens, J., Browne-Wilkinson, S., De Planque, N., & Gommers, D. (2023). Circular material flow in the intensive care unit—Environmental effects and identification of hotspots. *Intensive Care Medicine*, *49*(1), 65–74. https://doi.org/10.1007/s00134-022-06940-6

Nast, K., & Swords, K. A. (2019). Decreasing operating room costs via reduction of surgical instruments. *Journal of Pediatric Urology*, *15*(2), 153.e1-153.e6. https://doi.org/10.1016/j.jpurol.2019.01.013

Pencheon, D. (2009). *Health services and climate change: What can be done?*

Thomasson, B. G., Fuller, D., Mansour, J., Marburger, R., & Pukenas, E. (2016). Efficacy of surgical safety checklist: Assessing orthopaedic surgical implant readiness. *Healthcare*, *4*(4), 307–311. https://doi.org/10.1016/j.hjdsi.2016.01.005

Van De Klundert, J., Muls, P., & Schadd, M. (2008). Optimizing sterilization logistics in hospitals. *Health Care Management Science*, *11*(1), 23–33. https://doi.org/10.1007/s10729-007-9037-4

World Health Organisation. (2024, October 24). *Healthcare waste*. https://www.who.int/news-room/fact-sheets/detail/health-care-waste

Research paper
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From Empty Shops to Vibrant Communities: Adaptive Reuse as a Sustainable Response to Retail Decline

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Keywords: adaptive reuse; retail and hospitality design; local tourism; place-based potential.

Abstract: Rapid and significant reductions in global carbon emissions are needed to remain within Earth's limits. The construction and operation of buildings account for the largest share of the global consumption of raw materials, and they yield around 40% of global carbon emissions. Leading climate researchers therefore recommend adapting housing needs to existing building stock instead of constructing new buildings. This requires shifting the focus from what we desire to how we can adapt our needs to existing spaces. This paper, a work in progress, examines the misalignment between sustainability ambitions and tourism strategy in a Danish municipality. This municipality has yet to fully integrate the potential of its existing building stock into its tourism plans. This oversight is striking, given the municipality's ambitious goal of achieving CO_2 neutrality and availability of surplus building stock, including vacant retail spaces in shopping streets. Building on this observation, we propose a conceptual framework for incorporating existing buildings into the municipality's tourism strategies. Rather than expanding their climate footprint by constructing new accommodations for tourists, we suggest a solution centered on using vacant spaces and renovating existing structures. Specifically, we envision repurposing vacant retail spaces into holiday apartments, boutique hotels, or other types of housing. This paper lays a foundation for further research to increase awareness of this issue and to test and refine our proposal. The overarching goals are to support sustainable urban development, promote climate-friendly behavior, and strengthen local community and economic vitality in small and medium-sized towns through longer-lasting buildings.

Introduction

The consumption of materials and energy to construct new buildings poses a significant challenge to the effort to maintain global warming below 2°C (Richardson et al., 2023). Urgent and significant reductions in global carbon emissions, along with resilient strategies for addressing climate-related events, are essential to remaining within our planet's boundaries (Assefa & Ambler, 2017; Kuittinen, 2023). Leading experts urge avoiding new construction and instead fulfilling spatial needs by repurposing existing spaces (Kuittinen, 2023). This requires shifting the focus from satisfying users' desires to adapting their needs to existing structures. As Kuittinen (2023, pp. 565–566) suggests, a paradigm shift is needed in which we begin

> *"solving society's spatial needs without considering new buildings as the first solution. Instead, existing buildings should be used and renovated as far as possible. Europe, with its historic responsibility and capacity to reduce emissions, should lead by integrating this hierarchy into building regulations."*

This paper summarizes a work-in-progress study of Danish municipalities' approaches to carbon reduction and new buildings. It focuses on Sønderborg Municipality, which can be seen as an extreme case, to use Flyvbjerg's term (2006). Since 2007, Sønderborg Municipality has worked to reduce its carbon output, aiming to become carbon-neutral by 2029 via the public–private partnership called Project Zero. This goal is highly ambitious. The municipality takes pride in being a frontrunner in climate protection and states the following:

> *"Our recipe for a green transition not only has the potential to solve the climate challenge in Sønderborg. It can be used all over the world. We want to show other*

> *cities the way and inspire them to create their own transformation. Every year, we welcome decision makers and journalists from all over the world, who want to know more about our road to carbon neutrality."* (Project Zero, 2024)

Interestingly, while the municipality is intensely focused on carbon remission, they do not take this into consideration in their tourism and trade strategy. Tourism is one of the key avenues for growth in this rural municipality, as they hold the ambition to become the fifth most popular tourist destination in Denmark (Sønderborg Kommune, 2024). In their strategy, tourism is mentioned as one of the municipality's "lighthouses" together with Project Zero. This makes us wonder why the municipality does not integrate their plans to become carbon neutral into their tourism strategy. Contrary to what one might expect from a municipality with ambitious plans to achieve CO_2 neutrality, Sønderborg Municipality adopts a conventional mindset regarding tourism, supposing that accommodation options for tourists should be provided by building large resorts and new summer houses in designated areas.

The aim of this paper is to suggest alternative ways of approaching tourism in this community —approaches that take a holistic view of the building stock and focus on the adaptive reuse of empty buildings. This approach represents a sustainable solution for climate action that can potentially meet tourism demand and revitalize the local neighborhood while aligning with the municipality's ambitious plans for carbon reduction.

Background: Challenges on Multiple Levels

This case involves challenges on multiple levels. The climate crisis is a global challenge, while the desire to increase tourism operates on the national and municipal levels. Additionally, we have identified local challenges at what we might call the neighborhood level—where residents, business owners, and tourists are all affected stakeholders.

The climate crisis is an urgent global challenge, and the construction and operation of buildings account for approximately 40% of the world's energy consumption. Furthermore, buildings are the largest global consumers of raw materials and contribute roughly 40% of global CO_2 emissions (World Economic Forum, 2022). As such, it is not only the construction of new buildings that results in significant CO_2 emissions; as a general rule, the allocation of new areas for purposes such as summer houses or tourist attractions leads to a permanently higher CO_2 footprint (Hjalager, 2024).

Against this background, climate researchers strongly advocate avoiding new construction and, instead, aligning people's needs with the existing building stock. This can be achieved by utilizing vacant and shared spaces, renovating existing structures, or extending these spaces and structures where necessary (Kuittinen, 2024).

By 2040, housing shortages are projected to emerge in the 30 Danish municipalities that host larger cities (Sweco & Cobe, 2023), while smaller and medium-sized towns are expected to experience population declines. Sønderborg Municipality is also facing a future of demographic reductions (Sønderborg Kommune, 2023). Consequently, an increasing number of buildings in these areas are likely to become vacant. In many small and medium-sized provincial towns, vacant buildings are already a conspicuous issue (Hjalager, 2024; Realdania, 2024). In addition to population decline, shifting consumer habits have significantly impacted these towns. The rise of malls and online shopping has left many town centers with empty retail spaces, diminishing their appeal and functionality (Alexander & Cano, 2020; Frascet et al., 2021).

Vacant storefronts on shopping streets weaken the vibrancy of urban life at the neighborhood level (Groth & Fertner, 2022; Realdania, 2024). Fewer shops attract fewer visitors, ultimately reducing revenue and forcing even more businesses to close. This vicious cycle undermines the town center's traditional role as a community hub, making these areas increasingly unattractive to both locals and tourists.

Visits to local towns offer unique experiences that are integral to Denmark's tourism appeal (Realdania, 2024). Tourists' interactions with these towns shape their perceptions of Danish culture and society. Lively urban spaces are essential not only for preserving this cultural

appeal but also for supporting local businesses, as tourism generates significant economic value.

In addition to making town centers less appealing to both locals and tourists, vacant buildings harbor significant amounts of embedded CO_2. A climate-friendly approach to addressing this situation should involve efforts to extend the lifespan of existing buildings rather than demolishing them to make way for new construction (Hjalager, 2024; Kuittinen, 2023).

When we examined Sønderborg Municipality's approach to attracting more visitors through the construction of new hotels, resorts, and summerhouses, it became evident that this strategy is disconnected from their plan to reduce the area's climate footprint (Figure 1).

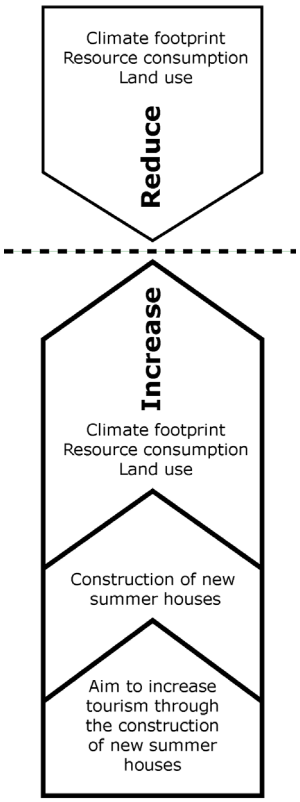


Figure 1. If the goal of accommodating more tourists is achieved by constructing new buildings, it will result in an expanded climate footprint. This contradicts efforts to reduce climate impacts.

A Conceptual Model for Solving Challenges at Various Levels

Revitalizing Empty City Centers and Neighborhoods for Environmental and Social Good

Using Sønderborg Municipality as a case, we can identify several problems that are not unique to Sønderborg but can be found in similar rural coastal communities. Over the past 50 years, the local economy has shifted from being driven by agriculture and industry to focusing on services, with tourism emerging as a particularly important contributor. This shift has been combined with a population decline (Sønderborg Kommune, 2023), leading to empty houses in villages and empty shops in the town centers (Figure 2).

By applying the concept of 'place-based potential' to the issue of existing building stock, we suggest a new conceptual model for addressing the dilemma of how tourism can be increased without a corresponding expansion in carbon footprint due to new constructions.



Figure 2. Empty store in the pedestrian street in Sønderborg in December 2024. Photos by the authors.

Place-based potential refers to the idea that the unique attributes of a geographic area—its

natural resources, cultural assets, economic structures, demographic characteristics, and social networks—can be harnessed to foster development and effectively address challenges. This approach contrasts with "one-size-fits-all" strategies by emphasizing that solutions and strategies should be tailored to the unique circumstances of each place.

The concept of place-based potential is not attributed to a single individual but has rather emerged from interdisciplinary fields, such as geography, urban planning, regional development, and the social sciences. This idea has been shaped by scholars and policymakers exploring the unique characteristics of specific locations and how they can be leveraged for social, economic, and environmental development. The concept gained significant traction in academic and policy discussions in the late 20th and early 21st centuries. Influential frameworks include the European Union's place-based approach, wherein the Barca Report, named after Fabrizio Barca (2009), outlines a participatory and context-sensitive framework for regional development, arguing against uniform approaches.

In the Danish context, the concept of place-based potential has been applied to address regional inequalities by redirecting the focus to the unique resources and characteristics of localities, especially in rural and peripheral areas (e.g., Tietjen & Jørsensen, 2016). It is widely used by the charitable trust Realdania, which funds projects in peripheral rural areas, including Sønderbog Municipality. In this paper, we are inspired by some of these projects. Our approach encourages efforts to revitalize such regions through strategic planning that emphasizes local assets, community engagement, and sustainable development strategies tailored to specific regional challenges.

Instead of expanding the area's climate footprint by constructing new buildings, we envision a solution in which the municipality implements the adaptive reuse of buildings, such as empty shops on shopping streets. This approach could enhance climate-friendly behavior, improve quality of life and the community for locals, and strengthen local businesses, while simultaneously enriching tourists' experiences in Denmark (Figure 3).

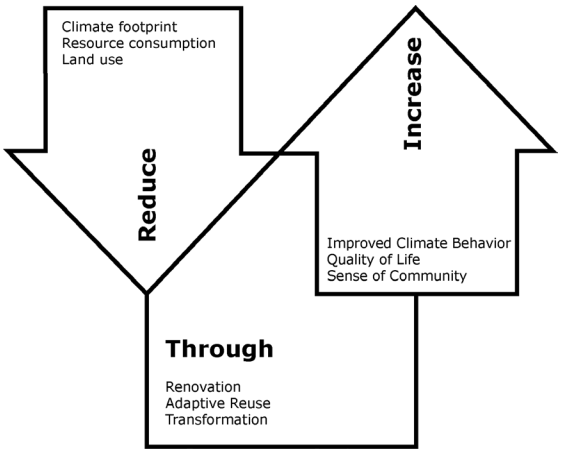


Figure 3. Our solution is one that, through the renovation of existing buildings, promotes climate-friendly behavior, enhances quality of life and the community for locals, and strengthens local businesses, while also improving the experience for tourists—all without constructing new buildings.

Challenges and Suggestions for Future Studies

Our proposal is entirely conceptual. This highlights the need for future studies to explore the potential of creating attractive settings for tourists through adaptive reuse, while simultaneously strengthening local life by developing design models and services that address the needs and aspirations of both tourists and locals.

A challenge of this approach may be managing stakeholders' expectations. To repurpose buildings originally constructed for different purposes involves practical challenges and will lead to different user experiences compared to purpose build constructions. This may, however, not be negative: A recent study on adaptive reuse and café design found that new occupants gained unexpected benefits such as spaciousness and unique atmospheres (Münster 2024).

We envision that our future studies will focus on 1) analyzing exemplary cases from other places, 2) exploring the place-based potential of the existing local building stock, and 3) conducting thorough investigations into the local needs, challenges, and aspirations of various stakeholders, including tourists, residents, local businesses, and policymakers.

In terms of exemplary cases, this would involve examining successful projects within the chosen municipality, elsewhere in Denmark, and abroad, and analyzing how these cases cater to both tourists and locals. This could include cases such as the small Frederiksberg-based boutique accommodation, Central Hotel and café (Figure 4), where overnight guests dine alongside locals in the neighborhood café on the ground floor.

On a larger scale, Copenhagen's Kanalhuset (Figure 5) offers accommodation for tourists along with activities for locals such as communal dining, yoga classes, and knitting clubs, where tourists can participate and meet locals. In addition to tourist accommodations, the hotel offers large rooms for meetings and parties, as well as smaller dining rooms with kitchens for locals hosting dinner guests.

As a result of their thoughtful design and service model, both hotels are centrally located in urban areas and have successfully integrated accommodation spaces with areas for locals to gather.



Figure 4. Photo of Central Hotel and Café, which houses both hotel rooms and a neighborhood café Photo by Central Hotel and Café.



Figure 5. Photo from Kanalhuset, which offers hotel rooms as well as communal dining, and activities like yoga classes and knitting clubs for locals as well as guests. Foto by the authors.

Locally, future research could examine cases such as Als Kloster, which houses a bed and breakfast for tourists, particularly those hiking along the Gendarmstien, while also hosting events and communal dining for both locals and tourists within the setting of a former monastery. The monastery's history is integrated into the experience through storytelling, making it a part of the user experience (Figure 6).

Identifying the locations that offer suitable place-based potential involves identifying and analyzing the opportunities within the local building stock and evaluating how these spaces can benefit both locals and tourists. In terms of studying local needs and challenges, we recommend participatory methods that engage locals, tourists or tourism agencies, urban planners, local politicians, and representatives of local business associations.

To take the project a step further, it could be considered whether vacant properties in small and medium-sized provincial towns facing future housing surplus can be viewed not only

as holiday homes but also as part of the solution to the housing shortage in bigger cities (Bevar Mere, 2024). For example, could housing in coastal municipalities be made so attractive that residents, institutions, or businesses from more densely populated areas would be encouraged to relocate to properties in these sparsely populated towns?



Figure 6. Als Kloster, which houses a bed and breakfast for tourists, while also hosting events and communal dining for both locals and tourists within the setting of a former monastery. Foto by the authors.

Conclusions

Through an analysis of Sønderborg Municipality's development strategy, we have identified a paradoxical relation between the municipality's two primary goals: achieving CO_2 neutrality and attracting more tourists. The municipality's strategy for increasing tourism involves constructing new resorts and summer houses, which contradicts their ambition to reduce carbon emissions. In line with expert recommendations to halt new construction as a means of lowering CO_2 emissions, we propose a comprehensive model that reconciles climate challenges with tourism aims. This model aims to foster climate-conscious behavior, promote tourism, revitalize towns, and enhance the well-being of locals and business owners through the adaptive reuse of existing buildings.

The adaptive reuse of vacant spaces—for example, reimagining vacant retail spaces as boutique hotels or other lively hospitality venues—offers a promising solution to pressing climatic and social challenges in Denmark.

This article lays the basis for further research and collaboration with stakeholders to test and refine these ideas. This will serve the ultimate goal of supporting sustainable urban development, encouraging climate-friendly behavior, and strengthening local culture and economic vitality in Sønderborg Municipality, in other Danish municipalities, and beyond.

References

Alexander, B., & Blazquez Cano, M. (2020). Store of the future: Towards a (re)invention and (re)imagination of physical store space in an omnichannel context. *Journal of Retailing and Consumer Services*, *55* (January 2019), 101913. https://doi.org/10.1016/j.jretconser.2019.101913

Assefa, G., & Ambler, C. (2017). To demolish or not to demolish: Life cycle consideration of repurposing buildings. *Sustainable Cities and Society*, *28*, 146–153. https://doi.org/10.1016/j.scs.2016.09.011

Barca, F. (2009). *An agenda for a reformed cohesion policy: A place-based approach to meeting European Union challenges and expectations*. European Commission.

Bevar_Mere. (2024). *Fremtidens Boliger i Nutidens Huse*. https://www.bevar-mere.dk/

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363

Frasquet, M., Ieva, M., & Ziliani, C. (2021). Online channel adoption in supermarket retailing. *Journal of Retailing and Consumer Services*, *59* (December 2020),102374. https://doi.org/10.1016/j.jretconser.2020.102374

Groth, N. B., & Fertner, C. (2022). Forsøg med bymidter: Omdan døde handelsgader til bolig-områder! Byplan Nyt I.

Hjalager, A.-M. (2024). Turismeplanlægning og CO2-Reduktion. Plan22+.

Kuittinen, M. (2023). Building within planetary boundaries: moving construction to stewardship. *Buildings and Cities*, *4*(1), 565–574. https://doi.org/10.5334/bc.351

Münster, M. B. (2024). Adaptive reuse: Atmospherics in buildings repurposed as coffee shops.

Sustainability (Switzerland), *16*(1585). https://www.mdpi.com/2071-1050/16/4/1585

ProjectZero. (2024). *A local solution to a global solution*.https://projectzero.dk/en/about-projectzero-2/

Realdania (2024). *Nakskov genvinder bymidten : Bymidtefond har løftet turisme og private investeringer*. https://realdania.dk/nyheder/2024/10/nakskov-genvinder-bymidten?utm_medium=email&utm_source=marketo&utm_campaign=RF-STP - 2024-11-05-10:53 - Støtte på 30 mio. kr. sender Bryggekulturens Hus et stort skridt nærmere realisering.&mkt_tok=Njg4LURCTi0zMzYAAAGW

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., … Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, *9*(37), eadh2458. https://doi.org/10.1126/sciadv.adh2458

Sweco & Cobe. (2023). *Potentialer for indretning af flere boliger i den eksisterende bygningsmasse*. https://realdania.dk/publikationer/faglige-publikationer/potentialer-for-indretning-af-flere-boliger-i-den-eksisterende-bygningsmasse

Sønderborg Kommune (2024). *Handleplan for Turisme og Handel 2025*. https://sonderborgkommune.dk/fr/plan-d%27action-tourisme-et-commerce-2025

Sønderborg_Kommune. (2023). *Befolkningsprognose 2023-2027*. https://sonderborgkommune.dk/sites/default/files/inline-files/Befolkningsprognosen 2023-2027.pdf

Sønderborg_Kommune. (2022). *Klimaprojektet ProjectZero. Byrådets Vision Og Fyrtårne*. https://sonderborgkommune.dk/vision-fyrtaarne

Tietjen, A., & Jørgensen, G. (2016). Translating a wicked problem: A strategic planning approach to rural shrinkage in Denmark. *Landscape and Urban Planning*, *154*, 29–43. https://doi.org/10.1016/j.landurbplan.2016.01.009

World Economic Forum. *A guide to decarbonizing the built environment*. https://www.weforum.org/agenda/2022/01/decarbonizing-the-built-environment/ (accessed on 22 September 2022).

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Evaluating Ecodesign Methodology in Yacht Design: A Professional Workshop Case Study

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Keywords: Sustainability; Ecodesign; Yacht design; Life Cycle Design; MPDS.

Abstract: The yachting industry faces increasing pressure to adopt sustainable practices driven by regulatory requirements and evolving consumer expectations. This study explores the application of Life Cycle Design (LCD), also referred to as ecodesign, methodologies within yacht design to address environmental challenges. Despite the critical importance of early-stage design in determining a product's environmental impact, the yacht sector lacks industry-specific sustainability guidelines.This research investigated the practical implementation of a generic LCD methodology - specifically the MPDS (Method for Product Design for Environmental Sustainability) - through an intensive workshop involving young professional yacht designers. Participants were tasked with developing concept designs for a 50-foot charter yacht, applying six LCD strategies: use extension, material consumption reduction, energy consumption reduction, material life extension, toxicity reduction, and resources conservation.The study outlined both opportunities and limitations in applying MPDS to yacht design. While participants achieved incremental improvements in certain strategies, the research highlighted the need for context-specific adaptations. Challenges included the methodology's generic nature and the complexity of yacht design processes.The findings underscore the potential of LCD principles in promoting sustainability within the nautical industry and provide a foundation for developing tailored guidelines that can effectively integrate environmental considerations into yacht design processes.

Introduction

The yachting industry has experienced remarkable growth in recent years, driven by the increasing demand for luxury vessels and an expanding global market (Yücenur, 2021; Montigneaux & Mower, 2023). However, this trend is accompanied by regulatory scrutiny and evolving consumer expectations. Stringent European and international regulations, such as the Paris Agreement (2016) and the International Maritime Organization (2023), have underscored the pressing need for sustainable practices across the sector (Jacquet et al., 2024). Beyond regulatory pressures, consumer demand for environmentally responsible luxury products has risen significantly, with sustainability becoming a relevant factor for modern yacht shipyards (Ansaloni et al., 2024; Liang & Birmingham, 2024).

The design stage is critical in determining a product's environmental impact, with over 80% of its footprint being established at this phase (EU - Directorate-General for Communication, 2020; Stark, 2024; Hauschild et al., 2018). Once a product is introduced to the market, opportunities to mitigate its environmental effects diminish considerably. As such, incorporating environmental considerations into the early stages of product development is essential for achieving meaningful impact reductions (Dahmani et al., 2021; Ahmad et al., 2018).

Current efforts within the yachting industry mainly align with the principles of Green Design, as defined by Ceschin & Gaziulusoy (2021). These efforts often focus on material or component-level solutions, such as exploring alternatives to teak or implementing low/zero-emissions propulsion systems (Liang & Birmingham, 2024). While these measures represent progress, they typically lack a comprehensive approach. A more holistic method, such as ecodesign, could better address the entire environmental impact of the product.

Ecodesign, also referred to as Life Cycle Design (LCD) (Vezzoli, 2018), is described as a systematic approach which considers environmental aspects in design and development to reduce adverse environmental impacts throughout the life cycle of a product

(International Organization for Standardization, 2020).

Although general LCD guidelines are available (Vezzoli, 2018; Ceschin & Gaziulusoy, 2021), the distinct attributes of specific product groups or individual products—such as their materials, manufacturing methods, and resource usage—significantly influence their life cycle impact, requiring customised approaches to address these differences (Chaves, 2008). Only in recent years have these been tailored to specific industries (Vezzoli & Conti, 2019; Yang & Vezzoli, 2024; Plaschke et al., 2019). However, despite the environmental challenges and opportunities within the yacht industry, no comparable guidelines have been designed yet.

The absence of industry-specific guidelines in yacht design presents a significant gap in the application of ecodesign principles. Bridging this gap is particularly difficult due to the complex characteristics of the product, considering the number of customised components, the degree of knowledge involved in production and the engineering-intensive activities (Hobday, 1998).

The aim of this paper is to contribute to addressing this gap by testing generic LCD guidelines in the context of a yacht design workshop. By evaluating their practical application and identifying their limitations, this study aims to generate insights into the specific needs of the yachting industry. The findings are intended to inform future research and guide the development of customised guidelines that can support designers and manufacturers in integrating sustainability into their processes.

In the following section, the structure of the workshop is outlined, detailing the LCD methodology and the tools used. The Results section presents the findings, focusing on the environmental performance of the developed projects and feedback on the use of the LCD methodology. Finally, the last section interprets these results, explores their broader implications for the field, and proposes directions for future research and industry practices.

Materials and Methods

MPDS

The chosen LCD methodology is MPDS (Method for Product Design for environmental Sustainability), developed by the Design and system Innovation for Sustainability (DIS) research unit of the Design Department at Politecnico di Milano (Vezzoli, 2018). The method is coherent with the UNI ISO/TR 14062:2007 norm, which deals with the implementation of environmental aspects in product design and development. MPDS is also flexible, enabling the designers to decide which proposed tools to use according to the specific activity that is being addressed in a given context.

Main phases of MPDS

The integration of MPDS is articulated according to the typical phases of new product development. During the Product Strategic Analysis (and brief) phase, the goal is to identify critical areas and LCD strategies with the greatest potential to reduce the environmental impact of the product being designed. During the Concept Design phase, the focus shifts to guiding concept generation toward environmentally sustainable solutions compared to existing products. In the Product Design (and engineering) phase, attention is directed to refining project details with an emphasis on sustainability relative to current products. To support the design process across the phases, MPDS suggests the use of the open-access ICS (Sustainable Concepts Ideation) toolkit, which integrates functions crucial for qualitative assessment, sustainability design orientation, and improvement comparison.

MPDS Product Strategic Analysis

Within the MPDS, the product strategic analysis phase is structured around three key processes, each one with suggested specific tools to apply.

The first process consists of the assessment of the environmental impact of the standard existing product, using software for complete or simplified LCA and a Checklist for evaluating existing products (ICS). The second process is the definition of environmental design priorities, linked to six LCD strategies:

1. Use extension/intensification.
2. Material consumption reduction.
3. Energy consumption reduction.
4. Material life extension.
5. Toxicity reduction.
6. Resources conservation/biocompatibility.

The design priorities can be visualised using the ESPI form (ICS).

In the last process, a visualisation of the environmental design priorities is created through the Multi-strategy radar (ICS),

indicating the priorities across the various LCD strategies.

MPDS Concept Design Phase

In the concept design phase, the MPDS includes two primary processes: sustainable idea generation and concept sustainability checks, both of which are integral to aligning product concepts with LCD strategies.
The process of sustainable idea generation starts by involving project participants in brainstorming activities to generate ideas targeting the six LCD strategies. Tools such as eco-ideas boards (ICS) and the multi-strategy radar (ICS) are employed in this process to assist in the categorisation and initial evaluation of the ideas, ensuring they align with sustainability priorities defined in the previous phase. The results of the brainstorming activities are later rearranged and organised to generate a preliminary concept.
The second process, the concept sustainability check, focuses on evaluating and refining the concept developed. This step involves the representation of the environmental features of the concept, including the definition and visualisation of its life cycle characteristics. Subsequently, an environmental improvement check is conducted to compare the new concept against the baseline product. Metrics and indicators are used to assess the relative improvements achieved across the six LCD strategies. Tools like LCD strategies pursuing evaluation checklist (ICS) and the ESPI form (ICS) are leveraged for this purpose, allowing for a structured evaluation of potential impacts.
Finally, in the last step of the concept sustainability check activity, the potential for further environmental strategic improvements is visualised using the multi-strategy radar (ICS). This visualisation enables designers to identify additional areas for refinement, aligning the concept more closely with sustainability priorities.

Case study: Application of MPDS in a yacht design workshop

The application of the MPDS method was carried out during a six-day intensive workshop involving 24 young professional yacht designers, organised into six groups of four participants each. The workshop focused on the concept design phase of a 50-foot charter yacht, focusing on the innovative "Albergo Nautico Diffuso" concept. This concept reimagines the traditional use of yachts by shifting toward a service-oriented model, offering a hotel-like experience (Legge regionale 21 giugno 2021, 2021).
Due to the workshop's focus on service-oriented yacht models, the Bali Catamarans 4.8 was chosen as the standard existing product, as it is widely used in this type of activity.
To enable participants to focus on the concept design phase, the strategic product analysis phase was completed by the research team in advance of the workshop. This preparatory work included assessing the environmental impact of a standard existing product using the ICS Checklist for evaluating existing products. The results of this assessment provided a baseline for identifying environmental design priorities across the six LCD strategies.
Based on the assessment, the environmental design priorities were established in Table 1.

LCD Strategy 1 Use extension/intensification	High
LCD Strategy 2 Material consumption reduction	High
LCD Strategy 3 Energy consumption reduction	Medium
LCD Strategy 4 Material life extension	Medium
LCD Strategy 5 Toxicity reduction	Medium
LCD Strategy 6 Resources conserv./biocompatibility	Medium

Table 1. Level of priority assigned for each LCD strategy.

These priorities provided the foundation for participants to generate innovative design ideas.
During the workshop, participants used the ICS eco-ideas boards to implement their concepts in alignment with the predefined priorities. In the final phase, the participants evaluated the environmental performance of their proposed designs using the LCD strategies pursuing evaluation checklist (ICS). The improvements or deteriorations in the product's environmental profile were further analysed by comparing the concepts to the baseline product through the ESPI form, which quantified the potential impacts of the proposed strategies.
Throughout the workshop, 30-minute project review sessions were held daily, providing participants with guidance and support in applying the MPDS. Feedback on the methodology and related tools was gathered

through unstructured interviews with the participants.
The questionnaire assessed the integration of ecodesign strategies during the yacht design workshop. It focused on their influence on the design process, ease of application, and impact on decision-making. The responses provided insights into the practicality of ecodesign principles and areas for improvement in their application.

Results

Interviews with participants

Participant feedback gathered during the daily review sessions is summarised in Table 2, highlighting both the positive and negative aspects identified in the application of the methodology and its associated tools.

PROS	CONS
• In general, the implementation of ICS tools does not significantly impact project timelines • Minimal prior knowledge of sustainability is required to use ICS tools • Some eco-ideas board suggestions are easily implementable • Some guidelines already enable immediate integration of sustainability considerations	• For complex products, the numerous guidelines make it challenging to simultaneously focus on all aspects • Most of the guidelines are excessively detailed and are applicable in subsequent stages of the product development • Certain LCD strategies and guidelines fall outside the nautical designer's scope

Table 2. Pros and cons of the methodology and its tools highlighted during project reviews.

Questionnaire

The questionnaire gathered feedback on the application of LCD strategies during the yacht design workshop. The key findings for each question are outlined in Table 3.

Q1	**How did the LCD strategies influence your overall yacht design process?**	All groups reported that the strategies influenced their design process, with 66.7% stating they significantly changed their approach. The remaining 33.3% noted moderate changes.
Q2	**Which LCD strategies did you find easiest to apply during your project?**	The most easily applied strategy was "use extension/intensification", used by 83.3% of the groups. The second, used by 66.7% of groups, was "material life extension". "Toxicity reduction" was last, since it wasn't indicated by any group.
Q3	**How easy or difficult was it to integrate LCD strategies into your existing design process?**	Half of the groups found the integration quite neutral, while 33.3% found the process easier. One group reported moderate difficulty.
Q4	**Were there any LCD strategies that you found difficult or impractical to implement? If so, why?**	Participants highlighted material-connected strategies as the most challenging due to insufficient knowledge of sustainable materials and the technical complexities of yacht production. Similarly, "toxicity reduction" required expertise beyond the participants' familiarity. Time limitations further hindered in-depth exploration of these strategies.
Q5	**How did the application of LCD strategies affect the decision-making process in your design? Did they change your design approach?**	33.3% of the groups reported that LCD strategies influenced their decision-making by emphasising sustainability, particularly in material and production considerations. 50% stated these strategies extensively guided their proposals or shaped their approach from the early stages, while one group found their integration challenging and reported only minor adjustments.

Table 3. Questionnaire regarding the application of the LCD strategies.

Qualitative assessment of projects

The results of the LCD strategies pursuing evaluation checklist (ICS) reveal how the six strategies were applied and their varying levels of effectiveness across the projects. For each strategy, the groups evaluated the degree of improvement achieved for each related guideline, using the following criteria:

- worse;
- no improvement;
- incremental improvement;
- radical improvement;
- not applicable.

The results shown in Table 4 illustrate the percentage of groups that assigned the specific level of improvement achieved for each strategy.

N/A – Not Applied **1** – Worse, **2** – No improvement, **3** – Incremental improvement, **4** – Radical improvement					
	N/A	**1**	**2**	**3**	**4**
LCD strategy 1	0%	0%	17%	83%	0%
• Design an appropriate life span • Design reliability • Facilitating renewability and adaptability • Facilitating maintenance • Simplifying repair • Simplifying re-use • Simplifying remanufacturing • Intensifying use					
LCD strategy 2	0%	0%	34%	66%	0%
• Minimizing the material content of a product • Minimizing scraps and waste • Minimizing the packaging • Choosing the most efficient material consumption system • Adopting flexible material consumption system • Minimizing material consumption in product design					
LCD strategy 3	0%	0%	83%	17%	0%
• Optimizing energy consumption for pre-prod. and production • Minimizing transportation and storage consumption • Choosing consumption systems minimizing resources in use • Adopting flexible energy system • Minimizing energy consumption in product design					
LCD strategy 4	17%	0%	33%	33%	17%
• Adopting a cascade approach • Adopting high recyclable materials • Simplifying collection and transportation after use • Identifying the materials • Minimizing the number of incompatible materials • Simplifying cleaning • Simplifying composting • Simplifying combustion					
LCD strategy 5	34%	0%	66%	0%	0%
• Reducing toxicity and harmfulness of materials • Reducing energy resources toxicity and harmfulness					
LCD strategy 6	33%	0%	50%	17%	0%
• Optimizing biocompatibility and conservation of materials • Choosing renewable and bio-compatible energy resources					

Table 4. Results of the LCD strategies pursuing evaluation checklist (ICS).

The data reveal that the strategy achieving the highest level of improvement was “use extension/intensification”, with 83.3% of the groups reporting incremental improvement. This was followed by “material consumption reduction”, where 66.7% of the groups similarly reported incremental improvement. Notably, none of the projects demonstrated worsening in any of the six LCD strategies, indicating that all groups achieved at least some level of environmental improvement or maintained the same environmental level of the existing product. This uniform absence of worsening underscores the participants’ focus on sustainability-oriented enhancements.

Overall, most responses across the strategies fell within the categories of no improvement or incremental improvement, with radical improvement observed only once, in the case of the material life extension strategy. For most strategies, the proportion of groups reporting not applicable (N/A) was minimal or absent, suggesting that nearly all LCD strategies were addressed in the projects. However, “toxicity reduction” and “resources conservation/biocompatibility” recorded the highest percentages of non-applicability, with 33.3% of groups indicating these strategies could not be effectively integrated into their designs.

Certain strategies, such as “energy consumption reduction” and “toxicity reduction”, showed limited success, as reflected by higher

percentages of responses in the no improvement category.

Discussion and Conclusions

The workshop demonstrated the practical application of a generic LCD methodology in yacht design, providing valuable insights into its effectiveness and areas requiring further refinement. Participants worked on developing sustainable concepts for a 50-foot charter yacht, using MPDS tools for testing the integration of LCD principles into their workflows. One of the projects can be seen in Figure 1.



Figure 1. Rendered view of one of the projects.

As anticipated by Vezzoli (2018), the implementation of the MPDS method requires adjustments tailored to specific contexts. Indeed, the methodology often proved too generic, providing only vague instructions on the use of specific tools.

Yacht design introduces additional complexities due to the wide range of roles and expertise involved, including naval architects, interior and exterior designers, project managers, and many other stakeholders.

This challenge was evident in the feedback collected from the Questionnaire and the interviews, as some aspects of the proposed tools required skills beyond the scope of a yacht designer.

Furthermore, parts of the methodology and its tools were overly detailed for the concept design phase of nautical projects. Consequently, during the interviews, it was highlighted that some guidelines within the eco-ideas boards were impractical to implement at such an early stage. This misalignment between the level of detail provided and the requirements of the nautical concept design phase limited the methodology's applicability.

These challenges were reflected in the sustainability outcomes of the projects, as summarised in Table 4. While some improvements were achieved, they were generally modest and predominantly concentrated in strategies that were better suited to the concept design phase and more aligned with the core responsibilities of a nautical designer.

While the study focused on a small participant group and exclusively on the concept design phase, these insights provide a valuable starting point. Future research could build on these findings by involving a broader range of participants and exploring the methodology's applicability across other phases of MPDS.

The results highlight the need for a tailored methodology and toolkit specifically designed for yacht design, structured to address the multi-stakeholder nature of the process and its articulated phases. Future adaptations of the MPDS methodology should define the activities and tools appropriate for each stakeholder, ensuring that they are practical, focused, and aligned with the expertise required for each role. Additionally, new tools and methods must consider the unique complexities of yacht design, balancing the need for detail with usability across different phases of the design process. Finally, the advantages highlighted from the unstructured interview can serve as a foundation for future developments.

In conclusion, this study highlights the potential of LCD methodologies to promote sustainability in yacht design while emphasising the need for context-specific adaptations. By addressing the gaps identified, future efforts can build on these findings to advance sustainable practices in the nautical industry and beyond.

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References

Ahmad, S., Wong, K.Y., Tseng, M.L., & Wong, W.P. (2018). Sustainable product design and development: A review of tools, applications and research prospects. Resources, Conservation and Recycling, 132, 49-61. https://doi.org/10.1016/j.resconrec.2018.01.020

Ansaloni, G.M.M., Bionda, A., & Ratti, A. (2024). The Evolution of Yacht: From Status-Symbol to Values' Source. In: Zanella, F., et al. Multidisciplinary Aspects of Design. Design! OPEN 2022. Springer Series in Design and Innovation, vol 37. Springer,

Cham. https://doi.org/10.1007/978-3-031-49811-4_17

Ceschin, F., & Gaziulusoy, I. (2021). Design for Sustainability: A Multi-level Framework from Products to Socio-technical Systems (1st ed.). Routledge. https://doi.org/10.4324/9780429456510

Chaves, L.I. (2008). Design for sustainability: A methodological approach for the introduction of environmental requirements in the furniture sector. *Product: Management & Development*, 6(2), 167–171.

Dahmani, N., Benhida, K., Belhadi, A., Kamble, S., Elfezazi, S., & Jauhar, S.K. (2021). Smart circular product design strategies towards eco-effective production systems: A lean eco-design industry 4.0 framework. Journal of Cleaner Production, 320, Article 128847. https://doi.org/10.1016/j.jclepro.2021.128847

Directorate-General for Communication (European Commission) (2020). Circular economy action plan: For a cleaner and more competitive Europe. Publications Office of the European Union. https://data.europa.eu/doi/10.2779/05068

Hauschild, M.Z., Rosenbaum, R.K., & Olsen, S. I. (2018). Life Cycle Assessment: Theory and Practice. Springer. https://doi.org/10.1007/978-3-319-56475-3

Hobday, M. (1998). Product complexity, innovation and industrial organisation. Research policy, 26(6), 689-710.

International Maritime Organization (2023). 2023 IMO strategy on reduction of GHG emissions from ships. https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

International Organization for Standardization. (2020). Environmental management systems — Guidelines for incorporating ecodesign (ISO Standard No. 14006:2020). https://www.iso.org/standard/72644.html

Jacquet, L., le Duigou, A., & Kerbrat, O. (2024). A systematic literature review on holistic lifecycle assessments as a basis to create a standard in maritime industry. Int J Life Cycle Assess 29, 683–705. https://doi.org/10.1007/s11367-023-02269-4

Legge regionale 21 giugno 2021, n. 13, “Riconoscimento dell'albergo nautico diffuso, modifiche alla legge regionale n. 16 del 2017.” (2021). Bollettino Ufficiale della Regione Autonoma della Sardegna (BURAS), n. 37, Parte Prima. https://buras.regione.sardegna.it/custom/frontend/viewInsertion.xhtml?insertionId=e1881fdd-d2f6-4be0-b62d-3e98f27b4b11

Liang, M., & Birmingham, R. (2024). Identification of technologies and processes to enhance the sustainable design, manufacture, operation, and end-of-life of the motor yacht above 24 meters. Proceedings of the International Conference on Design and Construction of Super and Mega Yachts 2019, Italy. https://doi.org/10.3940/rina.smy.2019.18

Montigneaux, R., & Mower, M. (2023). Global Order Book: Full Analysis of Yachts on Order in 2024. BOAT International. https://www.boatinternational.com/boat-pro/global-order-book/global-order-book-2024-report

Paris Agreement (2016). Official Journal, L 282, 4-18. CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:22016A1019(01)

Plaschke, L., Vezzoli, C., & Scullica, F. (2019). Product Design for Sustainability – Guidelines for the Life Cycle Design of Office Furniture. Proceedings of the 3. LeNS world distributed conference, Italy, Mexico, China, India, Brazil, South Africa, 3, 915-919. https://hdl.handle.net/11311/1122948

Stark, J. (2024). Product Lifecycle Management (Volume 6): Increasing the Value of PLM with Innovative New Technologies. Springer. https://doi.org/10.1007/978-3-031-53521-5

Vezzoli, C. (2018). Design for Environmental Sustainability: Life Cycle Design of Products (2nd ed.). Springer. https://doi.org/10.1007/978-1-4471-7364-9

Vezzoli, C., & Conti, G.M. (2019). Life Cycle Design (LCD) Guidelines for Environmentally Sustainable Clothing Care Systems: An Open and Operative Tool for Designers. Proceedings of the 3. LeNS world distributed conference, Italy, Mexico, China, India, Brazil, South Africa, 3, 859-864.

Yang, D., & Vezzoli, C. A. (2024). Designing Environmentally Sustainable Furniture Products: Furniture-Specific Life Cycle Design Guidelines and a Toolkit to Promote Environmental Performance. Sustainability, 16(7), 2628. https://doi.org/10.3390/su16072628

Yücenur, G.N. (2021). A Sequential Solution with MCDM Methods at the Motor-Yacht Construction Problem. Journal of ETA Maritime Science, 9(3), 177–191. https://doi.org/10.4274/jems.2021.8815

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Novel methodology for the selection and evaluation of R-strategies to support product design for circular economy

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Keywords: Circular economy; CE indicators; CE metrics; Design for Recycling; Design for environment.

Abstract: EU legislation demands manufactures to improve their product's circularity. The 9R Framework organizes strategies of a circular economy in a hierarchical manner based on their respective effectiveness in promoting circularity. Manufacturers need to determine which of these strategies can be implemented for their products and how well a certain design meets the requirements of these strategies. Therefore, a methodology is proposed allowing to identify feasible R-strategies that are appropriate for a specific type of product. In the next step, the methodology evaluates how the unique characteristics of a particular component allow for the application of these strategies. This methodology is applied to a case study of a vehicle door, considering and comparing the circularity readiness of various design variants. A set of specific Circularity-indicators (C-indicators) for each strategy is used for this purpose. This methodology enables comparisons among different design options, highlighting their impact on the product and material recyclability. Ultimately, the methodology helps to identify challenges in a targeted manner that guide designers in creating products that effectively support beneficial R-strategies.

Motivation & Problem Statement

In the framework of the European Green Deal the EU has triggered various legislations that require European and non-European vehicle manufacturers to strategically consider circularity requirements. For instance, the *Fit for 55* package aims to reduce the greenhouse gas emissions in the EU by 55% until 2030 with the long-term objective of achieving climate neutrality by 2050. Also, the EU has formulated the target of achieving a 25% share of domestic production for all materials according to the rules of the Critical Raw Materials Act (European Union, 2024). A circular economy (CE) could significantly contribute to achieving these goals as product and material recycling tend to reduce the carbon footprints of the respective products (Ellen Macarthur Foundation) and it would also serve the circulation of materials in a closed European system. Requirements on product circularity, as exemplarily shown in Table 1 put manufacturers under pressure, as many of them can only be realized with strategic decisions (Hansen et al., 2024). Strategic partnerships must be established to secure access to recycled materials, for example. Other maxims, such as meeting recycling quotas or ensuring the required dismantling of components (such as requirements E4.1-E7), can only be achieved with a focus on design for recycling. To fulfill these requirements, the automotive industry's access to recycled materials must be drastically improved. This can only be achieved if, in addition to mechanical recycling, other recycling options such as chemical recycling are introduced and scaled up to industrial scale. Further requirements, which, for example, promote a design that is suitable for dismantling (E7, C28) or demand implementations of CE measures for vehicles at a more strategic level (E9) will follow.

However, these targets can only be achieved through the consistent application of CE

measures and strategies across a product's entire life cycle which implies a consideration in product development already.

Law	Art.	Circular Economy Requirement
E	4.1	At least 85% of end-of-life vehicles are recyclable and 95% are recoverable
E	4.2	Collecting the necessary (material) data from the entire supply chain to determine recyclability and recoverability
E	6.1	Compliance with the recyclate content: Plastic must consist of at least 25% by weight of recycled plastic, 25% of which must be from end-of-life vehicles
E	6.2	Review of minimum recycled content for steel, aluminium, magnesium and rare earths to be followed by implementing acts
E	7	Construction of vehicles so that the removal of fixed components is not hindered (electric vehicle batteries, electric motors, engines, etc.)
E	9	Creation of a circularity strategy for vehicles (+ shift of responsibility to manufacturers)
E	10	Publication of the recycled content of certain (critical) materials in permanent magnets in electric drive motors, testing for aluminium, magnesium and steel
B	7	Mandatory carbon footprint declaration for batteries
B	8	Mandatory recycled content for battery manufacturing (cobalt, lithium, nickel)
C	28	Removability of neodymium magnets

Table 1. Excerpt of upcoming CE-related legislative requirements in the EU for automotive manufacturers; E: ELV Regulation; B: Battery Regulation; C: Critical Raw Materials Act; Art.: Article

In this context two classes of approaches to integrate CE requirements on product level can be distinguished. Process-based approaches, such as Life-Cycle-Assessments (LCA), apply modeling of end-of-life processes, which includes disassembly or mechanical recycling. The results allow to assess different product designs based on performance values. Criteria-based approaches, on the other hand, use predefined criteria to evaluate product designs (Kroll & Hanft, 1998; Roithner et al., 2022). These are for example the numbers of different materials or joining techniques used. However, existing criteria-based approaches that aim to integrate CE-requirements into product development through the application of indicators seem to over simplify the problem. These do not specifically evaluate the general applicability of R-strategies to a specific product type and thus do not assess the circularity readiness in a targeted manner. Further they often seem to only focus on one or two of the R-strategies exclusively and can thus not provide a full picture.

Against this background, the paper presents a methodology that helps product developers integrate circularity requirements into product design and management. It enables comparisons between different design options, emphasizing their effects on product and material recyclability. The remainder of this paper is structured as follows: The upcoming section presents the theoretical foundations and the current state of research on supporting CE-compliant product development, from which the research questions are derived. Following that, a methodology is introduced to incorporate circularity readiness into product development. The methodology is then applied to the example of a vehicle door in the subsequent section.

Theoretical Foundations & State of Research

This section firstly presents the overall concept of circular economy and then highlights the current research state on its integration into product development.

As explained in the introduction, there are process and criteria-based methodologies and approaches to assess the circularity of product design. For this analysis we only focus on the latter. These generally have the advantage of being more straightforward in their application but deliver less exact results.

The Concept of Circular Economy

The 9R framework consists of nine hierarchically organized strategies designed to promote CE principles, focusing on resource efficiency and sustainability. The hierarchy is based on the contribution each individual strategy could potentially have in fostering a CE (European Union, 2017). The strategies are ranked as follows: Refuse, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover. By following this hierarchy, companies can minimize waste, reduce environmental impact, and create value from resources throughout their life cycle, prioritizing the most effective strategies first.

In general, the CE describes an "economic system that replaces the end of life (EoL) concept with reducing, alternatively reusing,

recycling, and recovering materials in production/distribution and consumption processes" (Kirchherr et al., 2017).
The transition to a CE can only succeed by applying the circular practices at all system-levels from micro (e.g. product), meso (e.g. eco industrial park) to macro (e.g. city, country). A detailed explanation of the established CE-levels refer to Kirchherr et al. (2017). Current studies on the evaluation of circular product performance on micro level using C-indicators emphasize that many approaches do not fully capture the complexity of the levels scope (Roos Lindgreen et al., 2020). Therefore, Saidani et al. (2017) propose the nano level as an extension, focusing on the circularity of products, components, and materials across the life cycle. Within this context, a C-indicator can be defined to measure the extent to which a product or system aligns with practices and strategies aimed at advancing a CE. Higher circularity indicates that a product or system is closer to achieving the objectives established by the guiding principles of CE (Oliveira et al., 2021).

Research on Methods for integrating Circular Economy Principals into Product Development
To integrate the R-strategies into the product development process and to handle the expanded solution space due to the integration of the CE perspective, intensive research is being conducted on methods and tools in the context of circular product design.
The Circular Pathfinder is a tool developed to support companies select appropriate circular design strategies. Developed from original equipment manufacturer (OEM) case studies, it emphasizes ease of use and fills the gap in industry-driven tool development for circular and sustainable design. The software guides users through product-related questions and suggest suitable design strategies with practical examples. However, an evaluation of the tool found that its emphasis on usability overly simplifies the complexity of strategic design decisions (van Dam et al., 2017).
Aher et al. (2023) highlight the growing application of C-indicators in design processes, often assuming extensive design changes (e.g., material substitutions, end-of-life treatments) that may overlook trade-offs between indicators, technical performance and design feasibility. A simulation-based method is introduced that links design attributes and C-indicators to evaluate the impact on circularity and technological constraints, such as stiffness. The framework builds on the insights that micro level indicators generally comprise energy, mass and time terms, which can be estimated using commonly applied models (e.g., CAD, FEA) during the product development process.
Similar challenges are pointed out by Ortner et al. (2022) and Turke et al. (2024), noting that existing methods in circular product design often face difficulties in identifying the best solutions from numerous variants and to manage multiple, potentially conflicting or redundant CE objectives. To address these challenges, they propose a multi-objective optimization procedure exemplified through the integration of C-indicators.

Research on Metrics for the Circular Economy
Apart from integrating C-indicators into design methodologies, research is advancing the development of new CE measures. Recent review papers have examined the current state of metrics in the CE. For instance, a structured identification of indicators that aim to assess and monitor CE performance of products and companies is proposed by Saidani et al. (2019). The authors identified 55 different sets of C-indicators, which have been categorized in a newly developed taxonomy to facilitate their appropriate application and to highlight challenges in industry implementation.
Pascale et al. (2021) reviewed C-indicators across the established levels (macro, meso, micro) to evaluate their effectiveness in supporting the establishment of a CE. The study highlights that while indicators are valuable for supporting circularity, there is no standardized metric for measuring a CE. This lack of standardization poses a significant challenge to the consistent assessment of progress toward CE aspirations.
The research by Oliveira et al. (2021) presents a comprehensive review focused on nano and micro level indicators, evaluating them based on their relevance to sustainability pillars and life cycle stages (take, make, use, recover). The objective is to support decision-makers in selecting the most suitable indicators for circularity assessments.
Shevchenko et al. (2024) reviewed 544 articles to provide an inclusive research landscape.
By clustering recent publications with a focus on C-indicator-driven tools, four key areas were identified: "C-metrics-based tools for circularity assessment", "circular design-intended tools

built on C-metrics", "C-metrics-based tools for monitoring the process" and "database-related built on C-metrics". This leads to a research agenda comprising seven key challenges. These include, for example, the "lack of standardized design toolkits based on robust C-metrics that facilitate data-driven decision-making for developers, engineers, and designers in the early stages of product development".

In summary, the literature review identifies several major research needs. Firstly, for a given product category it needs to be identifiable which R-strategies actually make sense to apply. Secondly, when R-strategies have been identified, it needs to be evaluated to what extent a given product is able to fulfill the requirements that these strategies entail. Therefore, a set of different indicators exists (e.g., recycled content, product carbon footprint) that need to be combined to provide a holistic picture of a given case.

Methodology

As explained in the introduction automotive manufacturers are obligated to incorporate CE-Strategies on micro level. Therefore, they need to evaluate which of the R-strategies are applicable to their products and to what extent a specific product design meets the requirements of these strategies. To strategically address CE requirements, the procedure illustrated in Figure 1 is proposed. The main novelty lies in its dual-perspective evaluation of R-strategies applicability. Firstly, a qualitative assessment determines which R-strategies are applicable for a certain product type. Secondly, the focus needs to be how the R-strategies can be applied to a product regarding its specific characteristics. The overall procedure consists of six steps. The product for which CE strategy is to be applied must be specified. This pre-selection is crucial because the applicability of different strategies depends on the individual use. In the second step, the R-strategies are selected. This selection is guided by a questionnaire (annex) containing specific questions to determine whether the strategies are applicable to the object in question. Applying remanufacturing, for example, requires a demand for the product after its first use stage in a similar form with comparable characteristics and specifications. Subsequently, the CE level (nano, micro, meso or macro) for which challenges and enablers are to be determined needs to be selected. As discussed previously the challenges vary significantly depending on the perspective. These may include managing policies at the macro level, supply chains at the meso level or concern product design (micro/nano level).

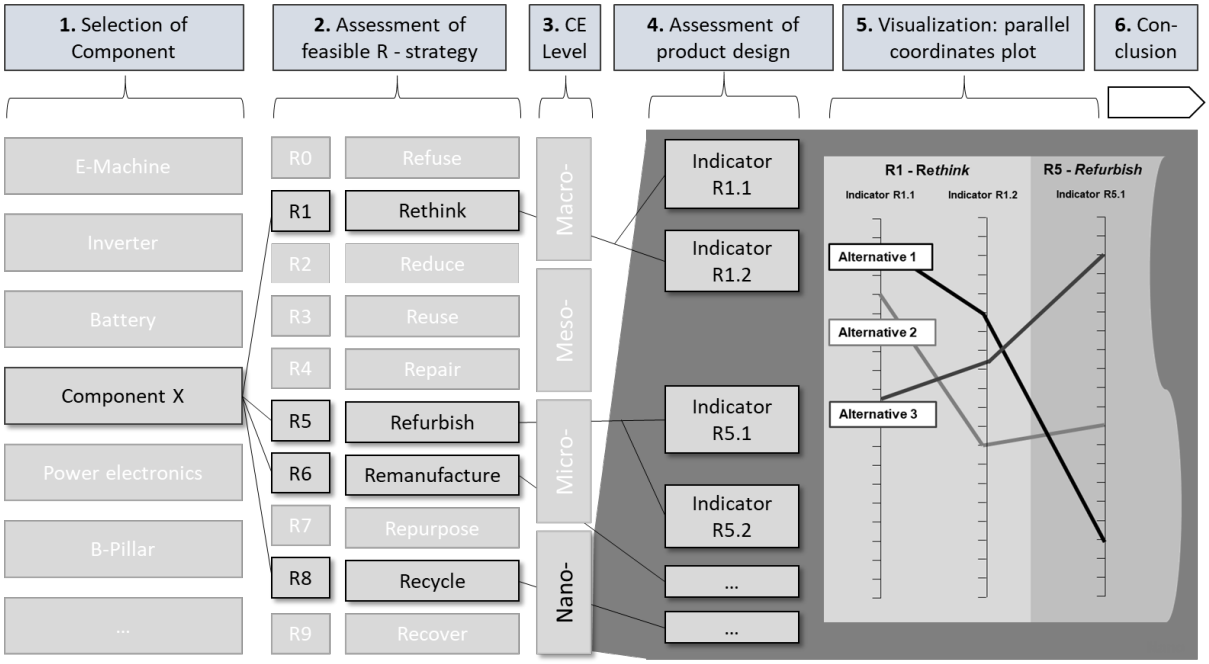


Figure 1. Methodology to derive R-Strategies for component types and evaluate their applicability for a specific product or component taking into account its specific characteristics

In the fourth step, R-strategy specific indicators are applied to assess the reference object in detail. These indicators help determine the extent to which the selected R-strategies are applicable to the object in its current conditions. Additionally, they enable comparisons with objects of the same kind, thus facilitating benchmarking. An excerpt of possible indicators that were extracted on the basis of the literature research is presented in the following section when applying the method and will be expanded in future work. The results of the quantification are visualized using a parallel coordinates plot, which enables a comparison of the different concepts. In the final step, the performance of the concept variants is compared to the best-performing solutions in terms of circularity, to identify the most critical challenges that need to be addressed.

Exemplary Application

In the following, the methodology presented in the previous section is applied to a case study.

Selection of the Component and feasible R-Strategies

The methodology starts with the selection of the component to be evaluated with regard to its circularity readiness. Within the case study a vehicle door is used. Table 2 shows the main characteristics of the vehicle door that is used as reference design. The data does not refer to an actual product but serves solely as an illustrative example to showcase the introduced methodology. To analyze different design decisions material substitutions are made to the door panel and window frame components, using steel and aluminum as alternative materials. In addition, the share of recycled plastic in the interior lock component is varied. Based on these design changes, two further concepts are derived, to which relevant and suitable indicators are applied (annex Table 5 and Table 6). Their key figures are then compared to evaluate the individual performance and trade-offs. Concept 1, the lightweight design concept, is characterized by a significantly higher proportion of aluminium, both in comparison to the reference design and to Concept 2. In contrast, Concept 2 is characterized by the highest proportion of recycled plastic for the interior lock among the designs.

In accordance with the first step of the methodology, the several R-strategy specific questions provided in annex (Table 4) were answered for the case study. The results indicate that the strategies reduce and recycling are applicable for the considered component among others.

Automotive vehicle door



Further characteristics

- Fictitious example based on research car body
- Steel door (reference)
- Total weight: 40kg
- Applicable for personal vehicles

Component	Composition/Alloy	Mass (kg)
Door Panel	Iron	19.9
	Carbon	0.1
Door Trim	Acrylonitrile	1.5
	Butadiene	1
	Styrene	2.5
	Impact Modifiers	0.6
	Heat Stabilizers	0.4
Window Frame	Aluminum	3.8
	Silicon	0.1
	Magnesium	0.1
Window	Soda-lime glass	3.5
	Polyvinyl butyral (PVB)	0.5
Seal	Ethylene	0.8
	Propylene	0.7
	Diene Monomer	0.4
	Processing Aids	0.1
Hinges	Iron	1.96
	Carbon	0.04
Window Regulator Mechanism	PA66 (Polyamide 66)	0.8
	Glass Fiber	0.1
	Impact Modifiers	0.1
Interior Lock	Polypropylene	0.8
	UV Stabilizers	0.1
	Colorants	0.1
Total Weight		**40 kg**

Table 2. Case study: Bill of materials of steel car door and its main characteristics (reference design). Image taken from Bader, 2022

Selection of C-Indicator Application

For the selected two R-strategies, selected C-indicators are assessed to evaluate the impact of the design decisions. The indicators are listed in Table 3 and have been derived from the presented state of research and will be explained in more detail below. These indicators represent a preliminary selection and are exemplary for this method. Oliveira et al. (2021) and Pascale et al. (2021) give an exemplary review of different indicators to measure circularity.

R-Strategy	C-Indicator	Description	Reference
Reduce	Mass fraction	Evaluation of reduced mass	-
	Material Carbon Footprint	Environmental impact through material selection	Federal Office for Economic Affairs and Export Control (2024)
	Production Waste (Wcp)	Waste from component production	Bracquené et al. (2020)
Recycle	Statistical Entropy (SE)	Evaluation of the material mixture	Roithner et al. (2022)
	Circular Economy Indicator	Comparison of tensile strength	Jamnongkan et al. (2022)

Table 3. Applied C-indicators to identify R-strategy readiness of a specific component or product

For the R2 strategy (reduce) three C-indicators are considered, namely mass fraction, carbon footprint and a waste production indicator (W_{cp}). The mass fraction evaluates the reduction in component mass compared to the mass of the reference design resulting from a design modification. In combination, the carbon footprint of material, expressed in tons of CO_2-equivalent (CO_2-eq), is utilized to assess the environmental impact of the selected material (BAFA, 2024). Additionally, the production waste indicator exemplarily representing the efficiency of the manufacturing process within this case study. This indicator is part of the Production Circularity Index (PCI) (Bracquené et al., 2020), and it assesses manufacturing efficiencies based on literature values for global production. This selection of C-indicators allows for an exemplary evaluation of the impact of design updates in the reduce context across the life cycle stages (Take, Make, Use, Recover).

For the R8 strategy (recycling), two C-indicators are applied as examples. The first is the product inherent recyclability index (RPR) as applied in Roithner et al. (2022) and the second is the Circular Economy Index (CEI).
The RPR evaluates the recyclability based on the statistical entropy (SE) of a product, which reflects the complexity of the material mixture. The more materials are used and the more evenly these are distributed, the worse the evaluation result.

The CEI represents a characteristic value where a recycled EoL product is set in relation to the value of a newly manufactured product. This approach offers the advantage of considering the recyclate quality without necessitating the conduction of a complex life cycle assessment (even though it cannot replace it). The value of the material can be determined by the monetary value, but also by a chemical or mechanical characteristic value (Di Maio & Rem, 2015). In this example, the value is simplified by using the mechanical quality, represented by tensile strength. The required quality is determined based on the tensile strength of the virgin material. According to studies by Jamnongkan et al. (2022), which measured a loss of 9% in tensile strength for polypropylene samples with 20 wt% recycled content (rPP20) and 12% for 40 wt% recycled content (rPP40), this can be assumed for the quality of the recycled material.
Figure 2 illustrates the results of the assessment performed in this study. The indicators are organized according to the R-strategy they evaluate. To ensure consistency, the scales of the indicators associated with the Reduce strategy are inverted, such that an upward trend reflects a positive outcome. Furthermore, all results are normalized relative to the indicator values of the reference design.
The Figure demonstrates how a design decision impacts multiple aspects of the R-strategies.
For example, the analysis of Concept 1 highlights that a material substitution results in a mass reduction but it also increases waste in the manufacturing process of the material. Simultaneously, this design decision reduces the intensity in the material mix, enhancing recyclability as reflected by the indicator RPR. In summary, the developed approach enables the identification of potential trade-offs, both between different R-strategies and within individual ones.

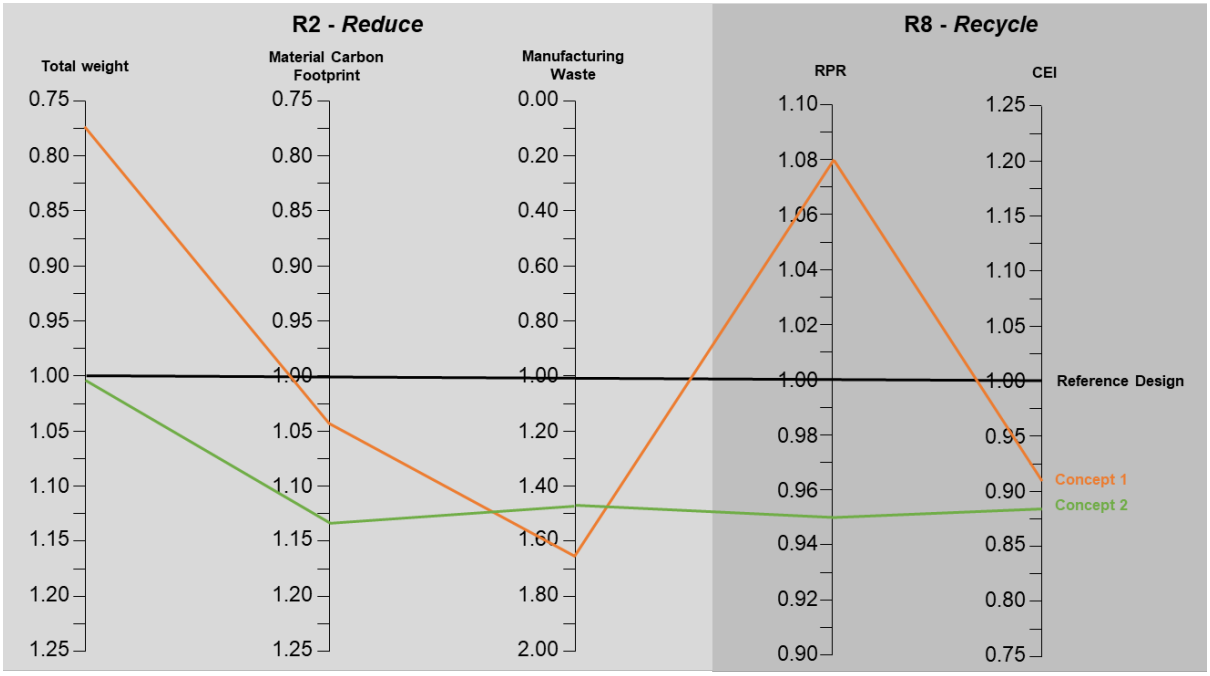


Figure 2. Results of the single indicators that have been applied to the reference design and the concept variants. The underlying results have been normalized, with the reference design assigned a baseline value of 1.00

Conclusion and Outlook

This work introduces a methodology for identifying and evaluating relevant R-strategies a given product to advance circular product design. Key contributions include a structured approach to derive potentially applicable strategies for certain product types and the identification application of suitable of C-indicators to assess to what extent the relevant strategies can actually be applied to a specific product design. Based on that, the developed approach allows for the identification of challenges that limit the strategies' practical implementation.

The developed methodology is exemplarily applied to a vehicle door on the nano level of CE. For this case study essential strategies from the 9R framework are identified. Subsequently, key characteristics of the vehicle door are changed. The results demonstrate that these changes significantly influence the applicability of the R-strategies, providing valuable insights to support decisions for a 9R-strategy-compliant design.

The C-indicators applied in the assessment were chosen to represent the applicability of the R-Strategies. However, within the scope of this contribution, only a selection of these indicators could be presented. In practice, 9R strategy-compliant design decisions are much more complex to make, which is why the examples shown here do not do justice to the complexity of the topic. This highlights the need for further development of the presented indicators and the inclusion of additional indicators to create a more comprehensive evaluation framework.

One example of an indicator requiring further refinement is the assessment of recyclability based on the statistical entropy of a material composition. While this approach accounts for the mixing of different materials, it remains independent of the specific materials used. Consequently, it cannot evaluate the extent to which the materials in a component can be effectively separated during a recycling process.

The use of recycled materials or material substitutions, as demonstrated in the case study, often demands design changes to maintain technological requirements e.g., the stiffness, strength, or dynamic behavior of the component. However, the indicators considered within this framework for the R2-strategy (reduce) do not provide insights into the mechanical properties of the component.

Furthermore, accurately assessing the material properties of recyclates is crucial for achieving EU targets for the integration of recycled materials in automotive manufacturing and advancing the circular economy.

The utilization of artificial intelligence (AI) as a methodological tool in this context presents a promising approach. This highlights the need to identify additional indicators that are more relevant and suitable for integration into the framework. Such design changes typically require computationally intensive and time-consuming structural analyses of the component. AI could also be brought into the product development and computational optimization process as it could provide a solution to these challenges. AI can potentially not only reduce computation time but also improve optimization outcomes. In addition, it can be used in the optimization process to resolve possible conflicting objectives of the R-strategies and to carry out design optimizations with sustainability and circularity requirements. Based on the evaluation, suitable Design for X (DfX) guidelines can be proposed, such as strategies to reduce mass through lightweight design or improve recyclability through modularization. Integrating these guidelines directly into CAD programs enhances acceptance and availability by enabling real-time tracking and evaluation of design decisions. This supports sustainable design choices while maintaining mechanical properties and technical performance.

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References

Aher, G., Boudjadar, J., & Ramanujan, D. (2023). Towards Simulation-Based Circular Product Design. *Procedia CIRP*, *116*, 690–695. https://doi.org/10.1016/j.procir.2023.02.116

Bader, B. (2022). *Ein methodischer Ansatz zur Potenzialbewertung hybrider Bauweise bei Fahrzeugstrukturbauteilen* [Dissertation, Technische Universität Braunschweig; Verlag Dr. Hut]. GBV Gemeinsamer Bibliotheksverbund.

Bracquené, E., Dewulf, W., & Duflou, J. R. (2020). Measuring the performance of more circular complex product supply chains. *Resources, Conservation and Recycling*, *154*, 104608. https://doi.org/10.1016/j.resconrec.2019.104608

Di Maio, F., & Rem, P. C. (2015). A Robust Indicator for Promoting Circular Economy through Recycling. *Journal of Environmental Protection*, *06*(10), 1095–1104. https://doi.org/10.4236/jep.2015.610096

Ellen Macarthur Foundation. *Completing the picture - How the circular economy tackles climate change.* Material Economics. https://www.ellenmacarthurfoundation.org/completing-the-picture

European Union. (2017). *9R Framework: as suggested by suggested by the PBL Netherlands Environmental Assessment Agency (2017)*.

European Union (2024). Critical Raw Materials Act: Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020Text with EEA relevance. *Official Journal of the European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1252&qid=1720020986785

Federal Office for Economic Affairs and Export Control. (2024). *Informationsblatt CO_2-Faktoren.* BAFA. http://www.bafa.de/

Hansen, S., Rüther, T., Mennenga, M., Helbig, C., Ohnemüller, G., Vysoudil, F., Wolf, C., Rosemann, B., Pavón, S., Michaelis, A., Vietor, T., Döpper, F., Herrmann, C., & Danzer, M. A. (2024). A structured approach for the compliance analysis of battery systems with regard to the new EU Battery Regulation. *Resources, Conservation and Recycling*, *209*, 107752. https://doi.org/10.1016/j.resconrec.2024.107752

Jamnongkan, T., Intraramongkol, N., Samoechip, W., Potiyaraj, P., Mongkholrattanasit, R., Jamnongkan, P., Wongwachirakorn, P., Sugimoto, M., Ito, H., & Huang, C.-F. (2022). Towards a Circular Economy: Study of the Mechanical, Thermal, and Electrical Properties of Recycled Polypropylene and Their Composite Materials. *Polymers*, *14*(24). https://doi.org/10.3390/polym14245482

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kroll, E., & Hanft, T. A. (1998). Quantitative evaluation of product disassembly for recycling. *Research in Engineering Design*,

10(1), 1–14. https://doi.org/10.1007/BF01580266

Oliveira, C. T. de, Dantas, T. E. T., & Soares, S. R. (2021). Nano and micro level circular economy indicators: Assisting decision-makers in circularity assessments. *Sustainable Production and Consumption*, *26*, 455–468. https://doi.org/10.1016/j.spc.2020.11.024

Ortner, P., Tay, J. Z., & Wortmann, T. (2022). Computational optimization for circular economy product design. *Journal of Cleaner Production*, *362*, 132340. https://doi.org/10.1016/j.jclepro.2022.132340

Pascale, A. de, Arbolino, R., Szopik-Depczyńska, K., Limosani, M., & Ioppolo, G. (2021). A systematic review for measuring circular economy: The 61 indicators. *Journal of Cleaner Production*, *281*, 124942. https://doi.org/10.1016/j.jclepro.2020.124942

Roithner, C., Cencic, O., & Rechberger, H. (2022). Product design and recyclability: How statistical entropy can form a bridge between these concepts - A case study of a smartphone. *Journal of Cleaner Production*, *331*, 129971. https://doi.org/10.1016/j.jclepro.2021.129971

Roos Lindgreen, E., Salomone, R., & Reyes, T. (2020). A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level. *Sustainability*, *12*(12), 4973. https://doi.org/10.3390/su12124973

Saidani, M., Yannou, B., Leroy, Y., & Cluzel, F. (2017). How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework. *Recycling*, *2*(1), 6. https://doi.org/10.3390/recycling2010006

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. *Journal of Cleaner Production*, *207*, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014

Shevchenko, T., Shams Esfandabadi, Z., Ranjbari, M., Saidani, M., Mesa, J., Shevchenko, S., Yannou, B., & Cluzel, F. (2024). Metrics in the circular economy: An inclusive research landscape of the thematic trends and future research agenda. *Ecological Indicators*, *165*, 112182. https://doi.org/10.1016/j.ecolind.2024.112182

Turke, L. M., Hoang, A.-D., & Vietor, T. (2024). Results of the Environmental Impact Balancing as a Restriction of Undercarriage Concepts. In *Proceedings of NordDesign 2024* (pp. 266–276). The Design Society. https://doi.org/10.35199/NORDDESIGN2024.29

van Dam, S. S., Bakker C.A., de Pauw I., & van der Grinten B. (2017). The circular pathfinder: Development and evaluation of a practice-based tool for selecting circular design strategies. In C. Bakker & R. Mugge (Eds.), *Research in design series: v. 9. Plate: Product Lifetimes And The Environment : Conference Proceedings of PLATE 2017, 8-10 November 2017, Delft, the Netherlands* (pp. 102–107). IOS Press.

Annex

Strategy	Questions on product type	Y/N
R2: Reduce	Can a material that significantly contributes to the total weight of the *c/p* be substituted with a lighter one?	
	Is it expected that significant amounts of material can be saved by applying methods and tools of lightweight design (e.g., shape optimization)?	
R3: Reuse	Can *p*-life be expected to be longer than the initial use phase without further intervention?	
	Can the service life of *c* be expected to exceed that of the entire product without further intervention?	
R4: Repair	Can the *p/c* be expected to be subject to wear and tear during its lifetime?	
	Is the lifetime of the entire *p* likely to exceed that of the *c*?	
R5: Refur-bish	Is it to be expected that a further utilisation phase for the *p/c* can be realised through targeted interventions?	
	Can the *p/c* also be used sensibly in a state below new condition?	
R6: Remanu-facture	Is it to be expected that a further utilisation phase for the *p/c* can be realised through targeted interventions?	
	Is there a need for the *p/c* beyond the first phase of use?	
R7: Repur-pose	Can the *p/c* be used sensibly in another application after the first use phase?	
R8: Recycle	(none)	
R9: Recover	Is it not possible to recycle *p/c* under any circumstances?	

Table 4. Excerpt of a possible questionnaire of R-strategy specific questions to identify which strategies are eligible for a certain general product (p) or component (c) type

Concept 1				
Component	**Composition/Alloy**			**Mass (kg)**
Door Panel	Aluminium			11,64
	Silicon			0,12
	Magnesium			0,12
Door Trim	Acrylonitrile			1,7
	Butadiene			0,5
	Styrene			2
	Impact Modifiers			0,2
	Heat Stabilizers			0,4
Window Frame	Aluminium			3,8
	Silicon			0,1
	Magnesium			0,1
Window	Soda-lime glass			3,5
	Polyvinyl butyral (PVB)			0,5
Seal	Ethylene			0,8
	Propylene			0,7
	Diene Monomer			0,4
	Processing Aids			0,1
Hinges	Iron			1,96
	Carbon			0,04
Window Regulator Mechanism	PA66 (Polyamide 66)			0,8
	Glass Fiber			0,1
	Impact Modifiers			0,1
Interior Lock	Polypropylene			0,8
	UV Stabilizers			0,1
	Colorants			0,1
*normalized to value of referenz design (basline value of 1)				
Total weight*	**Carbon Footprint***	**Production Waste***	**RPR***	**CEI***
0,77	**1,04**	**1,65**	**1,08**	**0,91**

Table 5. Characteristics and calculation results for the selected C-indicators of Concept 1

Concept 2				
Component	**Composition/Alloy**			**Mass (kg)**
Door Panel	Aluminium			11,64
	Silicon			0,12
	Magnesium			0,12
Door Trim	Acrylonitrile			1,5
	Butadiene			1
	Styrene			2,5
	Impact Modifiers			0,6
	Heat Stabilizers			0,4
Window Frame	Iron			6,08
	Carbon			0,32
Window	Soda-lime glass			3,5
	Polyvinyl butyral (PVB)			0,5
Seal	Ethylene			0,8
	Propylene			0,7
	Diene Monomer			0,4
	Processing Aids			0,1
Hinges	Iron			1,96
	Carbon			0,04
Window Regulator Mechanism	PA66 (Polyamide 66)			0,8
	Glass Fiber			0,1
	Impact Modifiers			0,1
Interior Lock	Polypropylene			0,8
	UV Stabilizers			0,1
	Colorants			0,1
*normalized to value of referenz design (basline value of 1)				
Total weight*	**Carbon Footprint***	**Production Waste***	**RPR***	**CEI***
0,86	**1,13**	**1,47**	**0,95**	**0,88**

Table 6. Characteristics and calculation results for the selected C-indicators of Concept 2

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Revising regulations unleashes engineered timber buildings potential for climate mitigation

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Keywords: Timber building; End-of-life modelling; Design for Deconstruction and Reuse; Reference service life; Temporary carbon storage.

Abstract: Engineered timber can substitute traditional carbon-intense building materials playing a critical role in climate action thanks to its capacity to store biogenic carbon removed from the atmosphere during forest growth. However, the existing regulations and standards developed in the past along with the development of traditional building practices based on concrete and steel, hinder the possibility to fully exploit the potential of engineered timber within the construction sector. Current standards impose 50 years as reference service life for buildings. While irrelevant for traditional materials, which are not carbon stocks, this imposition belittles this unique feature of timber-based materials. Furthermore, current standards for timber-based materials impose well-defined End-of-Life (EoL) scenarios, each culminating with the incineration of the timber – regardless of any cascading process. However, among the possible EoL scenarios, the possibility of reusing engineered timber materials maintaining the same function is not conceived, although technically feasible. Consequently, LCA of buildings following such standards are forced to neglect the potential positive impact of timber-based buildings possibly providing results that tend to favor traditional over timber-based materials. In this work, we show the potential of timber-based buildings to act as a mean of climate mitigation, calling for an urgent modification of the current standard and linked LCA practices. The case study of a timber-based multi-story building shows that RSL extension and reuse reduce the emission by 13% and 1-2% respectively compared to concrete, except for a RSL of 150 years for which the reduction is marginal.

Introduction

The construction industry is a significant driver of socio-economic growth (UNEP, 2021). However, it accounts for 50% of all raw materials extracted, more than 42 billion tons of material per year (UNEP, 2021). It is linked with one-third of waste generation (UNEP, 2021) and 37% of global energy-related CO_2 emissions (UNEP & Yale, 2023). About 10% of these emissions are due to construction materials (UNEP & Yale, 2023). The choice of building materials is crucial for reducing the embodied emissions of buildings (Pomponi et al., 2020). Mass timber construction products are exceptionally durable and flexible within their use phase (Duan et al., 2022). The use of wood in the construction sector can replace more carbon-intensive, non-renewable materials, contributing to climate change mitigation and resource conservation (Amiri et al., 2020). Timber-based buildings generally have lower Global Warming Potential (GWP) compared to reinforced concrete or steel buildings (Duan et al., 2022).

Wood is a renewable resource sourced from forests that absorb CO_2 as they grow. By using wood to produce durable goods, such as buildings, carbon can be stocked for a long time, generating a large mitigation benefit (Churkina et al., 2020). Buildings become a "second forest" and while they store carbon, further wood generated (Churkina et al., 2020; Garcia et al., 2020). For the sake of simplicity, hereby we refer to the carbon transfer between the atmosphere and the wooden biomass as CO_2 regardless of the carbon oxidation status, instead of referring to CO_2 for the absorption and to carbon for the storage (or stock) in wood.

The standards that currently guide LCA of buildings (EN 15804:2012+A2:2019 and the specific BS EN 16485:2014 for wood materials) present some criticalities when applied to wooden buildings: EN 15804:2012+A2 impedes the selection of "cradle to gate" system boundaries for products containing biogenic

carbon as well as the inclusion of biogenic carbon storage. This neglects timber-based materials' climate change mitigation potential. EN 16485:2014 considers four possible End-of-Life (EoL) scenarios for construction wood: landfill (i.e. release of CO_2 stored in wood); energy recovery (i.e. burn); recycling (cut and burn); reuse (chip and burn). Consequently, burning wood is considered as a carbon-neutral activity regardless of where and especially when the CO_2 is absorbed or released. The relevance of considering carbon storage in products is highlighted by the recent establishment of the EU certification framework for permanent carbon removals, carbon farming and carbon storage in products (European Parliament, 2024)

The Reference Service Life (RSL) is defined as the expected service life of a component or assembly in a well-defined set of conditions (Sandak et al., 2019). ISO standard 15686-1 (ISO, 2011) defines the RSL of materials according to their accessibility. Therefore, inaccessible, irreplaceable, or structural materials should have the same reference service life as the building. The other materials with progressively shorter reference service lives should be layered around the inaccessible ones so that materials with shorter reference service lives can be replaced without removing the inaccessible ones (Marsh, 2017). The RSL of a building is defined according to different categories, i.e., technical, functional, economic, and aesthetic lifetime (Haugbølle et al., 2021). However, at a practical level, it is often assessed as the technical RSL, and it is considered as the duration in which the building meets the functions for which it was established. ISO standard 15686-1 defines the factorial method to be used to estimate the RSL of a building and it is the most frequently used in recent years (Silva & De Brito, 2021). The RSL is calculated according to various factors associated with different usage conditions. For LCA purposes, RSL is an important parameter to determine the environmental impacts of a building. This parameter becomes more critical for timber buildings because a longer service life allows for a more extended carbon storage period – thus larger climate change mitigation potential. RSL can strongly influence environmental impacts in LCA studies (Hosamo et al., 2024; Marsh, 2017; Potrč Obrecht et al., 2019; Rauf & Crawford, 2015; Silva & De Brito, 2021). The literature shows significant variability in terms of RSL considered (Anand & Amor, 2017; Andersen et al., 2022; Goulouti et al., 2020; Janjua et al., 2021; Jayalath et al., 2020; Marsh, 2017; Niu et al., 2021; Petrovic et al., 2019; Pittau et al., 2019; Rauf & Crawford, 2015).
This broad variability exists because determining the RSL in LCA of complex systems as buildings is challenging. It depends on many factors, like maintenance, exterior environment, orientation, and material selection (Grant & Ries, 2013). Nevertheless, a building RSL of 50 years is dominant in LCA studies. This is typically justified by reference to previous works (Janjua et al., 2021; Marsh, 2017) and is driven by the application of ISO 15686-1 and BS EN 1990 (Eurocode 0), which assigns a design RSL of 50 years. However, empirical data regarding the current RSL of buildings, together with annual rates of new construction, renovation, and demolition, indicate that an average building lifespan of 100 years or more would be more accurate in sustainability assessments, reflecting the changes that occurred in the existing social, technical, and economic factors (Marsh, 2017). For instance, (Haugbølle et al., 2021) estimated an average reference service life of about 78 years for the Danish context, while for the U.S. context, a statistical analysis of residential buildings determined that the average building reference service life is about 61 years (Aktas & Bilec, 2012).

Against this background, this study explores the potential implications of considering alternative EoL choices as well as RSL other than 50 years, as imposed by the current standards. The implications are studied through the case of a timber-based multi-story residential building. To make sound comparisons, a functionally equivalent concrete and steel building is modeled as well. LCA is performed for both buildings across different scenarios considering different EoL or RSL alternatives.

Methods

The building case study

The product system under assessment is a multi-story residential building with an engineered timber structure. It comprises two building blocks of 4 and 6 stories, respectively, as shown in Figure 1. The height of each story is 3.25 m. The gross internal area of the whole construction is 2,881 m^2. The height of each story is 3.25 m. The gross internal area of the

whole construction is 2,881 m^2. The bearing structure is a post-and-beam system, under the Design for Deconstruction and Reuse principles (Cristescu et al., 2020), and both building blocks have a flat roof.

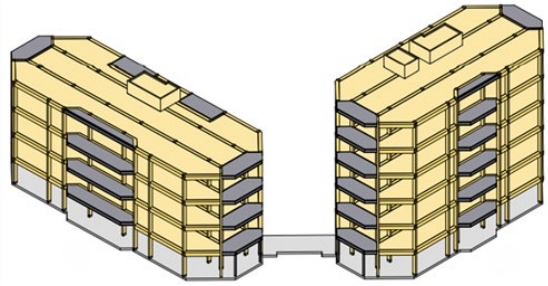


Figure 1. Structural design concept.

The columns and beams are composed of glue-laminated timber (Glulam), and the bearing structure of the floors and roof is made of cross-laminated timber (CLT) panels as well as the technical rooms and staircase shafts (core) and stabilizing wall. The foundation and terrain deck are made of concrete. The façades consist of wood skeleton elements in Laminated Veneer Lumber (LVL) with 2 layers gypsum on the inside, Oriented Strand Boards (OSB) in the middle, mineral wool insulation, and cement-based windbreaking boards on the outside, and a rain shield of tiles. Outdoor balconies are made of steel as bearing structure and fiber cement plates as the bottom of the balconies and as front plates.

Life Cycle Assessment

An attributional LCA was performed. The functional unit is the housing service provided for 150 years by 1 average m^2 of the gross internal area of a timber building.
The study follows a cradle-to-gate approach, thus including modules A1-A3 (e.g., the materials) as defined in EN 15804:2019. Module B4 (materials replacements) is included too as the focus of this study is on materials. This applies for both the engineered timber-based and the concrete-based buildings.

The life cycle inventory represents an average post and beam timber building system that can be ubiquitously implementable across Europe. Reserved primary industrial data have been used together with data retrieved from the literature (Rüter & Diederichs, 2012) for timber building elements manufacturing (i.e., CLT, Glulam, LVL, OSB).
Where data were unavailable, the inventory was based on the Ecoinvent database v. 3.6 (Wernet et al., 2016) and Environmental Product Declarations (EPDs). Ecoinvent 3.6 database was used to integrate the background data.
The assessment excludes minor elements such as furnishing components (e.g., windows, doors, etc.). Balconies and external cladding (i.e., tiles) have been supposed to be replaced every 75 years (Haugbølle et al., 2021).

EN 15804 +A2 Method V1.00 and EF 3.0 normalization and weighting set (Fazio et al., 2018) complying with EN 15804:2019 A2 (EPD International, 2019), and we focus on the global warming potential (GWP$_{100}$).

An equivalent building (in terms of FU) was modeled based on traditional materials (concrete and steel) to allow a comparison across buildings systems and materials. The bearing structure in this case is made in reinforced concrete, but the functional features (e.g., internal area) are maintained.

Scenarios

To account for the two investigated variables (RSL, and reuse at the End of Life), we defined eight scenarios, to capture all possible combinations (Table 1). The GHG emission related to the EoL phase are not included, but different EoL are modeled to enable performing an LCI over 150 years, as the focus is on material requirements and related emission.

Material	Scenario code	Reuse	RSL (years)		
			50	75	150
Engineered timber	BAU		x		
	RSL75			x	
	RSL150				x
	R50	x	x		
	R75	x		x	
Traditional	BAU		x		
	RSL75			x	
	RSL150				x

Table 1. Scenarios modeling. BAU = Business as usual (50 years RSL, no reuse); RSL75 = 75 years RSL, no reuse; RSL150 = 150 years RSL, no reuse; R50 = 50 years RSL and reuse, R75 = 75 years RSL and reuse.

Each scenario is compared with the results for the equivalent building based on traditional materials.

"Reuse" indicates the reuse of the timber elements deriving from the disassembly of the previous timber building. They are reused in a new, equivalent timber building keeping the same original function. Theoretically all the wood used in the building is protected and not exposed to external or internal weathering, thus falling in use class 1 (EN 335:2013), guaranteeing its durability. However, part of the timber deriving from the disassembly might be unsuitable for reuse (e.g., damaged during disassembly operations). Here, we adopt a highly conservative approach considering low reusability rates for the glulam framework (CLT slab, 50%), for the core (CLT, 50%), and for the façade (LVL 30%). All the timber-based material unsuitable for reuse is sent to incineration following the EoL imposed by EN 16485:2014. The concept of reuse with the same function is illustrated in Figure 2.

Furthermore, to investigate the relevance of accounting for the biogenic carbon and its climate change mitigation potential, on the one hand we tracked the temporal dynamics of the stock of biogenic carbon embodied in timber products. On the other hand, we tracked the carbon absorption through forest regrowth, occurring during the reference service life of the building. For that we assessed forest carbon uptake occurring in a spruce forest in Europe having a rotation period of 75 years. The IPCC Guidelines (IPCC, 2006, 2019) were used to estimate the carbon sink function in the forestry sector. In particular, the forest carbon stock dynamic is tracked over two growing periods, i.e., two fully mature forests were modelled to be generated over 150 years (75 years each). The cumulative carbon stock captured over time through the transfer from the atmosphere to the forest due to tree growth is tracked as well in order to account for the exceeding demand for wood due to the misalignment of the building lifetime and the forest rotation period. This means that when the building lifetime is shorter, a further (extra) stock of carbon in a mature forest will be affected, while when the building lifetime is longer, a further (extra) stock of carbon will be generated in another forest.

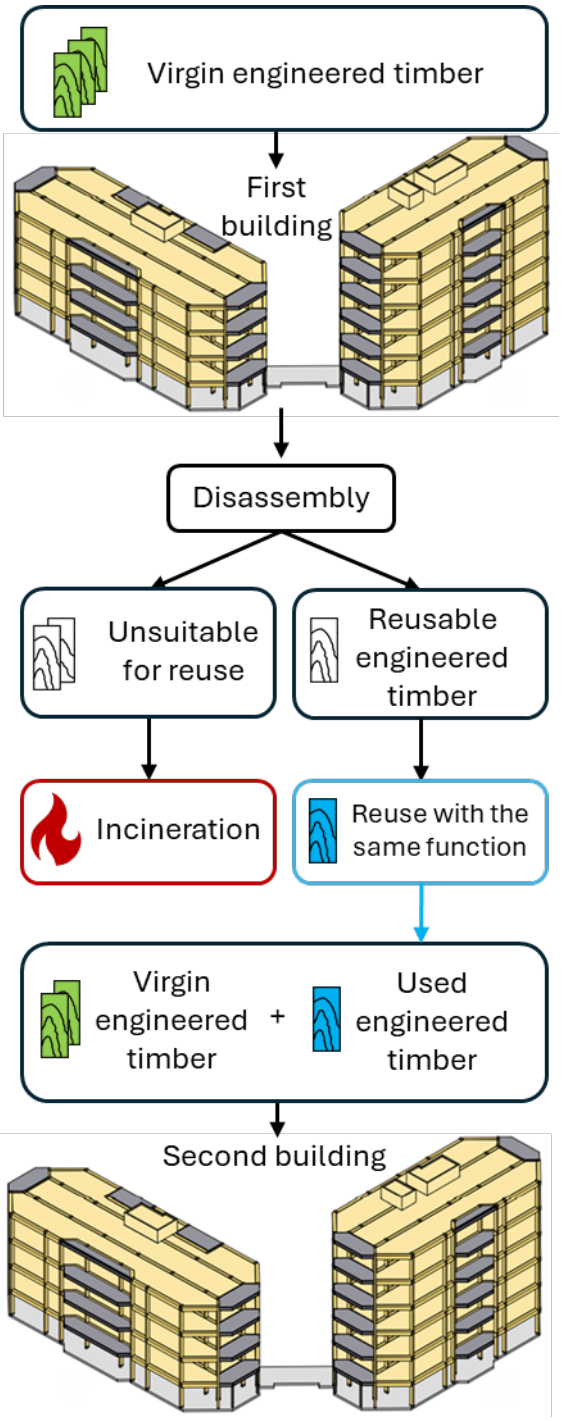


Figure 2. Schematic representation of how engineered timber reuse with the same function is modeled.

The cumulative carbon stock sequestered over time through atmospheric transfer from the atmosphere to the forest, driven by tree growth, is also monitored to account for the increased demand for wood resulting from the misalignment between building lifespan and

forest rotation period. The considered stocks include not only the carbon embodied in the building itself but also the emission generated for its production. The latter include the stock linked with the punctual emission due to the production of the building – product stage emission (A1 to A3) and the emission due to the replacement of ceramic tiles and balconies (B4 assumed to happen after 75 years). Although concrete carbonation could reduce the overall GHG emission, it was excluded for both engineered timber-based and concrete-based buildings due to its marginal significance (<5% (Collins, 2010; Yang et al., 2014) and to the high variability due to environmental conditions (Oyinkanola & Panesar, 2023; Possan et al., 2016).
This second part of the work is purely meant to provide insights into the necessity to consider the carbon dynamics that are significantly different between the two kinds of materials considered. The focus is specifically on timber and the related forest, i.e., what distinguishes it from concrete and steel. Accordingly, while we considered EoL emissions for timber (i.e., incineration) in the dynamic representations we did not include the impact for the EoL of other materials and none for the traditional materials-based building. This is meant to show the actual timber-related carbon flows, hindered by current regulations. Nevertheless, A dynamic and more complete analysis should be implemented to provide accurate results.

Results and discussion

The analysis reveals that either acting on the RSL or implementing a reuse with the same function for engineered timber allows to save GHG emissions, making it a potential mitigation strategy.
In particular, the longer the RSL the larger the mitigation potential (Table 2). Reuse contributes to saving GHG emissions too, but less significantly. A large part of the timber-based building is still made of traditional materials, thus making the reuse only applicable to part of the total materials. Reusable timber is reused with the same function in the second building, but most of the materials have to be sourced from new production. In all scenarios the engineered timber-based building presents lower GWP compared to the equivalent traditional one, although this difference is minimal for the RSL150 scenario (-0,3%).

Material	Scenario code	Overall GWP	GWP per m^2
		t CO_2eq	t CO_2eq/m^2
Engineered timber	BAU	1120.32	0.39
	RSL75	746.88	0.26
	RSL150	442.32	0.15
	R50	1097.91	0.38
	R75	724.47	0.25
Traditional	BAU	1283.85	0.45
	RSL75	855.90	0.30
	RSL150	443.66	0.15

Table 2. Scenarios results are shown for the overall 150-year period and per m^2 as per the functional unit.

The largest improvement is linked with scenario RSL 150 for the engineered timber-based building, resulting in 61% less GWP.
However, it is fundamental to distinguish between the types of materials composing the two modeled buildings, one mostly renewable (wood), and one mostly non-renewable (minerals). This difference becomes evident when considering the upstream processes that underly the (re)generation of wood and thus timber. Figure 3, Figure 4, and Figure 5 show how a dynamic representation of the carbon fluxes involved in the (re)generation of wood over the considered lifetime can better highlight this difference. Year 151 is also shown just to hint at the future dynamics.
While the quantified results in terms of share of GHG reduction are in line with the values found by Hart et al. (2021) (36% - 48%), no publication was found specifically addressing the GHG reduction linked with a normative change in the RSL and re-use and with a comparison between concrete- and engineered timber-based materials.

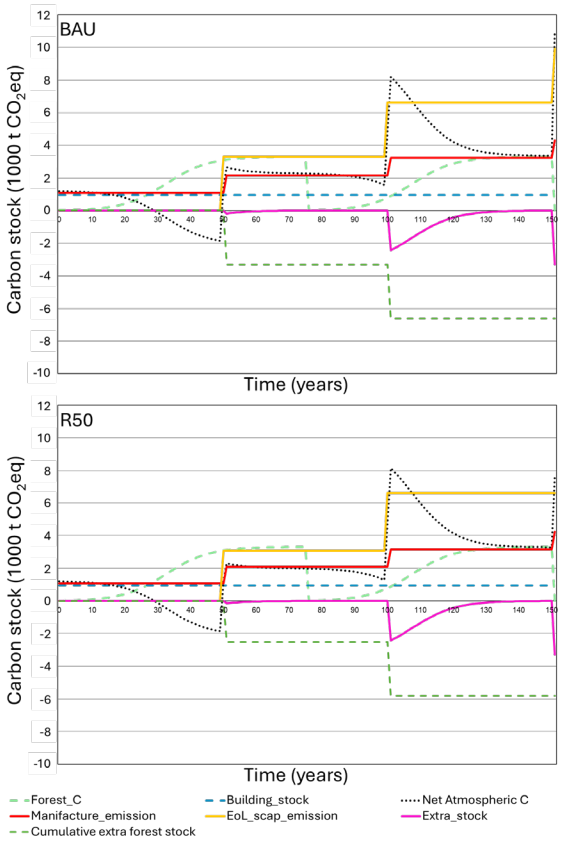


Figure 3. Forest, atmosphere, and building carbon stock and linked cumulative emissions or removals for the scenarios with a 50 years RSL. "Extra stock" indicates the deficit of wood over time.

Figure 3 shows how considering a RSL lower than the time to (re)generate wood (i.e., to bring a forest to maturity), incurs a positive carbon balance considering the GHG emission released into the atmosphere and absorbed by forest. This is due to the necessity to harvest "three forests" to build three times the building, while over the available time only two forests can reach maturity, thus being ready for harvest.

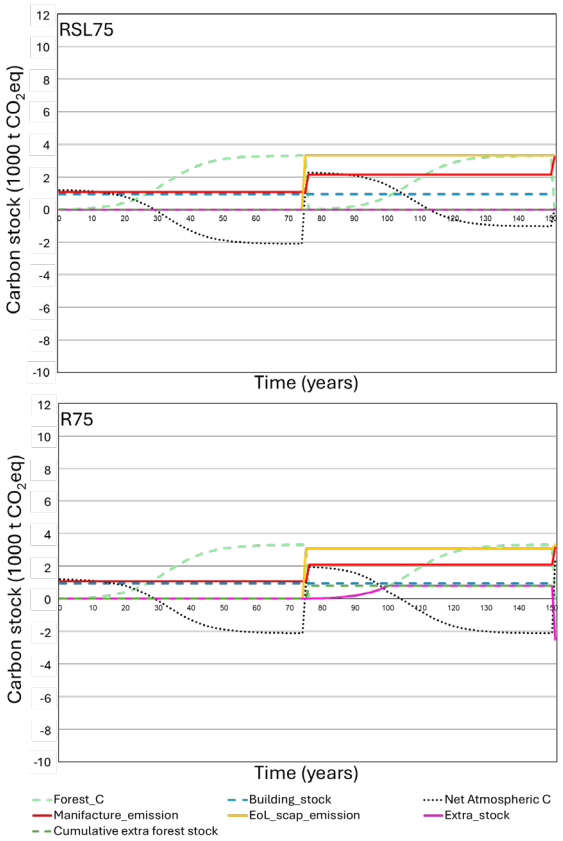


Figure 4. Forest, atmosphere, and building carbon stock and linked cumulative emissions or removals for the scenarios with a 75 years RSL. "Extra stock" indicates the surplus of wood over time.

Figure 4 shows how considering a RSL equal to the time to (re)generate wood (i.e., to bring a forest to maturity), incurs an alternating positive and negative carbon balance due to GHG emission released into the atmosphere and absorbed by forest. Since there is a balance between the carbon absorbed and transferred to timber, and the carbon released when incinerated after the RSL, the GHG emissions that affect the overall long-term growing trend are the ones linked with the manufacturing processes. However, the long-term storage of carbon in the building grants a significant time of lower balance, over which carbon is prevented from contributing to global warming, acting as a mitigating factor.
This becomes even more evident when the RSL is further extended to 150 years (Figure 5). In this case, over the considered temporal boundaries, twice the timber implied is generated. Consequently, the carbon balance becomes negative, even compensating the manufacturing (and replacement) emissions.

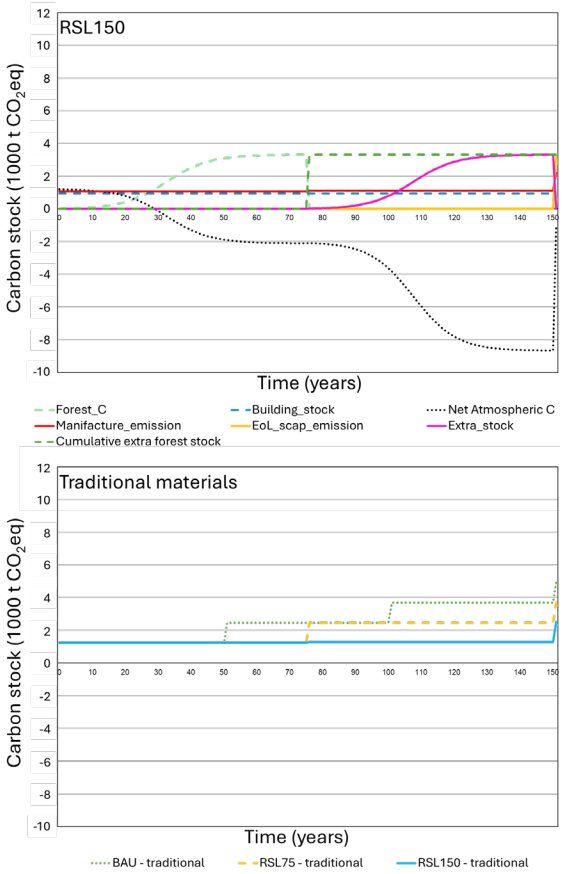


Figure 5. Forest, atmosphere, and building carbon stock and linked cumulative emissions or removals for scenario RLS150 and cumulative GHG emissions for the traditional building scenarios.

Instead, traditional materials-based buildings are linked with emissions that cannot be reabsorbed through the same process that generates the raw materials implied, i.e., what happens for timber.

Conclusions

Current standards and regulations were designed and meant for traditional materials-based buildings. However, the emergence of timber as an alternative, renewable, and more sustainable material requires a revision of such standards, and the linked environmental assessment practice. Our very conservative approach shows that reusing engineered timber with the same function is fit for climate action. Aligning the RSL of timber buildings to wood regeneration time could boost this climate action ensuring a sustainable use of a renewable resource. For this action to be put in place, it is fundamental a change in perspective. While current policies advocate for renewability, current regulations obstacle the needed shift from a fossil- to a renewable-based economy since they overlook the fundamental temporal feature that characterizes renewable resources as, in this case, wood. While the RSL is irrelevant for fossil resources as they are non-renewable by definition – thus linked with extremely long regeneration time – it is fundamental for renewable resources which are defined through a temporal feature.

A generalized systemic change is required to treasure the potential of timber to support climate action. This entails the creation of a market for engineered timber reusable with the same function, a substantial revision of the temporal dimensions of the standards, and a consequent modification of the linked environmental assessment practices.

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References

Aktas, C. B., & Bilec, M. M. (2012). Impact of lifetime on US residential building LCA results. *The International Journal of Life Cycle Assessment*, *17*(3), 337–349. https://doi.org/10.1007/s11367-011-0363-x

Amiri, A., Ottelin, J., Sorvari, J., & Junnila, S. (2020). Cities as carbon sinks—Classification of wooden buildings. *Environmental Research Letters*, *15*(9), 094076. https://doi.org/10.1088/1748-9326/aba134

Anand, C. K., & Amor, B. (2017). Recent developments, future challenges and new research directions in LCA of buildings: A critical review. *Renewable and Sustainable Energy Reviews*, *67*, 408–416. https://doi.org/10.1016/j.rser.2016.09.058

Andersen, J. H., Rasmussen, N. L., & Ryberg, M. W. (2022). Comparative life cycle assessment of cross laminated timber building and concrete building with special focus on biogenic carbon. *Energy and Buildings*, *254*, 111604.

https://doi.org/10.1016/j.enbuild.2021.111604

Churkina, G., Organschi, A., Reyer, C. P. O., Ruff, A., Vinke, K., Liu, Z., Reck, B. K., Graedel, T. E., & Schellnhuber, H. J. (2020). Buildings as a global carbon sink. *Nature Sustainability*, *3*(4), 269–276. https://doi.org/10.1038/s41893-019-0462-4

Collins, F. (2010). Inclusion of carbonation during the life cycle of built and recycled concrete: Influence on their carbon footprint. *The International Journal of Life Cycle Assessment*, *15*(6), 549–556. https://doi.org/10.1007/s11367-010-0191-4

Cristescu, C., Honfi, D., Sandberg, K., Sandin, Y., Shotton, E., Walsh, S. J., Cramer, M., Ridley-Ellis, D., Harte, A., Ui Chulana, C., Risse, M., Ivanica, R., De Arana-Fernández, M., García Barbero, M., Llana, D., Íñiguez-González, G., Nasiri, B., Hughes, M., & Krofl, Ž. (2020). *Design for deconstruction and reuse of timber structures – state of the art review*. https://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-52384

Duan, Z., Huang, Q., & Zhang, Q. (2022). Life cycle assessment of mass timber construction: A review. *Building and Environment*, *221*, 109320. https://doi.org/10.1016/j.buildenv.2022.109320

EPD International. (2019). *Construction Products PCR (2019:14)*.

European Committee for Standardization. (2013). *(BS) EN 335:2013. Durability of wood and wood-based products – Use classes: Definitions, application to solid wood and wood-based products*.

European Committee for Standardization. (2014). *EN 16485:2014 Round and sawn timber—Environmental product declarations—Product category rules for wood and wood-based products for use in construction*.

European Committee for Standardization. (2019). *EN 15804:2012+A2:2019 'Sustainability of construction works—Environmental product declarations—Core rules for the product category of construction products*.

Fazio, S., Biganzoli, F., De Laurentis, V., Zampori, L., Sala, S., & Diaconu, E. (2018). *Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods: Version 2, from ILCD to EF 3.0.* Publications Office. https://data.europa.eu/doi/10.2760/002447

Garcia, R., Alvarenga, R. A. F., Huysveld, S., Dewulf, J., & Allacker, K. (2020). Accounting for biogenic carbon and end-of-life allocation in life cycle assessment of multi-output wood cascade systems. *Journal of Cleaner Production*, *275*, 122795. https://doi.org/10.1016/j.jclepro.2020.122795

Goulouti, K., Padey, P., Galimshina, A., Habert, G., & Lasvaux, S. (2020). Uncertainty of building elements' service lives in building LCA & LCC: What matters? *Building and Environment*, *183*, 106904. https://doi.org/10.1016/j.buildenv.2020.106904

Grant, A., & Ries, R. (2013). Impact of building service life models on life cycle assessment. *Building Research & Information*, *41*(2), 168–186. https://doi.org/10.1080/09613218.2012.730735

Hart, J., D'Amico, B., & Pomponi, F. (2021). Whole-life embodied carbon in multistory buildings: Steel, concrete and timber structures. *Journal of Industrial Ecology*, *25*(2), 403–418. https://doi.org/10.1111/jiec.13139

Haugbølle, K., Mahdi, V., Morelli, M., & Wahedi, H. (2021). BUILD levetidstabel. In *BUILD levetidstabel* (Version 2021) [Rapport]. Institut for Byggeri, By og Miljø (BUILD), Aalborg Universitet.

Hosamo, H., Coelho, G. B. A., Buvik, E., Drissi, S., & Kraniotis, D. (2024). Building sustainability through a novel exploration of dynamic LCA uncertainty: Overview and state of the art. *Building and Environment*, *264*, 111922. https://doi.org/10.1016/j.buildenv.2024.111922

International Organization for Standardization. (2011). *ISO 15686-1:2011 Buildings and constructed assets—Service life planning*.

IPCC. (2006). *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* (H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.; IGES, Japa).

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Janjua, S. Y., Sarker, P. K., & Biswas, W. K. (2021). Sustainability implications of service life on residential buildings – An application of life cycle sustainability assessment framework.

Environmental and Sustainability Indicators, *10*, 100109. https://doi.org/10.1016/j.indic.2021.100109

Jayalath, A., Navaratnam, S., Ngo, T., Mendis, P., Hewson, N., & Aye, L. (2020). Life cycle performance of Cross Laminated Timber mid-rise residential buildings in Australia. *Energy and Buildings*, *223*, 110091. https://doi.org/10.1016/j.enbuild.2020.110091

Marsh, R. (2017). Building lifespan: Effect on the environmental impact of building components in a Danish perspective. *Architectural Engineering and Design Management*, *13*(2), 80–100. https://doi.org/10.1080/17452007.2016.1205471

Niu, Y., Rasi, K., Hughes, M., Halme, M., & Fink, G. (2021). Prolonging life cycles of construction materials and combating climate change by cascading: The case of reusing timber in Finland. *Resources, Conservation and Recycling*, *170*, 105555. https://doi.org/10.1016/j.resconrec.2021.105555

Oyinkanola, T. M., & Panesar, D. K. (2023). Natural carbonation of uncracked and cracked concrete: Sensitivity of regional geographical variations on the CO2 uptake-to-emissions ratio compared to global estimates. *Construction and Building Materials*, *409*, 134010. https://doi.org/10.1016/j.conbuildmat.2023.134010

Petrovic, B., Myhren, J. A., Zhang, X., Wallhagen, M., & Eriksson, O. (2019). Life cycle assessment of a wooden single-family house in Sweden. *Applied Energy*, *251*, 113253. https://doi.org/10.1016/j.apenergy.2019.05.056

Pittau, F., Dotelli, G., Arrigoni, A., Habert, G., & Iannaccone, G. (2019). Massive timber building vs. Conventional masonry building. A comparative life cycle assessment of an Italian case study. *IOP Conference Series: Earth and Environmental Science*, *323*(1), 012016. https://doi.org/10.1088/1755-1315/323/1/012016

Pomponi, F., Hart, J., Arehart, J. H., & D'Amico, B. (2020). Buildings as a Global Carbon Sink? A Reality Check on Feasibility Limits. *One Earth*, *3*(2), 157–161. https://doi.org/10.1016/J.ONEEAR.2020.07.018

Possan, E., Felix, E. F., & Thomaz, W. A. (2016). CO2 uptake by carbonation of concrete during life cycle of building structures. *Journal of Building Pathology and Rehabilitation*, *1*(1), 7. https://doi.org/10.1007/s41024-016-0010-9

Potrč Obrecht, T., Kunič, R., Jordan, S., & Legat, A. (2019). Roles of the reference service life (RSL) of buildings and the RSL of building components in the environmental impacts of buildings. *IOP Conference Series: Earth and Environmental Science*, *323*(1), 012146. https://doi.org/10.1088/1755-1315/323/1/012146

Rauf, A., & Crawford, R. H. (2015). Building service life and its effect on the life cycle embodied energy of buildings. *Energy*, *79*, 140–148. https://doi.org/10.1016/j.energy.2014.10.093

Regulation of the European Parliament and of the Council Establishing a Union Certification Framework for Permanent Carbon Removals, Carbon Farming and Carbon Storage in Products, No. PE-CONS 92/24, European Parliament (2024).

Rüter, S., & Diederichs, S. (2012). *Ökobilanz-Basisdaten für Bauprodukte aus Holz* (Arbeitsbericht Aus Dem Institut Für Holztechnologie Und Holzbiologie). Thünen-Institut, Vorgängereinrichtung, Johann Heinrich von Thünen-Institut, Institut für Holztechnologie und Holzbiologie. https://literatur.thuenen.de/digbib_extern/dn050490.pdf

Sandak, A., Sandak, J., Brzezicki, M., & Kutnar, A. (2019). *Bio-based Building Skin*. Springer Singapore. https://doi.org/10.1007/978-981-13-3747-5

Silva, A., & De Brito, J. (2021). Service life of building envelopes: A critical literature review. *Journal of Building Engineering*, *44*, 102646. https://doi.org/10.1016/j.jobe.2021.102646

United Nations Environment Programme. (2021). *2021 Global Status Report for Buildings and Construction: Towards a Zero emission, Efficient and Resilient Buildings and Construction Sector*. UNEP.

United Nations Environment Programme, & Yale Center for Ecosystems + Architecture. (2023). *Building Materials and the Climate:*

Constructing a New Future. United Nations Environment Programme. https://wedocs.unep.org/xmlui/handle/20.500.11822/43293

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The ecoinvent database version 3 (part I): Overview and methodology. *The International Journal of Life Cycle Assessment*, *21*(9), 1218–1230. https://doi.org/10.1007/s11367-016-1087-8

Yang, K.-H., Seo, E.-A., & Tae, S.-H. (2014). Carbonation and CO2 uptake of concrete. *Environmental Impact Assessment Review*, *46*, 43–52. https://doi.org/10.1016/j.eiar.2014.01.004

Extended Abstract
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Reusable Packaging Systems: Design recommendations for fostering and sustaining consumer adoption.

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Keywords: Design; Reusable Packaging; User Experience; Circular Economy; Sustainability.

Introduction

Multiple factors influence the success and sustainability of reusable packaging systems, including consumer behaviour (Bradley & Corsini, 2023). Recent findings from UK trials emphasise the need for continued consumer engagement to ensure reusable packaging systems are profitable and provide environmental benefits (Tesco, 2021). Specifically, product categories with high turnover (e.g., household care, personal care and food & beverage) are considered preferable (IDG, 2021; Center for the Circular Economy & US Plastics Pact, 2025), but a change in consumer behaviour is needed to ensure sufficient reuse rates are met (WRAP, 2023; Center for the Circular Economy & US Plastics Pact, 2025).

Whilst consumers are currently familiar with recycling practices, only 55% of plastic packaging is recycled in the UK (WRAP, 2023). Meanwhile, consumer intentions to recycle at-home show a downward trend, reducing by 7% in 2023 (RECOUP, 2023). Alternative strategies to limit plastic waste contribution should be explored. Reusable packaging systems can reduce single-use reliance, but an assessment of consumer barriers is needed to promote successful implementation (Bradley & Corsini, 2023). Specifically, consumer-centric systems can provide additional value to the consumer, reducing the barriers to consumer adoption.

Relatively new to the UK, some retailers have invested in reuse trials. For example, Marks and Spencer's (M&S) supported reuse schemes in 2019 and further investment in reuse systems (for prefilled containers) was made in 2022 through a collaboration with Reposit, City to Sea and Ecover (M&S, 2024a). Overall, consumers (69%) are willing to interact with reusable packaging systems (City to Sea, 2023); however, research highlights that reuse schemes need to be accessible, available and affordable to drive wide-spread adoption (Bradley & Corsini, 2023). M&S restricts the potential uptake of its reuse scheme by limiting availability to just 25 UK stores (M&S, 2024b), and while 10,000 consumers engaged with M&S's prefill initiative in 2023/4, this remains a small fraction of its annual consumer base of 32 million. Thus, systems need to be designed to consider the potential barriers to wider adoption (M&S2024c). Previous schemes, such as Tesco's partnership with Loop, have failed due to poor consumer retention, experience and lack of affordability (Tesco, 2022). Exploring how to motivate adoption and retain consumers is necessary to maintain viability and attain profitability.

Whilst previous research has explored consumer perceptions of current reuse systems (i.e Miao et al., 2023; Greenwood et al., 2021, IGD, 2021), this research aims to identify the influence of consumer demographics on consumer attitudes and behaviours. Results from this research help form insights for varying demographic groups. In doing so, this research supports system designers in developing effective reuse systems from the outset.

This study answers the research question: Do consumer demographics influence attitudes and behaviours towards reusable packaging systems?

Methodology

To understand current consumer behaviours and attitudes with respect to current reusable packaging systems, this oral presentation presents the findings of an online consumer

survey (n=375). For this abstract, respondents are refined to UK residents (n=283).

Consumers are asked to reflect on current experiences, whilst avoiders identify key barriers to reuse adoption. Survey recruitment was primarily limited to social media (i.e. LinkedIn, Facebook and Instagram), and recruited both users (n=204) and non-users (n=79) of reuse schemes.

Based on consumer-centric factors identified by Bradley & Corsini (2023), 52 statements (refer to Table 1.) were measured for each reuse archetype (refill-on-the-go, refill-at-home, return-on-the-go and return-from-home) on a 5-point Likert scale (Strongly Disagree = 1, Strongly Agree = 5). Factors measured are defined as either "system design" and/or "packaging design" depending on applicability (see Table 1). For this abstract, datasets are combined to form insights of reusable packaging systems. Higher scores on these dimensions suggest areas for greater consideration is required and therefore should form priority factors (see Findings).

To assess whether there was a significant difference between sample demographics a series of statistical analysis (e.g., MANOVA and t-Test) were performed for each priority factor identified. This oral presentation explores how consumer demographics (age, sex, education and salary) influences consumer ratings for three of the top priority factors.

Furthermore, qualitative questions gather insights on how systems can be improved for consumer retention and adoption. Insights are thematically coded, identifying key areas of improvement, forming consumer-orientated recommendations.

Table 1. Statements measured according to factors (Bradley & Corsini, 2023).

	P	S
Material Selection & Production	**X**	**-**
Recycled Content	X	-
Material Type	X	-
Packaging Weight	X	-
Consumable Weight	X	-
Use	**X**	**-**
Usage volume	X	-
Transportation		**X**
Distance		X
Shrinkage	**X**	**X**
Return Rate	X	x
Deterioration Rate	X	-
Loss Rate	X	-
End-of-Life	**X**	**X**
Disposal Scenario	X	X
Convenience	**X**	**X**
Convenience	X	X
Cleaning and maintenance	X	X
Service location, access and availability	-	X
Usability	**X**	**X**
Service usability	-	X
Product usability	X	-
Awareness	**X**	**X**
Labelling	X	**-**
Marketing	-	X
Consumer Perception	**X**	**X**
Functional design	X	X
Aesthetic design	X	X
Service experience	-	X
Value for money	X	X
Product quality	X	-
Hygiene	X	X
Sustainability	X	X
Consumer Behaviour	**-**	**X**
Consumer knowledge and education	-	X
Familiarity of product/ service	-	X
Availability of low waste alternatives	-	X
Peer pressure	X	-
Market trends	X	-
Type of reuse model	-	X
Product category	-	X
Policies and Legislation	**-**	**X**
Strategies to increase consumer behaviour change	-	X
Customer Retention	**-**	**X**
Customer retention	-	X
Brand loyalty	-	X
Financial incentives	-	X
Deposit return schemes	-	X
Loyalty schemes/ subscription services	-	X
Product Features	**X**	**-**
Standardisation (of the packaging)	X	-
Product protection	X	-

**P*=Packaging Design, S = System Design
** X = Statement provided to participant

Findings

Findings presented in this abstract focus on UK participants. Refer to Table 2-5.

Gender	N	%
Male	68	24
Female	210	74.2
Other	5	1.8

Table 2. Consumer Demographics (Gender)

Age	N	%
18-29	46	16.3
30-39	42	14.8
40-49	63	22.3
50-59	69	24.4
60-69	43	15.2
70+	20	7.1

Table 3. Consumer Demographics (Age)

Edu. Lvl	N	%
Lvl. 1-4 (below higher edu.)	73	25.7
Lvl. 5 (e.g DipHE, HND)	17	6.0
Lvl. 6 (e.g Bachelors)	93	32.9
Lvl. 7 (e.g Masters, PGCE)	78	27.6
Lvl. 8 (e.g PhD)	20	7.1

Table 4. Consumer Demographics (Education)

Income.	N	%
<12 570	33	11.7
£12 571 to £20 185	32	11.3
£20 186 to £27 295	46	16.3
£27 296 to £50 270	120	42.4
£50 271 to £100 000	40	14.1
£100 000+	12	4.2

Table 5. Consumer Demographics (Salary)

Consumer attitudes towards Reusable Packaging Systems

Whilst key factors to consider are dependent on the specific reuse model, results show Material Selection & Production (M=3.55, S.D=0.63), Consumer Retention (M=3.09, S.D=0.51), Usage Volume (M=2.98, S.D=0.96) and Product Features (M=2.97, S.D=0.54) require greater consideration during the design phase (see Figure 1). These overarching categories highlight the need to utilise recycled materials (M=3.59, S.D=0.90), and consider the packaging weight (M=3.13, S.D=0.96) and consumable weight (M=3.73, S.D=0.87). Consumers are also likely to consider container functionality, incorporating features (i.e pump dispensers) to limit usage may influence adoption (M=2.98, S.D=0.96). Interestingly, consumers were less likely to adopt containers for their individuality (M=2.06, S.D=0.85) highlighting the potential for standardize packaging design. However containers supplied should provide adequate product protection (M=3.95, S.D=0.71).

Designers should consider methods to engage a consumer. Currently, discounts fail to engage consumers (M=2.22, S.D=0.96) – however, including deposits where possible, may lead to increased consumer retention (M=3.58, S.D=1.08).

To explore how the overarching factors impacting the sustainability of reusable packaging systems can be influenced by consumer demographics (sex, age, education, salary), a series of statistical analysis is conducted.

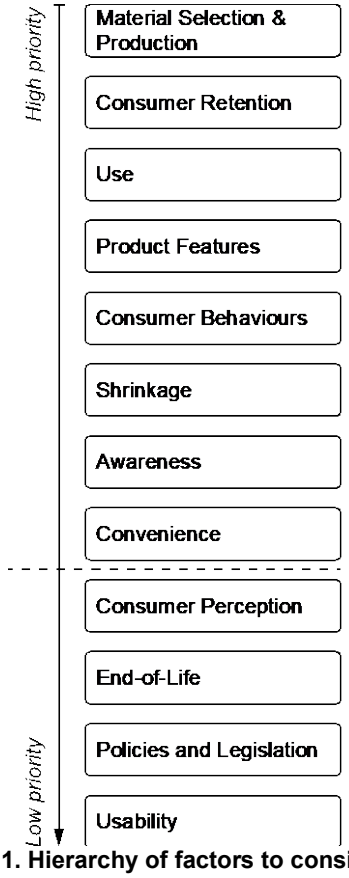


Figure 1. Hierarchy of factors to consider when re-designing reusable packaging systems.

Conclusion

This abstract presents initial findings from a descriptive analysis. Within the oral presentation, relationships between consumer demographics (age, gender, education and salary) and consumer attitudes and behaviours are explored for UK participants. Findings show reusable packaging systems are influenced by consumer demographics, particularly for the factors: Shrinkage, End-of-Life, Awareness, and Product Features. Throughout this presentation, recommendations for designing reusable packaging systems for sustained consumer engagement are presented.

Whilst results from a G*Power analysis suggests an appropriate sample size was recruited for this work (n>270), limitations of this study should be acknowledged. Participants were recruited primarily from social media (i.e LinkedIn, Facebook, Instagram). Whilst selection bias may be present, this should be limited by targeting relevant groups. Targeting sustainability-focused groups increased the diversity of participants and the likelihood of lived-experience with reuse systems. This dataset presents insights for all age, salary, gender and education categories, however notable skew between males (n=68) and females (n=210) is present.

Notably, self-reported data can be influenced by recall bias and social desirability bias, potentially affecting the accuracy of responses. Further research should be conducted to determine the influence of consumer demographics on individual reuse archetypes.

Acknowledgments

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References

Center for the Circular Economy & US Plastics Pact (2025). Retrieved March 24, 2025, from Getting Ready for Reuse in Retail. https://www.closedlooppartners.com/research/getting-ready-for-reuse-in-retail-2/.

City to Sea (2023). Ready to Prefill: Market Innovation to Unlock Growth in the Reuse Market. Retrieved December 03, 2024, from https://www.citytosea.org.uk/wp-content/uploads/2023/06/Ready-to-Prefill-Market-Innovational-to-Drive-Growth-2023.pdf

C. G. Bradley & L. Corsini (2023). A literature review and analytical framework of the sustainability of reusable packaging. Retrieved December 03, 2024, from https://doi.org/10.1016/j.spc.2023.02.009

Institute of Grocery Distribution (IGD)(2021). How to help consumers adopt reusable packaging. Retrieved 27 March 2025, from https://www.igd.com/Social-Impact/Reports/How-to-help-consumers-adopt-reusable-packaging/35716 [Report]

Marks & Spencer (2024a) M&S Expands Popular Refilled Scheme. Retrieved December 03, 2024, from https://corporate.marksandspencer.com/media/press-releases/ms-expands-popular-refilled-scheme-25-stores-across-uk

Marks & Spencer (2024b). Plastics and Packaging. [Online]. Retrieved December 03, 2024, from https://corporate.marksandspencer.com/sustainability/plan-a-our-planet/plastics-and-packaging

Marks & Spencer (2024c). Reshaping M&S Annual Report. Retrieved December 03, 2024, from https://corporate.marksandspencer.com/sites/marksandspencer/files/2024-06/M-and-S-2024-Annual-Report.pdf

S. C. Greenwood, S. Walker, H. M. Baird, R. Parsons, S. Mehl, T. L. Webb, A. T. Slark, A. J. Ryan, R. H. Rothman (2021). Many Happy Returns: Combining insights from the environmental and behaviours sciences to understand what is required to make reusable packaging mainstream. https://doi.org/10.1016/j.spc.2021.03.022

Tesco (2022). Use. Rese. Repeat. Sharing Learning on Reusable Packaging. Retrieved December 03, 2024, from https://www.tescoplc.com/media/759307/tesco-reuse-report.pdf

RECOUP (2023). Citizen Plastic Recycling Behaviours Insights Study 2023. Retrieved December 03, 2024, from https://www.recoup.org/wp-content/uploads/2023/12/Citizen-Plastics-Recycling-Behaviours-Insights-Study-2023-Summary.pdf

WRAP (2023). The UK Plastics Pact Annual Report 2022-2023. Retrieved December 03, 2024, from https://www.wrap.ngo/sites/default/files/2023-11/the-uk-plastics-pact-annual-report-2022-2023-0.pdf

X. Miao, L. Magnier, R. Mugge (2023). Switching to reuse? An exploration of consumers' perceptions and behaviour towards reusable packaging systems. https://doi.org/10.1016/j.resconrec.2023.106972

Extended Abstract
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Design for Circularity (DfCE) – How to Align Product Requirements With R-Strategies to Enhance Circular Economy on an Operational Level

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Keywords: Circular Economy; R-Strategies; Product Design; Sustainable Design.

Introduction

The circular economy has emerged as a pivotal concept in promoting sustainable development by redefining how resources are utilized, products are built and used, and waste is managed. Foundational to this concept is the framework of R-strategies (Refuse, Reduce, Rethink, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover) (Potting et al., 2017) which serve as guiding principles towards adopting sustainability objectives. Understanding how each R-strategy influences product design, lifecycle, and end-of-life handling is crucial for aligning product development with circular economy goals. (Diaz et al., 2021) Product requirements, defined as the attributes necessary for meeting circular objectives, play a significant role in this paradigm shift. Key circular economy theories emphasize integrating R-strategies into product design, manufacturing, use, and value retention. (Ibid.)

This study aims to explore how R-strategies shape product requirements clustered in sub-categories (see figure 1), such as durability, reparability, and modularity, and to identify the role of design considerations in enhancing product circularity. Existing studies either focus on specific product or material groups (e.g., plastics, textiles, electronic devices, or composite fibers) (e.g. Berwald et al., 2021; Bovea & Pérez-Belis, 2018; circular.fashion UG, 2018; Joustra & Bessai, 2021), limiting their applicability, or are too generic for practical design processes (Diez, 2023; Earley & Politowicz, 2023; Shahbazi, 2023). They also lack a common definition of R-strategies and their sub-categories (Eberhardt et al., 2022), causing confusion when combining guidelines. Furthermore, the interconnections between sub-categories of design for circularity (DfCE) have not been thoroughly investigated, yet these interconnections are crucial for understanding how overlapping and complementary strategies can enhance

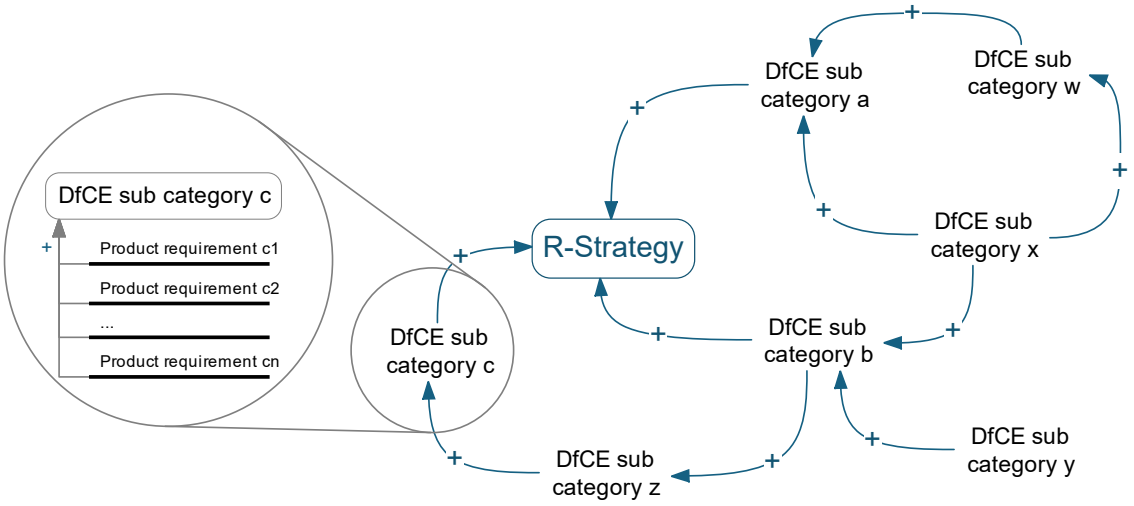


Figure 1. Schematic topology of R-strategies' causal loops to design for circularity sub-categories and their related product requirements.

circularity (Shahbazi & Jönbrink, 2020). By clarifying the relationship between R-strategies and product requirements, this review seeks to support more effective implementations of the circular economy. The ultimate goal is to derive a consistent set of DfCE guidelines and gain a deeper understanding of the interconnections among related sub-categories.

Methods

A systematic literature review following PRISMA guidelines was conducted using a comprehensive search string incorporating synonyms of circular economy-related terms (e.g., R-strategies, circularity), design (e.g. product) and guidelines (e.g., strategy, concept, framework, tool). The search yielded a total of 767 articles published between 2018 and 2023, sourced through Fraunhofer eLib, which simultaneously searches over 250 databases, including Web of Science, Scopus, SpringerLink, and Elsevier ScienceDirect. Additional 59 articles were identified through snowballing. After removing duplicates and irrelevant articles following exclusion criteria, 77 were included in the review.

Relevant literature was coded using an inductive system (Kuckartz & Rädiker, 2023) following source terminology. This approach facilitated the identification of relevant sub-categories of DfCE. Then network mapping was conducted to visualize the interdependencies between different sub-categories of DfCE guidelines and their connections to the various R-strategies. To enhance clarity, redundancies were identified, and sub-categories closely related in content were merged and renamed during a workshop with experts. Given the different R-concepts used in the articles, the 10R framework by Potting et al. (2017) was uniformly applied to all sub-categories, resulting in adjustments to the network connections. Each guideline was reviewed for suitability and reassigned to the appropriate sub-categories if necessary.

Results

Initially, 63 sub-categories were identified from the literature. Following restructuring and standardization, 45 sub-categories of DfCE guidelines were established, encompassing all ten R-strategies. Over 1000 separate product requirements aimed at instructing developers and designers on creating more circular products were retrieved and condensed into approximately 600 final requirements.

To illustrate the differences between R-strategies regarding their relevant sub-categories, specific strategies and their associated guidelines were examined. For example, *remanufacturing* is predominantly supported by sub-categories such as accessibility, aesthetics, cleanability, compliance, disassembly, documentation, physical durability, inspection, interchangeability, logistics, longevity, reassembly, recyclability, and update capability (Babbitt et al., 2021; Shahbazi, 2023; Zhang et al., 2019). In contrast, the *reduce* strategy is mainly affected by sub-categories such as waste elimination, simplification, efficiency, longevity, physical and emotional durability, user participation, and dematerialization (Acaroglu, 2020; Aguiar & Jugend, 2022; Alivojvodic et al., 2020; Babbitt et al., 2021; Hollander, 2018). This demonstrates that these R-strategies are associated with distinct sets of product requirements and design considerations, highlighting significant differences in how each strategy influences product development to enhance circularity effectively.

Discussion

The distinct emphases observed across different R-strategies highlight the nuanced ways in which they influence product requirements. Narrowing strategies, excluding Refuse, place greater importance on organizational considerations, suggesting that internal processes and systems are critical for enhancing circularity through these strategies. Slowing strategies focus on product architecture, emphasizing design features that extend product lifespans, such as ease of repair and upgradeability. Closing strategies focus on materials, highlighting the crucial role of material selection and recyclability in achieving a closed-loop system. Refuse stands out due to its unique focus on material and functionality and its relatively limited number of categories. These findings indicate that each R-strategy may necessitate specific design considerations aimed at addressing particular aspects of product development to proactively enhance circularity. Understanding these nuances allows for a more targeted application of DfCE guidelines, enabling designers and developers to prioritize attributes that align with the desired R-strategy.

Conclusions

By synthesizing and standardizing guidelines from the literature to a common framework, the study offers a structured approach to integrating circularity into product design. These insights assist designers and developers in aligning products with specific R-strategies, ultimately enhancing the effectiveness of circular economy implementations. As not every product solely incorporates features that can be assigned to a distinct product or material group but rather are a combination of such, it is important to build future specific guidelines on a common framework to allow for combination and transfer. This research establishes the groundwork for such standardization. Future work should focus on creating standardized metrics for assessing adherence to R-strategies at the product requirement level, as suggested by Aguiar et al. (2017), enabling easy assessment and documentation of relevant actions. Additional studies could examine the practical application of these guidelines in industry, providing empirical data to refine DfCE strategies.

References

Acaroglu, L. (2020). Quick Guide to Sustainable Design Strategies. Disruptive Design. https://medium.com/disruptive-design/quick-guide-to-sustainable-design-strategies-641765a86fb8

Aguiar, J. de, Oliveira, L. de, Da Silva, J. O., Bond, D., Scalice, R. K., & Becker, D. (2017). A design tool to diagnose product recyclability during product design phase. Journal of Cleaner Production, 141, 219–229. https://doi.org/10.1016/j.jclepro.2016.09.074

Aguiar, M. F., & Jugend, D. (2022). Circular product design maturity matrix: A guideline to evaluate new product development in light of the circular economy transition. Journal of Cleaner Production, 365. https://doi.org/10.1016/j.jclepro.2022.132732

Alivojvodic, V., Drobac, J., Maksić, P., & Stamenovic, M. (2020). Circular economy framework for sustainable product design strategies. MATEC Web of Conferences, 318. https://doi.org/10.1051/matecconf/202031801023

Babbitt, C. W., Althaf, S., Cruz Rios, F., Bilec, M. M., & Graedel, T. E. (2021). The role of design in circular economy solutions for critical materials. One Earth, 4(3), 353–362. https://doi.org/10.1016/j.oneear.2021.02.014

Berwald, A., Dimitrova, G., Feenstra, T., Onnekink, J., Peters, H., Vyncke, G., & Ragaert, K. (2021). Design for Circularity Guidelines for the EEE Sector. Sustainability, 13(7), 3923. https://doi.org/10.3390/su13073923

Bovea, M. D., & Pérez-Belis, V. (2018). Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment. Journal of Environmental Management, 228, 483–494. https://doi.org/10.1016/j.jenvman.2018.08.014

circular.fashion UG (Ed.). (2018). CIRCULAR DESIGN KIT: Design strategies for material cyclability and longlivity. https://circular.fashion/en/software/brands.html

Diaz, A., Schöggl, J.-P., Reyes, T., & Baumgartner, R. J. (2021). Sustainable product development in a circular economy: Implications for products, actors, decision-making support and lifecycle information management. Sustainable Production and Consumption, 26, 1031–1045. https://doi.org/10.1016/j.spc.2020.12.044

Diez, S. (2023, June 19). CIRCULAR DESIGN GUIDELINES. https://www.diezoffice.com/circular-design-guidelines/

Earley, B., & Politowicz, K. (2023, July 31). The TEN - Circular Design. https://www.circulardesign.org.uk/research/ten/

Eberhardt, L. C. M., Birkved, M., & Birgisdottir, H. (2022). Building design and construction strategies for a circular economy. Architectural Engineering and Design Management, 18(2), 93–113. https://doi.org/10.1080/17452007.2020.1781588

Hollander, M. den. (2018). Design for Managing Obsolescence: A Design Methodology for Preserving Product Integrity in a Circular Economy [Doctoral dissertation, Delft University of Technology]. https://doi.org/10.4233/uuid:3f2b2c52-7774-4384-a2fd-7201688237af

Joustra, J., & Bessai, R. (2021). Circular Composites: A design guide for products containing composite materials in a circular economy. https://doi.org/10.34641/mg.23

Kuckartz, U., & Rädiker, S. (2023). Qualitative content analysis: Methods, practice and software (2nd edition). SAGE.

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring innovation in the product chain. PBL Netherlands Environmental Assessment Agency.

Shahbazi, S. (2023, February 1). Guidelines for circular product design and development. Technical University of Denmark. https://circitnord.com/tools/guidelines-for-circular-product-development/

Shahbazi, S., & Jönbrink, A. K. (2020). Design Guidelines to Develop Circular Products: Action Research on Nordic Industry. Sustainability, 12(9), 3679. https://doi.org/10.3390/su12093679

Zhang, X., Zhang, S., Zhang, L., Xue, J., Sa, R., & Liu, H. (2019). Identification of product's design characteristics for remanufacturing using failure modes feedback and quality function deployment. Journal of Cleaner Production, 239, 117967. https://doi.org/10.1016/j.jclepro.2019.117967

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Implementing circular design strategies through co-creation: An action-research case in the household goods sector

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Keywords: circular design; circular economy; co-creation.

Context

This study examines how co-creation can facilitate the adoption of circular design strategies in product development, including longer-lasting products, repair, refurbishment and recycling. The research was conducted in collaboration with a multinational company producing small household goods. The goal of this research was to explore how the co-creation process can support the implementation of circular design strategies in the product development process.

Co-creation (Sanders & Stappers, 2008) is recognised to have great potential for the success of circular propositions, especially in stakeholder engagement, organizational change, value creation and innovation (Brown et al., 2021; Dokter, 2023; Pedersen et al., 2023; Van Dam et al., 2021). However, a gap is identified, in measuring how and to what extent co-creation contributes to the adoption and upscale of the circular economy (Van Dam et al., 2021).

The company's existing eco-design guidelines centered around energy efficiency, avoiding harmful substances, packaging, recycled materials and repairability. As part of its sustainability strategy, the company aimed to enhance these and explore other circular strategies, such as design for durability, aesthetic longevity, and refurbishment. Co-creation was employed to develop and implement circular design guidelines while aligning and engaging various actors within the company and involving them in decision-making throughout the process.

Methodology

Action research was iteratively conducted, in close collaboration with a company representative, who acted as a change agent throughout the process. The research plan consisted of three phases and included explorative interviews, co-creation sessions and follow-up interviews (Figure 1). Phase I. and II. has been carried out prior to submitting this abstract. Both interviews and workshops took place online, due to participants being located in various countries in Europe and Asia.

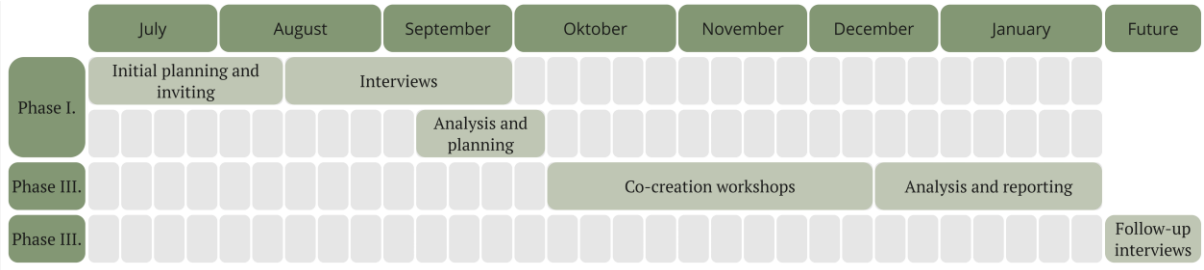


Figure 1 Research timeline.

In the first phase, 15 interviews were conducted, to explore challenges and opportunities around existing eco-design guidelines and the transition towards circularity. The participants fulfilled various roles within the company in product development, procurement, marketing, quality, etc. The interview results served as a basis for designing the co-creation workshops.

Three co-creation workshops were planned in total, with objectives building on each other. The first workshop aimed to envision circular futures within the company, with emerging topics such as longer-lasting products, timeless collections, servitization and subscription systems. Building on this, several circular scenarios and design principles were explored in more detail in the second workshop, including, for instance, recycling, repair,

standardization and modularity. The third workshop set the goal to consolidate which strategies the company will focus on in the upcoming years and create implementable roadmaps towards them.

Each workshop aimed to include around 10 participants, some of them returning. Several co-creation techniques were incorporated into the exercises, such as scenarios, roleplaying, visioning, road-mapping and design games to support the participants' visions of a more sustainable (company) future and engagement in tangible design decisions.

The data analysis from this collaboration is still in progress, after which a set of follow-up interviews is planned to take place in the spring of 2025 to evaluate the impact of co-creation on the implementation of new circular guidelines.

Results

Circular strategies

Preliminary findings regarding the implementation of circular strategies revealed challenges such as organizational and value-chain readiness, lack of knowledge sharing and difficulties in applying product design guidelines in out-of-house product development. It also highlighted tensions, for instance between 'product quality vs. recycled material content', 'manufacturing cost vs. design for repair', 'consumer safety vs. right to repair', 'product longevity vs. current standard of designing products for 5-7 years'.

Opportunities have also been highlighted, for instance, focusing on standardization and modularity which could open possibilities for upgrading products; launching self-repair programs; expanding warranty; extending the understanding of refurbishment to include all returned products and exploring take-back programs both for refurbishment and a way to increase recycling rates.

The roadmaps developed over the third workshop offer actionable and time-bound insights into the next steps on circular strategies prioritized by the company. Actions for the first year, for instance, include 'developing an overview of material needs for all business units' to upscale recycling, 'creating an overview of key components that could be standardized cross-category' for repair or 'mapping current partners and their capacity to expand' on refurbishment, among others.

Follow-up interviews will offer an opportunity to reflect on which actions have been completed, which challenges have been resolved and which opportunities have been leveraged successfully following the co-creation process, and what role co-creation played overall.

The co-creation process

In line with co-creation literature findings, challenges around the co-creation process have been also confirmed. These included selecting and engaging participants, especially in an online environment, and addressing power dynamics among participants, and between participants and the design research team. But also, organizational barriers, such as hierarchy, conflicting goals, changes in management, lack of management support, and time constraints.

Co-creation impact

While the impact of the co-creation process on the implementation of circular strategies will be clearer after follow-up interviews have been conducted, it was indicated by participants that the co-creation process successfully negotiated between relevant actors and brought forth relevant challenges and ambitions which need to be addressed for a successful transition. Furthermore, relevant opportunities have been highlighted, which the company can leverage in the future to create a circular impact.

Conclusion

This study provides actionable insights into how co-creation can support the implementation of circular strategies, like longer-lasting products, repair, refurbishment or recycling in the product development process. By reflecting on challenges and opportunities around the outcome and the process, findings contribute to practical implications of transitioning towards circularity in an organizational context, as well as to the academic discourse on the role of co-creation in scaling the circular economy.

The final results of this collaboration – expected to be concluded in the spring of 2025 - will offer actionable insights into co-creation's role in advancing product longevity, making a significant contribution to the PLATE 2025 discussions.

References

Brown, P., Baldassarre, B., Konietzko, J., Bocken, N., & Balkenende, R. (2021). A tool for collaborative circular proposition design. Journal of Cleaner Production, 297, 126354. https://doi.org/10.1016/j.jclepro.2021.126354

Dokter, G. (2023). Circular design through co-creation: Exploring perspectives and future directions for design in a circular economy. Chalmers University of Technology.

Pedersen, S., Clausen, C., & Jørgensen, M. S. (2023). Navigating value networks to co‐create sustainable business models: An actionable staging approach. Business Strategy and the Environment, 32(1), 240‐258. https://doi.org/10.1002/bse.3127

Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. CoDesign, 4(1), 5–18. https://doi.org/10.1080/15710880701875068

Van Dam, S., Sleeswijk Visser, F., & Bakker, C. (2021). The Impact of Co-Creation on the Design of Circular Product-Service Systems: Learnings from a Case Study with Washing Machines. The Design Journal, 24(1), 25–45. https://doi.org/10.1080/14606925.2020.1851427

Extended Abstract
6th PLATE 2025 Conference
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Design for Evolving Play: Exploring Levels of Adaptability in Toy Design

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Keywords: Evolving toys; Adaptability; Half-way design; Open-ended play; Toy longevity.

Introduction

The short lifespan of children's toys, driven by rapid child development and desire for novelty, causes significant resource loss and waste (Robertson-Fall, 2021; Watkins & Mestre, 2019). Many parents discard still-usable toys, and children often lose interest in new ones quickly (Choi & Kennedy, 2024; Robertson-Fall, 2021). Addressing this issue requires rethinking toy design, production, and use.

Open-ended (Fousteri & Liamadis, 2021) and emotionally durable toys (Heljakka, 2022) tend to last longer. A promising approach for these is developing evolving toys adopting half-way design approach. Half-way design involves partially designing and manufacturing products, allowing users to complete and personalise them (Fuad-Luke, 2009). Such adaptability can extend toy lifetimes by fostering product attachment and meeting changing user needs. Evolvability requires modularity and rethinking product structures as component systems (Doğan, 2017). Local production of these also offers environmental, social, and economic benefits (Doğan & Walker, 2008). Existing toy systems such as Free Universal Construction Kit (Stephensen & Hansen, 2015) and TOYI (toyi.io, n.d.) exemplify how modularity and adaptability can support evolving play experiences.

This paper addresses limited research on applying these principles to toy design by presenting a project conducted at Yaşar University, Department of Industrial Design. It explores design considerations for toy connectors that promote adaptability, evolving play experiences, and extended toy lifetimes.

Design Project and Method

In the “toy connection parts for evolving play” project, 3D-printed connectors allowing children to construct personalised and evolving toys in the design and use phases were created. Adopting half-way design approach, third-year design students developed downloadable connectors for local production, allowing form, size, color, and texture adjustments. Designed to combine with household waste like cork and cardboard, the connectors promote personalisation, rebuilding, and upcycling.

Eight students developed five toy kits targeting specific age groups and toy types. The researcher conducted visual content analysis to assess their adaptability, followed by expert discussions to develop themes.

Results and Discussion

Table 1 summarizes each project. Four adaptability levels—*surface, form, function, and structure*—were identified, fostering toy evolvability (Table 2).

Surface adaptability involves altering a toy’s visual qualities (e.g. color, texture) through personalisation of re-used materials and 3D-printing without changing form, function, or structure. All projects enabled this, allowing children to personalise toys and narratives, which can foster a personal connection with the toy—an element often missing in mass-produced toys. However, surface adaptability alone may not extend toy use as it may not alter how the toy is played. For instance, P4 supports only surface adaptability and one product form, limiting open-ended play.

Form adaptability involves changing a toy’s form during use. *Part variety* (P2, P3) and *versatile design details allowing multi-angle connections* (P3, P5) supported this. Adaptable forms influence how toys are interpreted and played with, enabling evolving functions and narratives. Changing function without altering form relies on children's imagination, as they adapt the same object to different scenarios, making adaptable forms valuable for open-ended play.

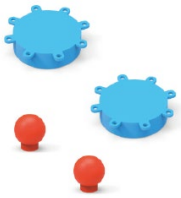
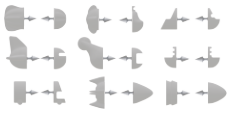
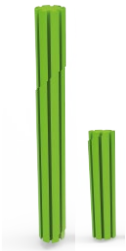
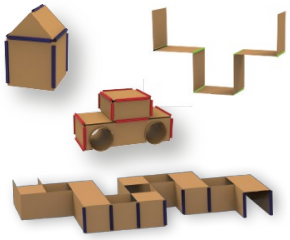
PROJECT EXPLANATION	CONNECTORS	RE-USED MATERIALS	VARIATIONS
P1 lets children create musical toys by attaching a cardboard tube to connectors, adding sound materials, and using pencils and spheres as mallets, all of which can be personalised through decoration, alternative pencils, and varied sound materials. By Yağmur Doğan, Deniz Kızıldereli			
P2 features 18 connectors that attach to corks to create vehicles, which can be personalised by decorating the corks. By Utku Serinoğlu			
P3 involves connectors attaching popsicle sticks at different angles, allowing structures to be built and further personalised by decorating the sticks. By Ece Öner, Sena Tokul			
P4 has five parts connecting cardboard tubes and a rubber band, forming a wind-up toy that is personalised through decoration. By Berkay Kazak			
P5 features a connector 3D-printed at different heights, attaching to cardboard at various angles with further personalisation by decorating cardboard. By Melisa Alşan, Zeynep Tuğrul			

Table 1. Summary of the student projects

Functional adaptability changes a toy's primary purpose. A vehicle toy that remains the same after user intervention lacks functional evolvability, but one that transforms into different vehicles can evolve. P2, P3, and P5 evolve functionally due to part variety (P2, P3) and versatile design details (P5), while P1 and P4 do not, which retain their initial functions. Functional adaptability can be the most critical for toy longevity as it increases open-ended play possibilities, encouraging imaginative play, problem-solving, and storytelling.

Structural adaptability involves expanding a toy in one or more directions. P1 expands in one direction *using a longer tube,* while P3 and P5 expand in multiple directions due to *part variety*

(P3) and *versatile design details* (P3, P5). Structural adaptability in multiple directions, facilitates adaptable forms and functions, and promote open-ended play and continuous experimentation, which can extend the useful life of a toy.

	Surface	Form	Functional	Structural
P1	+	-	-	+
P2	+	+	+	-
P3	+	+	+	+
P4	+	-	-	-
P5	+	+	+	+

Table 2. Adaptability levels offered by each project.

The half-way design approach added construction play to the play experience as seen in P1, where a maracas became a construction toy. Thus, the approach may enhance the play value of toys. It also enabled personalisation through integrating re-used materials, which may promote attachment that needs to be studied further.

Part variety and versatile design details contribute to evolving forms, functions, and structures, which are essential for open-ended play. P5 demonstrates that even without part variety, versatile design details alone can support evolvability. However, when part variety does not allow structural evolvability, as in P2, the number and diversity of parts become crucial for maintaining open-endedness and functional evolvability.

Conclusions

This study explored how toys can evolve adopting half-way design approach, identifying four adaptability levels—surface, form, function, and structure—and their implications for toy longevity. Functional adaptability emerged as the most critical for open-ended play and longevity, enhancing toys' versatility for various play contexts. Surface adaptability alone may foster attachment but be insufficient for longevity. Part variety and versatile design details can facilitate evolvability and open-ended play. Designers can consider these adaptability levels and design attributes when creating toy connection parts for evolving and enduring play experiences.

References

Choi, Y. J., & Kennedy, B. (2024). Understanding product hibernation periods with children's products and exploring motivations and barriers for product care to encourage their reuse. *Resources, Conservation and Recycling*, 205, 107576. https://doi.org/10.1016/j.resconrec.2024.107576

Doğan, Ç. (2017). Transforming and prolonging design lifespans: design education cases for sustainability. In C. Bakker & R. Mugge (Eds.), PLATE: Product Lifetimes and the Environment, (pp. 114-119). Delft, NL. https://doi.org/10.3233/978-1-61499-820-4-114

Doğan, Ç., & Walker, S. (2008). Localisation and the design and production of sustainable products. *International Journal of Product Development*, *6*(3-4), 276-290. https://doi.org/10.1504/IJPD.2008.020396

Fousteri, A., & Liamadis, G. D. (2021). Toy stories for the common good. In M. Botta & S. Junginger (Eds.), Swiss Design Network Symposium, (pp. 584-599).

Fuad-Luke, A. (2013). *Design activism: Beautiful strangeness for a sustainable world*. Routledge. https://doi.org/10.4324/9781849770941

Robertson-Fall, T. (2021). *Creating a circular economy for toys*. Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org/articles/creating-a-circular-economy-for-toys.

Stephensen, J. L., & Hansen, L. K. (2015). (In) tangible arguments about play, creativity, and the political economy of 3D printing: the free universal construction kit. *tripleC: Communication, Capitalism & Critique. Journal for a Global Sustainable Information Society,* 13(1), 112-135. https://doi.org/10.31269/triplec.v13i1.638

Toyi (n.d.). https://toyi.io/tr/

Watkins, M. & Mestre, A. (2019). A comparative and exploratory study of toy products in the circular economy. In N. F. Nissen & M. Jaeger-Erben (Eds.), PLATE: Product Lifetimes and the Environment, (pp. 835–842). TU Berlin. https://doi.org/10.14279/depositonce-9253

Extended Abstract
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Circular bioeconomy business ecosystem in Finland: from barriers to solutions for wood reuse in construction

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Keywords: Circular economy; business ecosystem; reused wood; wood construction; circular solution.

Introduction

Changing to circular economy requires reconsidering how value is created and captured among the value networks, and what new roles of actors in business ecosystems can be identified (Iurato & Schanz, 2024). Earlier studies found the construction sector is globally a substantial source of waste and blamed for carbon emissions. Hence, ensuring material circularity worldwide and within the European Union (EU) in construction business is crucial. Previous research also found that wood has the greatest reuse capacity when compared to conventional building materials. Although the European Union is emphasizing circularity in wood construction, the current rates of recycling are still at a marginal level (European Parliament and Council, 2015). In Finland, wood is the 2nd largest share of construction and demolition waste (after mineral waste), while most of wood waste from construction is incinerated for energy purposes (Puuinfo, 2024). The reasons for low recirculation rates of wood in construction are manifold, ranging from technological barriers, regulatory rigidity, market inefficiencies and cultural obstacles (Kirchherr et al., 2018). The focus of our study is especially on market and cultural barriers, as well as the potential of addressing them through business ecosystem development. Previous research has shown that further enhancement of business ecosystem is critical for the increase of wood material circularity in the field of both new and renovation construction. Empirically this study explores the characteristics of business ecosystem and need for actors' involvement in different life phase of buildings for material circulation in case of Finland and analyses the rationale behind the identified barriers toward finding solutions for increasing wood material reuse.

Methods

This research relies on a multi-stage explorative approach. Our qualitative research is conducted through 14 semi-structured interviews and dialogue data from two workshops organized with experts involved in different life phases of wood construction. Both stakeholder interviews on barriers data collection and stakeholder workshops on solutions was organized in between November 2022 - June 2024. Based on Braun and Clarke's (2006) step-by-step guide, a thematic analysis of the data was carried out. Coding and theme identification were performed through the qualitative data analysis software ATLAS.ti.

Results

From the business ecosystem for wood material reuse perspective, our study found the diversity of pool of actors and the need for wood-related expertise throughout building life phases. We first mapped the actors and identified architects, building designers and planners, financers, real estate investors, construction companies, developers and contractors to be the core actors of circular business ecosystem. While manufacturers, construction material retailers, waste management companies, real estate maintenance operators, and demolition or deconstruction companies are found to be extended actors. We found many potential actors and intermediaries that are still missing in different life phases of buildings. For instance, there are no recycled product monitoring organizations at any level from EU to city level. Also, physical hub or recycled wood material storage is absent in Finland.
Considering the barriers of wood material circularity, this study found that strong links

between construction operational level actors focusing on reused material market are yet largely missing. Moreover, while used wood from construction is available, one of the key challenges is related to lack of interest from potential end users and industrial destinations. In fact, strong positions of the forest industry and virgin wood products in Finland may serve to weaken the uptake of used wood from construction. These market barriers are linked with the cultural ones, such as perceived high risks of the new practices, wariness towards innovation in a conservative industry, competing goals and lack of coherent vision on sustainability priorities, and the resulting lack of collaboration throughout the value chain. In this regard, our interview findings emphasize the significant role of intermediating actors, such as the management of material hubs, in addressing market and cultural barriers and accelerating the circular economy in wood construction. From two workshops data we dive deeper into practical solutions, including also the use of digital platforms for better circulation of wooden building materials. Moreover, one of the aims of these workshops is to support the emergence of cross-sectorial perspectives by giving a voice to actors that might not be explicitly part of the construction process, yet are critical from the perspective of circularity, such as repair and maintenance service providers.

Conclusions

We Found the cross-sectoral approach and raising awareness among business ecosystem actors on the opportunities related to wood recirculation may help to harmonize wood-related reuse practices to better integrate both circular economy value retention goals and bioeconomy's strive for increased value-added from renewable resources. Moreover, this study found more integrated circular community build up, public-private partnerships, diversification of wood products, change of language of "waste", and harmonization of Construction regulations are the key to established reused wood market in Finland. Additionally, the building construction industry's collaborative demo projects experience beyond internal piloting can be defined as the first opportunity for fostering wood recirculation in construction. Furthermore, reclaimed wood products to be compete in the market, not only have to resolve standardized settings but also consider reputational and cultural appeal, which could generate common understanding about the products qualities among different stakeholders. All in all, we can say the ambition, motivation, and willingness of actors will be instrumental to circulate wood more. Failure to do so will persist in the problem of incineration and energy recovery. Future research is still needed on understanding the end-user inclusion process in the business ecosystem and their acceptance of reused wooden materials. The further development of standards ensuring the safety and quality of circulated materials would be also paramount. Future research could further benefit by identifying how and what novel approaches are required for public–private partnerships to accelerate the circular economy practices in the built environment. Additionally, future research could also progress with how different ongoing Finnish reused woodworking projects are following the EU taxonomy criteria, since they have already committed to produce sustainable and financially profitable business model make out from reclaimed wood (Puuinfo, 2024).

Acknowledgments

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References

Braun, V., & Clarke, V. (2006) Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

European Parliament and Council, 2015. COM/2015/0614 final – communication from the commission to the European parliament, the Council, the European economic and social committee and the committee of the regions closing the loop - an EU action plan for the circular economy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri¼CELEX:52015DC0614.

Iurato, C., & Schanz, H. (2024). Industry associations as levers for the implementation of cascading - A longitudinal study of post-consumer wood recycling in Germany. Resources, Conservation and Recycling, 207, 107594. https://doi.org/10.1016/j.resconrec.2024.107594

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the Circular Economy: Evidence From the European Union (EU). Ecological Economics, 150, 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028

Puuinfo, 2024. Towards an economically viable use of recycled wood. Retrived from: https://puuinfo.fi/2024/06/18/towards-an-economically-viable-use-of-recycled-wood/?lang=en

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Product-service Systems for Regenerative and Long-lasting Buildings: Case of Wood in Finland

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Keywords: wooden material; product-service systems; innovation; buildings; circular economy.

Introduction

New market demands on building solutions both mitigating and adopting to both climate change and biodiversity are on the rise. Wood material has been considered to be renewable, low carbon and regenerative material for buildings. As a response to expected market growth there are many bundles of innovations brought forth by the companies and their collaborative partners in the realm of sustainable buildings and connected to wood material in a spectrum of ways. In our study we focus on mapping the range of innovations designed to make buildings and embedded materials longer lasting, encompassing new products, services, and most importantly enhancing product-service systems in Finland. By applying insights from 20 qualitative interviews and literature on product-service systems (PSS), sustainable innovation and different typologies of servitized, circular, and regenerative business models, we are able to shed light on new sustainable innovations developed by forefront companies and connected to the use of wood material. We elaborate on wooden construction and retrofit innovations with a focus on adaptive, flexible and extending building with longevity (Pelsmakers and Warwick 2022; Kuittinen, 2023). The main functionalities of these innovations centered around resource efficiency but could be bundled more tightly together to achieve greater sustainability impact to favor circular economy and resilience to environmental challenges.

Literature background

Conceptually our study draws from product service systems (PSS), sustainable innovation and business models. PSS have been depicted as promising new approach to business models (Ghafoor et al. 2023; Pelli and Lähtinen 2020). PSS represents a system of products, services, supporting networks and infrastructure designed to be competitive, satisfying customer needs, but also lowering the environmental impact when compared to conventional business models (Mont, 2002). In circular economy, the focus on system solution is important, where the outcome ensures slowing or closing the loops. Reim et al. (2015) observe that the business model in PSS implementation is defining its success, and it is crucial to understand how the value creation, delivery and capture take place. In our study, we rely on the interlinked literature that brings forth servitization business models (Yang & Evans 2019; Pelli 2021), circular business models (Ghafoor et al. 2023; Rieke et al. 2018) and regenerative business models (Konietzko et al. 2023). Moreover, in the buildings context it is crucial to combine the business model thinking with the waste management hierarchy, as developed by Kuittinen (2023), positing that that existing buildings should be used and renovated as far as possible to ensure longevity and efficient use. In our study, we are interested in the shared value propositions of the building innovations. Sustainable innovation market diffusion has been investigated in the past by Fichter and Clausen (2016) and identification of new markets by Yang and Evans (2019). The focus of our study was to detect new market paths that could alternate from the current construction sectors path dependencies largely relying on new concrete-material based solutions as opposed to circular and hybrid-material solutions.

Materials and methods

Finland has strong traditions on building with wood in single housing sector, but at the same time its construction sector for multistorey buildings has a clear path dependency on concrete-material based practices and products with high environmental impact. Thus, Finland represents an interesting case study setting of how the capabilities in the construction sector

could be renewed with new sustainable innovations. Thereby, we collected and analyzed qualitative interview data of 20 Finnish company informants. Data was collected between 2021–2024. Data was coded and categorized using the Qualitative Data Analysis & Research Software ATLAS.ti 9. Key themes coded were connected to sustainable innovations of the services integrated to products and solutions to enhance longevity.

Indicative results

From our data, we were able to detect different types of sustainable innovations. The majority dealt with mere improved products or systems, such as introduction of cross-laminated timber (CLT) and wood frame elements that enable prefabrication. However, part of the sustainable innovations were representations of PSS that could be viewed as constellations of several connected innovations in an attempt to introduce systemic innovations to the markets. The innovations were connected to extending the lifecycle of certain existing buildings via renovation; adding on regenerative materials (such as wood) to the building stock to substitute concrete; introducing recycled construction materials as part of buildings; or through new service-innovation to avoid the excessive material-use altogether. Also, the service appears in the data as for instance installation services, or possibility to refurbish and reuse CLT elements.

The proposed hierarchy of Kuittinen (2023) for preferring use of existing spaces, renovating, adapting or extending the existing buildings over new construction is a useful frame for analyzing our data and it is gaining relevance with the European Renovation Wave and EU taxonomy to sustainable finance putting stricter requirement for material reuse share. In addition, we were able to detect some innovations that would have significant sustainability impact if they were connected to bigger bundles of multi beneficial construction solutions and having synergies with nature-based solutions. The most systemic concepts and ideas with widest sustainability impact are still mainly in pre-market phase.

Tentative conclusions

There is a need for sustainable and wood material related innovations for buildings that go beyond one company's value offerings. The product-service systems are being ideated as conceptual designs and occasionally initiated as small-scale pilots. However, the need for radical and systemic sustainable innovations for buildings is growing simultaneously with the worsening environmental problems, creating new markets both domestically in Finland and internationally.

Acknowledgments

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References

Ghafoor, S., Hosseini, M., Kocaturk, T., Weiss, M., & Barnett, M. (2023). The product-service system approach for housing in a circular economy: An integrative literature review, Journal of Cleaner Production 403 (2023) 136485. https://doi.org/10.1016/j.jclepro.2023.136845

Kuittinen, M. (2023). Building within planetary boundaries: moving construction to stewardship, Buildings and Cities, 4(1), p. 565–574. DOI: https://doi.org/10.5334/bc.351

Mont, O. K. (2002). Clarifying the concept of product–service system, Journal of cleaner production, 10(3), p. 237-245.

Pelli, P., & Lähtinen, K. (2020). Servitization and bioeconomy transitions: Insights on prefabricated wooden elements supply networks, Journal of Cleaner Production 244 (2020) 118711. https://doi.org/10.1016/j.jclepro.2019.118711

Pelli, P. (2021). Service innovation and sustainable construction: Analyses of wood vis-a-vis other construction projects, Cleaner Engineering and Technology 2 (2021) 100061. https://doi.org/10.1016/j.clet.2021.100061

Pelsmakers, S., & Warwick, E. (2022). Housing adaptability: new research, emerging practices and challenges, Buildings and Cities, 3(1), p. 605–618. DOI: https://doi.org/10.5334/bc.266

Reike, D., Vermeulen, W., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options, Resources, Conservation & Recycling 135, pp.146 – 264.

https://doi.org/10.1016/j.resconrec.2017.08.027

Reim, W., Parida, V., & Örtqvist, D. (2015). Product–Service Systems (PSS) business models and tactics–a systematic literature review, Journal of Cleaner Production, 97, p. 61-75. https://doi.org/10.1016/j.jclepro.2014.07.003

Enduring Consumption



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How “Fast” is Fast Furniture?

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Keywords: Fast Furniture; Lifetimes; Value; Consumer Behaviour; Consumption.

Abstract: This paper explores the emerging concept of fast furniture, a rapidly growing sector characterized by quick production, low costs, and short product life cycles. Despite its substantial environmental impact, fast furniture remains underexplored in academic literature. Drawing parallels to fast fashion in its focus on trends, disposability, and mass production, this study examines the intersections of consumer behaviour, industry practices, and sustainability challenges within the context of fast furniture. Through a mixed-methods approach, combining a quantitative/qualitative survey of UK consumers and interviews with industry professionals, the study reveals significant insights into consumer perceptions, motivations, and the role of fashion-driven consumption in shaping the furniture market.

Key findings indicate that while consumers increasingly engage with trend-driven furniture purchases, many are unaware of the term "fast furniture." Moreover, despite their significant market share, brands like IKEA are not strongly associated with the "fast" model by consumers, who instead view their products as affordable and functional, yet temporary. Industry professionals, meanwhile, emphasize that the "fastness" of furniture is determined largely by consumer choices, not necessarily the manufacturing process.

This research stems from a larger doctoral study that contributes to the growing body of knowledge on sustainable consumption, advocating for a broader understanding of fast furniture as a consumer-driven phenomenon rather than an industry-defined product category. Future research is suggested to further explore the global dynamics of fast furniture consumption, the role of consumer education, and sustainability initiatives within the industry.

Introduction

Context and Background

The global furniture industry is valued at over $579 billion (Statista, 2024); yet more than 12 million tonnes of furniture are discarded in landfills each year. This staggering statistic highlights the significant waste generated by the furniture industry, which is often overlooked in comparison to other consumer goods. It paints a stark picture of the environmental cost of furniture consumption worldwide and underpins the urgency for a more sustainable approach to both the production and disposal of furniture. While much research has focused on automobile emissions (Buberger et al., 2022; Fekete et al., 2021), the efficiency and disposal of white goods (Yilmaz et al., 2019; Cole et al., 2019), and fast fashion (Cooper, 2022; Centobelli et al., 2022), the furniture sector—and more specifically, the issue of fast furniture—has received relatively little academic attention. Fast furniture is a concept that remains academically undefined and presents an exciting avenue for exploration.

Framing Fast Furniture

The term "fast furniture" has yet to be fully explored or defined within the literature, offering a unique opportunity to examine the intersection of consumer behaviour, design practices, and sustainability in a rapidly growing sector. Similar to the rise of fast fashion, where trends in clothing are driven by rapid production, quick turnover, and disposability, fast furniture refers to quick manufacturing, affordable pricing, and a short life cycle of furniture items. This practice aligns with the broader pattern of hyper-consumerism that prioritizes convenience and low cost over longevity and quality.

The throwaway notion of fast implies a lack of value placed on these items as they are easily discarded. Value can be defined as “the regard

in which we perceive something." But if consumers place little value on their furniture, how can this lead to keeping and enjoying items, ensuring their longevity?

Literature Review

The Rise of Fast Consumption

Globally, the rise of hyper-consumerism has driven an increasing demand for products, with the fashion industry being one of the most notable examples. For instance, high street brands like Zara produce 450 million items of clothing annually, while Shein, a Chinese brand, releases 2 million items every year—equating to around 6,000 new styles per day (Vara, 2022). This rapid turnover of products has transformed consumer expectations, leading them to expect constant novelty. Similarly, in the furniture industry, trends change every one to four years (Mote, 2023), and the desire to stay "on-trend" has led to the emergence of fast furniture, a term that reflects the low-cost, trend-driven, and disposable nature of furniture in today's market.

Historically, fast consumption has been studied in industries like fast food and fast fashion, which share similar characteristics—namely, a focus on affordable, mass-produced, and disposable products. The key similarity between fast food, fast fashion, and fast furniture lies in the rapid turnover and the temporary satisfaction of meeting immediate consumer needs. As consumer demand for inexpensive, trendy, and disposable products has grown, it has created a pattern of high consumption and waste, leading to environmental concerns.

Defining Fast Furniture

The concept of fast furniture has yet to be academically defined, but it draws heavily from the concept of fast fashion. Like fast fashion, fast furniture is characterized by low-cost production, mass manufacturing, and quick consumption cycles and disposability (often driven by fashion trends).

The term "fast furniture" first emerged in internet searches around 2008 (Matroka, 2008), but earlier references can be found in mainstream media, with publications like The New York Times using the term to describe aspects of rapid manufacturing or distribution in furniture production (Clancy, 1996; Kight, 1993). However, the term has since evolved to more broadly capture the short-term nature of the furniture cycle—highlighting the fast consumption, disposal, and replacement of furniture items.

While the term "fast furniture" lacks a unified academic definition, it shares several traits with fast food and fast fashion, which are typically characterized by:

- Quick production
- Inexpensive pricing
- Non-durable quality
- Trend-driven appeal
- Short lifespan

Drawing from both grey literature and academic sources, fast furniture is often described as fashionable, inexpensive, non-permanent, poor quality, mass-produced, and easily thrown away (Kirchmer, 2023; Maier, 2021; Young, 2023; Kamin, 2022). These characteristics align with the ephemeral nature of the products, where the focus is on immediate consumer satisfaction rather than long-term durability. Russell et al. (2021) and Cummins (2020) emphasize this disposable nature and highlight the lack of long-term investment in fast furniture, making it an important area for further research.

For this study, fast furniture will be defined as: "Furniture that is quick and low cost to make, purchase, consume, and dispose of."

This definition reflects the rapid production and consumer turnover, while acknowledging that not all cheap, quick-to-make furniture is inherently poor quality. The focus of the definition is on the speed and cost of the process rather than the inherent quality of the product.

Consumer Behaviour and the Lifespan of Fast Furniture

The concept of how fast furniture is "fast" is often tied to the lifespan of these products. Fast furniture typically has a lifespan ranging from one to five years (Delgado, 2022). However, this range is not fixed; the actual lifespan depends on factors such as how the furniture is treated, the environment it is placed in, and the material quality. As fast furniture is often purchased to fulfil temporary trends, its short lifespan is seen as a justification for replacing it when trends change.

In line with consumer redecorating behaviours, studies suggest that British consumers redecorate their homes every one to five years, with the living room being the most frequently updated space (Heath, 2017; Evans et al., 2024). As consumers seek to stay in style, they turn to inexpensive and disposable furniture

that can easily be replaced when their décor changes. This cycle of purchasing and discarding is integral to the fast furniture model, with the quick turnover of affordable, on-trend items enabling consumers to stay up to date with the latest fashion trends in home interiors. With the above in mind the question of what consumers and industry professionals themselves think of fast furniture is important to consider.

Methodology

This study employs a mixed-methods approach to examine consumer and industry perspectives on fast furniture. The research combines a quantitative/qualitative survey to gather insights into consumer attitudes and behaviours, alongside qualitative interviews with industry professionals to explore the production and sustainability challenges of fast furniture.

A quantitative/qualitative online survey (Table 1) was distributed to UK-based consumers aged 18 and over. The survey focused on understanding consumer attitudes toward fast furniture, including purchasing patterns, motivations, and perceptions of sustainability. Using a combination of multiple-choice and open-ended questions to gather data on these topics data collection was done through social media platforms and online communities, ensuring a diverse and varied sample. The survey was open for 6 months and received 620 responses.

Questions
Which age category do you fit into?
What is your employment status?
What is your household income before tax?
How many adults live with you?
Do you have knowledge or familiarity of the furniture industry?
Where do you purchase/ acquire your furniture from?
Why do you purchase these items?
What might deter you from purchasing a second-hand item of furniture?
At what point would you consider getting rid of a piece of furniture?
Where would you get rid of your furniture?
How many of your pieces of furniture have lasted less than 5 years?
What type of furniture was this?
Which room of the house was the furniture located in?
What is your understanding of 'fast furniture'?

Table 1. Survey Questions

To complement the survey data, semi-structured interviews were conducted with 5 industry professionals, including furniture designers, manufacturers, and sustainability experts. These interviews focused on understanding the challenges of producing sustainable furniture, the influence of consumer demand on production practices, and the perceived environmental impact of fast furniture. The interviews were conducted via Microsoft Teams and recorded with participant consent for transcription and analysis. These individuals were approached based on their expertise in the industry, ensuring insights into both design and manufacturing processes.

Data Analysis

Survey responses were analysed using a combination of descriptive statistics, such as frequency counts and mean scores, to identify trends in consumer behaviour and purchasing decisions on Excel, and thematic analysis to understand consumer attitudes toward fast furniture and sustainability.

The interviews were transcribed and analysed thematically (Braun and Clarke, 2021). Key themes related to sustainability, consumer demand, and production practices were identified and coded. This allows for a deeper understanding of the industry's perspective on fast furniture and how it aligns with or contrasts consumer attitudes.

Ethical Considerations

All participants were informed about the purpose of the study and provided informed consent before participating. The survey responses were anonymised, with no personally identifiable information collected. Interviews were recorded with consent, and transcripts anonymised to protect participants' privacy. The data is securely stored and used solely for research purposes.

Limitations

This study is limited by its focus on UK-based consumers and industry professionals, which may affect the generalizability of the findings to other regions or markets, however, it is important to note that the companies spoken to are all global.

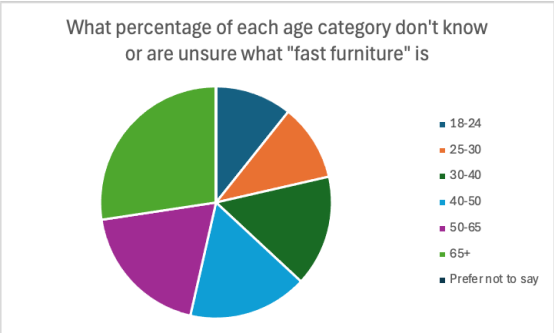


Figure 1. Pie Chart showing unsure viewpoints of fast furniture from the survey.

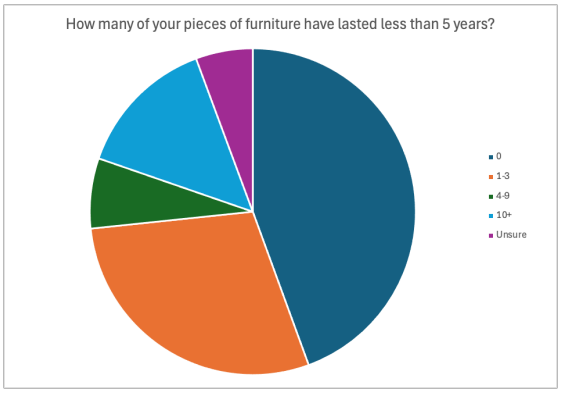


Figure 2. Pie chart looking at survey data around broken furniture.

Discussion

Attitudes to Fast Furniture

This study reveals significant insights into the concept of fast furniture and the consumer's relationship with it, as well as highlighting the disconnect between consumer perceptions and industry viewpoints.

One of the most striking findings from the survey is that 24% of respondents—particularly from those over-50—were unfamiliar with the term "fast furniture" (Figure 1). This suggests that the concept of fast furniture may not yet be a widely recognized or understood term for many consumers, especially in older generations. This aligns with Russell et al. (2021), who note that the lack of academic literature around fast furniture may contribute to such gaps in consumer awareness. In contrast, younger consumers—who are more likely to be engaged in trend-driven consumption—appear to have a clearer understanding of the idea of disposable or trend-based furniture. This could be why "fashion furniture" is a more fitting term for this concept, where the lifecycle of the product is dictated less by durability and more by aesthetic trends.

Consumer Behaviour and the Ikea Effect

The global furniture industry, valued at $579 billion (Statista, 2023), has witnessed an increase in demand for affordable, mass-produced furniture that can be replaced quickly. IKEA—a dominant player in the global furniture market—emerges as a key example. Although 60% of survey respondents reported purchasing furniture from IKEA (Figure 2), only 5% of respondents associated the retailer with the term "fast furniture." This disconnect suggests that, despite IKEA's reputation for producing cheap, stylish, and easily replaceable furniture, consumers don't explicitly equate it with the "fast" consumption model typical of fast food or fast fashion.

The findings indicate that consumer perceptions of IKEA (and similar brands) are more closely linked to affordability and convenience, rather than the disposable nature of the products. The "IKEA effect" could be playing a role here, as consumers may view their products as temporary but still functional for a significant period, thus obscuring the "fast" concept.

The survey findings suggest that while IKEA is a dominant player in the UK market, its global footprint means that the perceptions of fast furniture are not just limited to the UK but are indeed part of a larger, global consumption pattern. Consumers across the Western world often share similar values about affordability, convenience, and design trends, even if they are not using the exact term "fast furniture."

Moreover, 44% of respondents stated they have never had a piece of furniture break (Figure 3), which could suggest a misalignment between the perception of furniture as a durable asset and its role in trend-driven consumption. This is especially notable when examining the 18-24 age group, which represented 7% of the sample. This age group, often characterized by

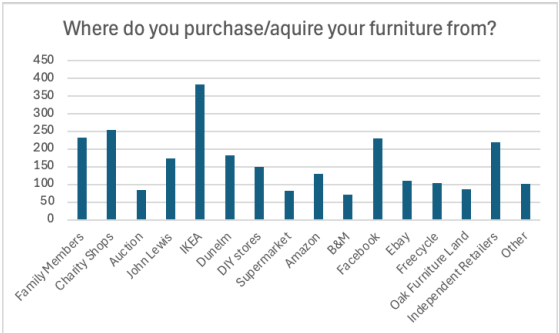


Figure 3. Chart to show where consumers from the survey purchase their furniture.

shorter ownership cycles and a greater tendency to redecorate or "refresh" their homes, likely influences the overall perception that furniture is designed to last longer than it does in practice.

Interestingly, when asked about their behaviour toward replacing furniture, most participants indicated they would only buy new furniture when the existing item was broken or unsuitable, aligning with findings in the fast fashion literature (Fletcher, 2015; Fletcher, 2019) where items are typically replaced due to perceived obsolescence rather than quality degradation. This highlights the cyclical nature of furniture consumption, where fashion-driven factors prompt consumers to replace furniture long before it has reached the end of its useful life cycle.

It is clear from both the survey data and industry insights that fast furniture is a subjective concept shaped by consumer behaviour and the value placed on furniture. While furniture might be inexpensive, mass-produced, and trendy, it is ultimately the consumer who determines its longevity and disposability based on how well they care for and utilize it. This suggests that fast furniture is as much about the consumer's engagement with the product than it is about its manufacture.

This brings us to a deeper reflection: if consumers view fast furniture as an aesthetic choice, influenced by the trends of the moment, can we really claim that such pieces are inherently "fast"? Or is fastness simply a function of the consumer mindset? The global nature of this issue—demonstrated by the fact that major furniture companies like IKEA have international reach—further complicates the question.

Industry Viewpoint

On the other hand, industry representatives view time in a different context. From a production and lifecycle perspective, many professionals assert that domestic furniture does not inherently have a set lifetime, nor is it classified as "fast" by the industry. Instead, they emphasize the importance of consumer behaviour in determining the product's longevity. The industry's perspective is grounded in the idea that how long furniture lasts depends on how well it is cared for, rather than being an issue of design or production speed. This resonates with findings from McDonagh (Delgado, 2022) and Kirchmer (2023), who suggests that fast furniture, in the context of domestic settings, is more about how it fits into a trend-based cycle rather than its functional durability. Industry professionals emphasized that furniture could last a long time if it is maintained well, indicating that the "fastness" of furniture is subjective, and consumer driven.

However, there is an inherent tension between the industry's longer-term view of furniture's lifecycle and the consumer's shorter-term consumption habits. While industry representatives may believe that furniture can last for many years if maintained properly, consumer habits suggest that the temporal lifespan of furniture is largely defined by shifting trends and the desire for novelty, rather than the inherent durability of the product.

Thus, time plays a dual role: on one hand, the consumer-driven need for frequent trend updates compresses the lifespan of the product, leading to rapid turnover; on the other, the furniture itself could potentially have a longer usable life if cared for appropriately.

Conclusion

This study concludes that the concept of fast furniture is not necessarily tied to any intrinsic qualities of the product itself, but rather it is a value-based perception created by the consumer's actions and attitudes. While designers do not intentionally create furniture to be "fast" or disposable, it is ultimately the consumer's choices—driven by consumer culture, fashion trends, and disposability norms—that determine whether furniture is perceived as fast. The term "fast furniture" should, therefore, be understood less as a description of the product's inherent properties and more as a reflection of how quickly it is purchased, consumed, and discarded.

From this study, we can define fast furniture as "quick and cheap to make, purchase, consume, and dispose of." However, as fast furniture is a complex area, an open definition allows for different interpretations. This is just one part of the larger doctoral study and will, therefore, continue to develop as more is understood. This definition doesn't necessarily rule out the possibility that items within this category could become slow over time. For example, an item of furniture may be mass-produced cheaply, but its longevity or durability could extend depending on how the consumer treats it or how it fits into their changing needs or spaces. Fast furniture, therefore, cannot always be easily categorized by clear beginning and end points. There is nothing in the definition that dictates

whether a piece of furniture must have a set lifespan or whether it should inevitably reach an end point of disposability.

The study also highlighted how difficult it is to definitively classify fast furniture within the domestic setting, as consumer behaviours and trends, rather than inherent product characteristics, largely determine the pace of consumption. This stands in contrast to sectors like the commercial furniture market, where health and safety regulations and defined lifespan standards give a clearer picture of time frames and more specific notions of product lifecycle. In this context, there is much to be explored in the concept of fast furniture in commercial spaces, where the pace of consumption might be more regulated, and the lifecycle more predictable.

Looking ahead, this study suggests that more research is needed to fully understand how the concept of fast furniture can be applied to different contexts—whether in domestic or commercial settings—and to explore how cultural, economic, and environmental factors influence consumer attitudes. The concept of fastness is not a one-size-fits-all definition, and consumer values will continue to shape this understanding. While sustainability concerns might encourage consumers to hold on to their furniture for longer, the short lifespan of trends and the need for regular updates to interior spaces suggest that fast furniture will remain a complicated concept—one that deserves further investigation.

Ultimately, while fast furniture is not inherently "bad", the current consumer-driven cycle raises important questions about how we value the durability, longevity, and disposability of the objects that furnish our homes. Further exploration is needed to untangle the complexity of how we define and regulate what is, after all, a highly subjective and culturally constructed concept.

Future Research

Given the complexities outlined in this study, future research could explore:

- The impact of consumer education on the lifespan of fast furniture and how maintenance and care influence its longevity.
- A deeper exploration of the global context, particularly focusing on how consumer values and fashion cycles differ across regions and how this shapes perceptions of fast furniture.
- Investigating commercial furniture as a specific area where time frames and expectations of product longevity are clearer and more regulated, offering a contrast to domestic fast furniture.
- Further qualitative research into the sustainability practices in the industry, focusing on how designers and manufacturers view the sustainability of mass-produced furniture and whether they have a role in mitigating the "fast" model.

By investigating these areas, we can continue to unravel the multifaceted nature of fast furniture and how the concept of "fastness" may evolve in response to changing consumer values and global sustainability goals.

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References

Buberger, J., Kersten, A., Kuder, M., Eckerle, R., Weyh, T., & Thiringer, T. (2022). Total CO2-equivalent life-cycle emissions from commercially available passenger cars. *Renewable and Sustainable Energy Reviews, 159*, 112158. doi:10.1016/j.rser.2022.112158

Centobelli, P., Abbate, S., Nadeem, S. P., & Garza-Reyes, J. A. (2022). Slowing the fast fashion industry: An all-round perspective. *Current Opinion in Green and Sustainable Chemistry, 38*, 100684. doi:10.1016/j.cogsc.2022.100684

Clancy, C. (1996). Furniture chain finds room to gooverseas. *Tampa Bay Business Journal, 16*(19), 1. Retrieved from https://ntu.idm.oclc.org/login?url=https://www.proquest.com/trade-journals/furniture-chain-finds-room-go-overseas/docview/235157806/se-2?accountid=14693 https://llr.primo.exlibrisgroup.com/openurl/44NTU_INST/44NTU_INST:NTU_VU10?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%253Aabidateline&atitle=Furniture+chain+finds+room+to+go+overseas&title=Tampa+Bay+Business+Journal&issn=0896467X&date=1996-05-03&volume=16&issue=19&spage=1&au=Clancy%252C+Carole&isbn=&jtitle=Tampa+Bay+Business+Journal&btitle=&rft_id=info:eric/96-58543&rft_id=info:doi/

Cole, C., Gnanapragasam, A., Cooper, T., & Singh, J. (2019). Assessing barriers to reuse of electrical and electronic equipment, a UK

perspective. *Resources, Conservation & Recycling: X, 1*, 100004. doi:10.1016/j.rcrx.2019.100004

Cooper, T., & Claxton, S. (2022). Garment failure causes and solutions: Slowing the cycles for circular fashion. *Journal of Cleaner Production, 351*, 131394. doi:10.1016/j.jclepro.2022.131394

Cummins, E. (2020, Fast furniture is an environmental fiasco. *New Republic,* Retrieved from https://newrepublic.com/article/156208/fast-furniture-environmental-fiasco

Delgado, C. (2022). *How to avoid fast furniture and minimize waste*. Online: Discover Magazine. Retrieved from https://www.discovermagazine.com/environment/how-to-avoid-fast-furniture-and-minimize-waste

Evans, L., Sawyer, C., Jameson, P., Morgan, A. & Parker, C. (2024). 5 designers share how often you should redecorate your bedroom. Retrieved from https://www.dreams.co.uk/inspire/5-designers-on-redecorating-your-bedroom

Fekete, H., Kuramochi, T., Roelfsema, M., Elzen, M. d., Forsell, N., Höhne, N., . . . Gusti, M. (2021). A review of successful climate change mitigation policies in major emitting economies and the potential of global replication. *Renewable and Sustainable Energy Reviews, 137*, 110602. doi:10.1016/j.rser.2020.110602

Fletcher, K. (2010a). Slow fashion: An invitation for systems change. Fashion Practice, 2(2), 259–265. doi:10.2752/175693810X12774625387594

Fletcher, K., & Tham, M. (2019). Earth logic Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:lnu:diva-92820

Heath, O. (2017). This is how often we decorate our living room, hallway and bedroom. Retrieved from https://www.housebeautiful.com/uk/decorate/news/a2373/decorating-home-habits/

Heti, S., Julavits, H., Shapton, L. (2014). Women in Clothes. United States: Blue Rider Press, a member of Penguin Group (USA).

Kamin, D. (2022, Nov 2). 'Fast furniture' is cheap, stylish and clogging american landfills. *The New York Times* Retrieved from https://search.proquest.com/docview/2730918033

Kirchmer, K. (2023). Assemble-it-yourself: The perceived value of residential furniture. *Transforming issues in housing design* (pp. 171–185) doi:10.1002/9781119857198.ch13 Retrieved from https://doi.org/10.1002/9781119857198.ch13

Knight, D. (1993). Of quick ship, fast furniture, and speedy delivery. *Facilities Design & Management, 12*(1), 26. Retrieved from https://ntu.idm.oclc.org/login?url=https://www.proquest.com/trade-journals/quick-ship-fast-furniture-speedy-delivery/docview/216011664/se-2?accountid=14693 https://llr.primo.exlibrisgroup.com/openurl/44NTU_INST/44NTU_INST:NTU_VU10?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%253Aabiglobal&atitle=Of+quick+ship%252C+fast+furniture%252C+and+speedy+delivery&title=Facilities+Design+%2526+Management&issn=02794438&date=1993-01-01&volume=12&issue=1&spage=26&au=Kight%252C+Douglas&isbn=&jtitle=Facilities+Design+%2526+Management&btitle=&rft_id=info:eric/00671265&rft_id=info:doi/

Maier, A. (2021). *Environmental impacts of fast furniture*. White Paper

Matroka, B. (2008). European fashion influences on America have resulted in not only new top brands and trends, but also new patterns in spending and the shopping experience. Retrieved from https://www.labelnetworks.com/european-fashion-influences-on-america-have-resulted-in-not-only-new-top-brands-and-trends-but-also-new-patterns-in-spending-and-the-shopping-experience/

Miller, D. (2013). The Comfort of Things. Germany: Polity Press.

Miller, D. (2001). Home Possessions: Material Culture Behind Closed Doors. Spain: Berg Publishers.

Mote, W. (2023). How long do interior design trends last? Retrieved from https://homedesigninstitute.com/question/14592/how_long_do_interior_design_trends_last/

Russell, J. D., Huff, K., & Haviarova, E. (2021). Measuring the benefits of cascading-use of wood furniture within the circular economy via value-retention processes (Version 1). University of Limerick. https://hdl.handle.net/10344/10238

Shove, E. (2003). Comfort, Cleanliness and Convenience: The Social Organization of Normality. United Kingdom: Berg Publishers.

Statista. (2024). Furniture, furnishings & household items. Retrieved from https://www.statista.com/markets/415/topic/469/furniture-furnishings-household-items/#overview

Vara, V. (2022). Fast, cheap, and out of control: Inside Shein's sudden rise. Retrieved from https://www.wired.com/story/fast-cheap-out-of-control-inside-rise-of-shein/

Yilmaz, S., Majcen, D., Heidari, M., Mahmoodi, J., Brosch, T., & Patel, M. K. (2019). Analysis

of the impact of energy efficiency labelling and potential changes on electricity demand reduction of white goods using a stock model: The case of Switzerland. *Applied Energy, 239*, 117–132. doi:10.1016/j.apenergy.2019.01.137

Young, M. (2023). What is fast furniture? Retrieved from https://www.wescover.com/blog/2023/02/06/what-is-fast-furniture/

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Not Just Luck: Uncovering the Secret Skills and Expertise of Second-hand Shoppers

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Keywords: Second-hand products; skill acquisition; expertise; consumer; thrift shopping.

Abstract: In this paper, we study second-hand shopping as an expertise that can be practiced. While second-hand markets are rapidly growing, consumers still find it difficult and challenging to purchase second-hand, as the shopping experience is messier, complex and unpredictable. We investigate the process of skill acquisition to understand the skill development of shopping second-hand. Based on 14 interviews, this research illustrates a progression in second-hand shopping behaviors as individuals gain experience. This study categorises second-hand shopping expertise into six levels, highlighting distinct behaviors and strategies. We find: 1) *Novices* are overwhelmed, lack confidence, and rely entirely on others to assess quality and price. 2) *Initiates* show a narrow focus on specific products and apply external expertise but struggle to broaden their scope. 3) *Apprentices* use structured strategies, targeting pre-researched items and avoiding unstructured second-hand environments. 4) *Journeymen* demonstrate proficiency within selected product categories, researching brands and quality indicators to compare items with nuanced criteria. 5) *Experts* possess deep but abstract knowledge of product quality and durability, allowing them to identify high-resale potential items without prior research while maintaining frequent, informed engagement with second-hand markets. 6) *Masters* showcase comprehensive expertise, relying on intuition, ingrained knowledge, and fast-browsing techniques to navigate diverse product categories effortlessly. These findings offer a framework for improving second-hand shopping skills across expertise levels.

Introduction

Second-hand consumption is one way to achieve a circular economy in a '*throwaway society*' (Cooper, 2005). Despite the remarkable expansion of second-hand markets over the past years (Kim & Woo, 2021; Smith, 2023), scholarly inquiries consistently underscore the problems and challenges encountered by consumers in purchasing second-hand (Frahm, Boks, et al., 2024; Gregson & Crewe, 2003)

Scholars have several motivational drivers and barriers influencing both the propensity and frequency of second-hand shopping (Bohlin, 2019; Cervellon et al., 2012; Steward, 2020; Zaman et al., 2019). Past research has also outlined diverse strategies employed in second-hand sales (Frahm et al., 2023; Gregson & Crewe, 2003; Parsons, 2002, 2005).

The challenges inherent in the second-hand shopping experience, such as clutter, disorganization, and information gaps, contrast with conventional retail stores' more structured and uniform environments. While some second-hand establishments actively strive to emulate the ambience of first-cycle retail outlets, others diverge from this model, often influenced by market dynamics and constraints (Frahm, Laursen, et al., 2024; Gregson et al., 2002; Gregson & Crewe, 2003).

Hence, in this paper, we suggest that second-hand shopping requires knowledge, practice and the development of skills. We propose investigating this skill acquisition process. To do so, we use a skill acquisition framework to investigate second-hand shopping as an expertise that can be practiced and developed. Thus, we strive to identify the different skills and strategies used by second-hand consumers at different expertise levels.

Theory

Difficulties in second-hand shopping

Navigating second-hand markets requires work and knowledge, regardless of whether you are selling or purchasing items. Second-hand retailers handle uncertain streams of diverse

products, revalorize them, and support a shopping experience that suits the buyer. This requires knowledge of, e.g., maintenance, cleaning, economic value, advertisement, and store designs to increase the chances of a sale (Frahm et al., 2023; Frahm, Laursen, et al., 2024; Parsons, 2002).

Likewise, from a consumer perspective, numerous obstacles complicate second-hand shopping. This includes irregular or unavailable product information (Guiot & Roux, 2010), and cluttered store designs (Bardhi, 2003; Frahm, Laursen, et al., 2024; Hur, 2020). This may lead to other issues, such as extensive requirements of time and effort put into finding the desired items (Frahm, Boks, et al., 2024; Henseling et al., 2010; Mugge et al., 2017). Besides this are some more structural issues, such as the lack of exchange services or warranty, which may strengthen concerns about product obsolescence and wear and tear (Edbring et al., 2016; Mugge et al., 2018; van den Berge et al., 2021). As such, consumers need to overcome several problems and barriers to shop second-hand.

The current scientific literature provides very limited information about the development of skills and competencies needed to overcome the challenges of second-hand markets. To address this gap, we turn to the literature on expertise, as we propose that shopping second-hand is a skill that can be achieved through experience and practice.

Skill acquisition and expertise

We categorise expertise into different levels to better understand how consumers acquire knowledge on how to purchase second-hand items. Following Chi (2013), we define expertise as a skill set or level of proficiency that beginners can attain through practice.

Expertise is often depicted as a hierarchy of five or six skill levels, ranging from beginners who are new to the field or have minimal exposure to it to masters who understand the standard ways of working within a field. Beginners are new to the field; to cope, they tend to follow strict rules provided by more skilled people in the field, but are incapable or unaware of independent decision-making. Whereas a master at the other end of the spectrum does not see these methods as set in stone but rather as adaptable, context-dependent, and open to questioning or reinvention. In other words, they can “freestyle”. They are regarded as the experts of experts and are skilled enough to teach others at a lower level. They are considered the top authority, especially in a specific area of knowledge (Chi, 2013; Lawson & Dorst, 2009).

Methodology

Theoretical framework: Skill acquisition in second-hand shopping

To investigate the strategies employed at various levels of expertise, we translate the skill levels identified above into the context of second-hand shopping. Consequently, during the interviews, the informants were asked to assess their position on a scale of second-hand shopping expertise. The scale contained several quotes on a line going from ‘beginner’ to ‘master’, e.g., *“I hardly know anything about purchasing products second-hand”* to *“I have a lot of knowledge and experience with purchasing almost any products/product categories second-hand – and I would be able to teach others on how to do it”* (Figure 1). This aimed to investigate whether the informants who assess themselves as belonging to the same level of expertise align in their second-hand shopping strategies.

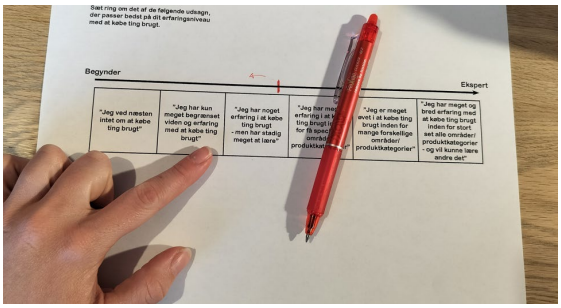


Figure 1. Self-assessment of second-hand shopping skills.

Informant selection: purposive sampling

The study's informants were deliberately chosen to contain a wide range of experiences with and frequency of second-hand shopping. Purposive sampling (Acharya et al., 2013) was used to select the informants, ensuring a diverse pool of informants. Thus, the informants are purposefully selected to contain people with limited experience with second-hand shopping, people who primarily purchase second-hand items and make a living from them, and those in between the two. Secondly, the informants were selected to ensure diversity in gender,

age, and economic background. All interviews were conducted in Denmark, audio-recorded, and lasted an average of 60 minutes.

Data collection: Applied Cognitive Task Analysis (ACTA)

Expertise can be hard to investigate, as experts typically do not excel in expressing their knowledge, as it has become an intuition. Hence, the Applied Cognitive Task Analysis (ACTA) method (Militello & Hutton, 1998) is used to study this. ACTA is a method comprised of three types of interviews (Figure 2), which together extract information about the skills and cognitive demands required for a specific task – in this case, purchasing second-hand products.



Figure 2. Overview of interview types included in the ACTA method.

For this study, the ACTA method is focused on a single second-hand product bought by the informant, which the informant selected for the interview. The product had to comply with two criteria: 1) the informant had to have paid money for the product (hence no heirlooms, exchanged, or otherwise free products were allowed), and 2) the product must be an item typical/well-known to purchase second-hand by the informant. This was to ensure that the informants had a monetary investment when acquiring the product and had some level of expertise in purchasing the specific product type.

Before each interview, the informants had to find such a product and take at least five pictures to showcase the product in detail during the interview. Furthermore, the informants were asked to do a self-assessment of their second-hand shopping skills on a qualitative scale (see Figure 1). Hereafter, the ACTA method was used to gain insight into their second-hand shopping skills.

The ACTA method contains three complementary interview techniques: 1) The *task diagram*, which aims to create a broad overview of the performed task (in this case, purchasing a specific second-hand product) and the required skills. Hence, it highlights complex cognitive demands, which will be further investigated using the following techniques. 2) The *knowledge audit* aims to clarify the aspects of expertise required for the task. Hence, this included a series of questions related to investigating the knowledge depth (e.g., whether they were specialists in purchasing a particular product type) and knowledge width (e.g., whether they generally excelled at purchasing a product category second-hand). Furthermore, it uncovers concrete strategies used for searching, evaluating, and purchasing the specific second-hand product and its category. As a part of this, challenges for inexperienced people are also uncovered. 3) The *simulation interview* is used to probe the cognitive processes of the informant in the specific context and scenario of purchasing the selected second-hand product. This technique allows for additional exploration of surrounding issues, e.g., assessment of the situation and how this impacts the course of action. Furthermore, it uncovers the context-specific issues that can be hard for novices to handle and how the informant's actions have changed with the development of their current level of second-hand purchasing skills (Militello & Hutton, 1998).

Data analysis: Affinity diagramming

Affinity diagramming was used to analyze the data, allowing for a comprehensive examination and categorization of second-hand shopping skills. The 14 interviews were transcribed for the qualitative analysis to identify examples of second-hand shopping strategies. The quotes were coded using affinity diagramming (Hanington & Martin, 2019; Harboe & Huang, 2015) on each expertise level. This method aims to group many items (in this case, quotes related to second-hand shopping skills) based on their natural connections.

Analysis and Discussion

Our analysis reveals a spectrum of purchasing strategies and approaches to second-hand shopping that correspond to six levels of expertise. We name these: Novice, Initiate, Apprentice, Journeyman, Expert, and Master (Figure 3), adapted from (Chi, 2013). Each level is characterized by distinct behaviours and attitudes toward second-hand shopping, indicating how increasing expertise transforms the consumer's strategy, confidence, and market awareness.



Figure 3. Six levels of second-hand shopping expertise.

Novices: Participants categorized as Novices demonstrate significant confusion and lack a coherent purchasing strategy in second-hand environments. Even when accompanied by a knowledgeable shopper, Novices are overwhelmed by the selection and organization of second-hand items and do not demonstrate strategic decision-making in their purchases (Figure 4).

Novices entering second-hand markets feel like the 'good' products are hidden in plain sight. They rely heavily on guidance from others and completely lack confidence in navigating second-hand markets independently. They cannot judge whether a product has the right price or quality to classify it as a bargain.

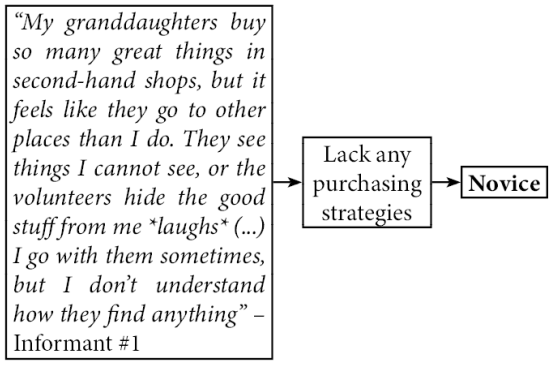


Figure 4. Example of data coding for Novices.

Initiates: Initiates show early signs of strategic decision-making, primarily by adapting expertise from other areas of life. For instance, an Initiate who is a carpenter may focus exclusively on wooden items, such as wooden toys, but does not broaden this interest to other types of wooden products or toys of other materials (Figure 5). Despite some focus, Initiates continue to rely on external guidance from others in second-hand markets and often experience confusion or difficulty distinguishing value. Their approach remains highly selective and narrow, focusing only on specific types of items rather than expanding their expertise to a wider range of products.

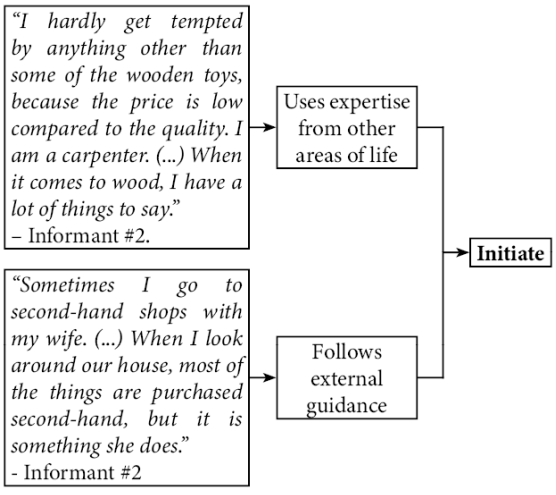


Figure 5. Example of data coding for Initiates.

Apprentices: Apprentices exhibit a more structured approach to second-hand shopping. They employ a specific search strategy, usually beginning by identifying desired products elsewhere before searching for those exact items second-hand to save money, e.g., on a sofa. Other examples found are parents of small children, who purchase children's clothing

second-hand, often from a few very familiar brands, while rejecting all other second-hand product categories.

For Apprentices, the preferred second-hand outlets are limited to physical shops with very few product categories and online shops that allow for filtration like regular web shops, supporting easy comparison of price and quality of identical products. This process emphasizes precision and control, as Apprentices typically look for exact copies of specific products they have already evaluated elsewhere (Figure 6). Their second-hand purchases are limited to known products rather than exploring new categories or brands, and they seek to avoid the time-consuming shopping experiences of unspecific second-hand markets (e.g., charity shops with multiple and shifting product categories). This strategy represents a shift towards more independent decision-making and cost-efficiency, though the approach remains narrow in focus.

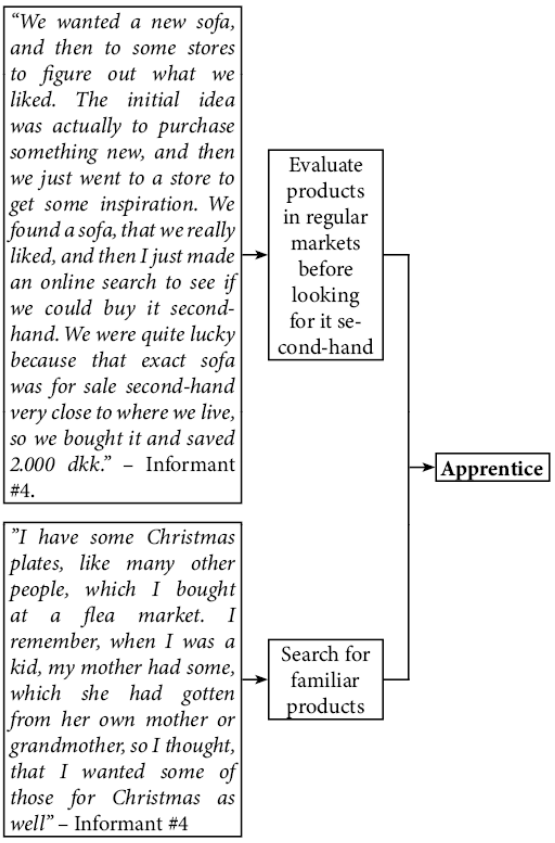


Figure 6. Example of data coding for Apprentices.

Journeyman: Journeymen exhibit significant expertise within a few product categories, e.g., related to personal interests like home décor, interior design, or hobbies like mountain biking. When seeking a new category of items, they thoroughly research brands, designs, and quality indicators (often online) to understand the value of second-hand options (Figure 7).

While Apprentices would start off by identifying a specific product in first-hand markets and afterwards look for it second-hand, the Journeymen have a broader perspective which begins directly in the second-hand market; their initial research process includes learning about brand markers, design features, and price indicators as well as exploring and comparing the available second-hand options. Within their narrow field, a Journeyman would have a qualified guess on where to go and which quality indicators to look for, to find a bargain. While an Apprentice would compare identical products, Journeymen begin to develop a more nuanced perspective, allowing them to compare products with similar yet different features.

Journeymen shop both online and in physical second-hand markets but typically visit only when searching for a specific item, suggesting a focused yet cautious approach. Additionally, they demonstrate a willingness to pay higher prices for quality but continue to weigh price considerations carefully.

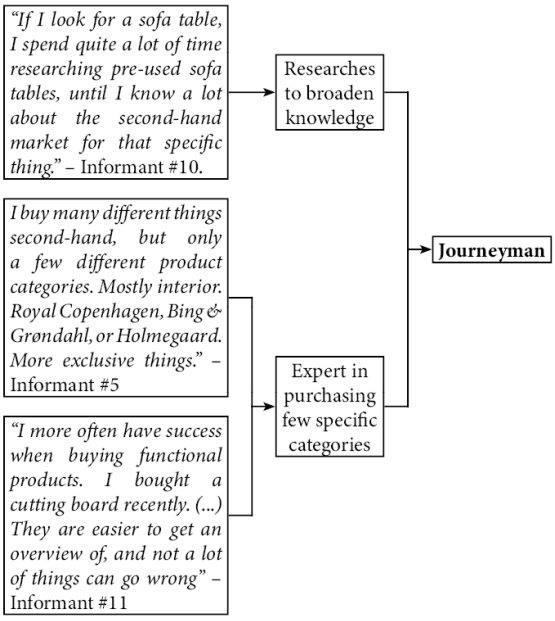


Figure 7. Example of data coding for Journeymen.

Expert: Experts show an advanced understanding of quality indicators, selecting items with high resale potential and may consider second-hand purchases as temporary acquisitions. In other words, they consider the timeline and afterlife of their second-hand purchases, while the lower expertise levels focus on how the product solves a problem here and now. This perspective reflects a deep familiarity with product categories and materials rather than, e.g., pure brand preferences.

Their knowledge and expertise in recognising materials, manufacturing, or particularly well-made products allow them to purchase a broader range of second-hand products without initial research, unlike the Journeymen, who rely on this. Consequently, the Experts have only a few product categories, which they will not be capable or willing to purchase second-hand (Figure 8). They are willing to spend more time finding bargains and make frequent visits to both physical and online second-hand shops, maintaining a consistent engagement with the second-hand market.

While Experts are selective, their criteria are highly informed. They focus on durable, high-quality materials and products that fit well into the second-hand cycle.

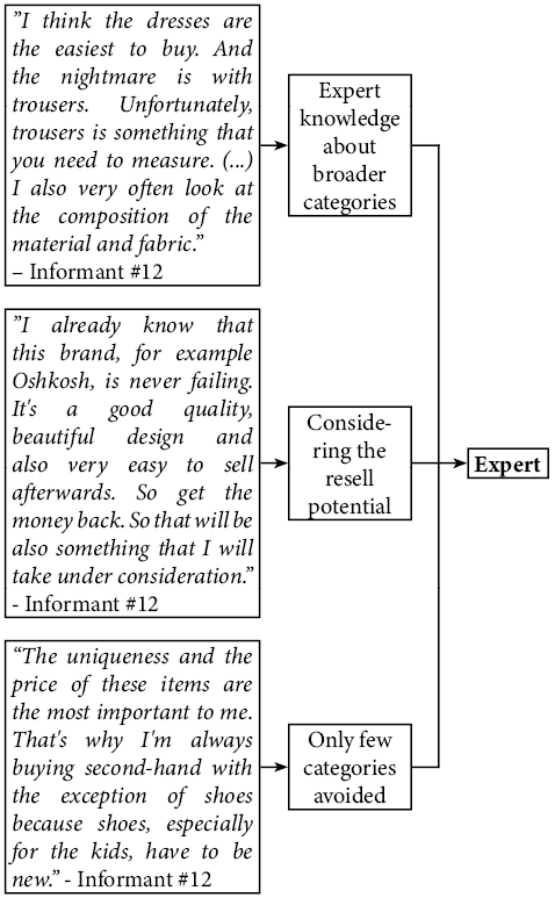


Figure 8. Example of data coding for Experts.

Master: Masters display the highest level of second-hand shopping expertise, having developed a general yet comprehensive strategy that includes browsing every item within a shop and relying on extensive knowledge acquired over time. Their expertise spans multiple product categories, which is also informed by their professional backgrounds. Masters know of reliable second-hand shops, visit them frequently, and take any opportunity to explore new markets. Thus, their expertise includes knowledge of what constitutes 'good' second-hand products, as well as a mental map of trustworthy and valuable second-hand outlets.

Unlike less experienced levels, they do not rely on prior research before shopping; instead, they operate on ingrained knowledge and intuition and can tell the 'good' markets from the 'bad' ones. Their search strategies become more general, as they have become fast browsers willing to spend time turning over every item while recognizing product quality just by briefly touching a product. They have a

broader understanding of the second-hand market and mention areas (e.g., a part of a town) as 'second-hand hotspots' rather than thinking about the individual stores (Figure 9). They perceive second-hand markets as their primary shopping market and develop their own mental map of which stores/markets to go to for specific items, even though the stores sell a broader range of products.

Like Experts, Masters also actively participate in the second-hand market as sellers and donors, reinforcing their understanding of item value across market roles. During the interviews, Masters also began to advise the interviewer on navigating second-hand markets.

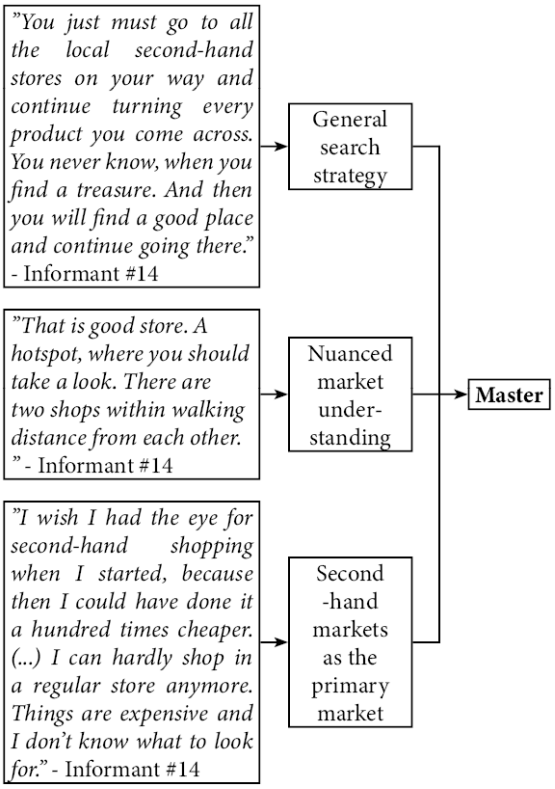


Figure 9. Example of data coding for Masters.

Conclusions

This study contributes to the literature on circular consumer behaviour by showing how expertise in a second-hand market develops.

Our research demonstrates the progression of six levels of second-hand shopping expertise, going from uncertainty and reliance on external guidance to showcasing an advanced understanding and approach to second-hand shopping.

Novices experience significant confusion, overwhelmed by the variety and organization of second-hand markets. They lack confidence and decision-making skills, are unable to assess price or quality, and rely entirely on others for guidance.

Initiates show emerging focus by applying expertise from other areas of their lives (e.g., a carpenter prioritizing wooden toys) but struggle to expand beyond narrow interests or identify value independently.

Apprentices develop targeted strategies, typically searching for specific products already evaluated elsewhere (e.g., a sofa or children's clothing from known brands). They prefer structured environments like filtered online shops and avoid broad, time-intensive exploration of diverse second-hand markets.

Journeymen demonstrate proficiency within select categories tied to personal interests (e.g., home décor or hobbies). They research brands and quality indicators beforehand, allowing them to evaluate a wider range of similar products directly in online and physical second-hand markets while maintaining a cautious, value-conscious approach.

Experts are deeply familiar with quality indicators and identify durable, high-resale potential items across diverse product categories. Unlike Journeymen, they rely on ingrained knowledge rather than prior research, embracing frequent engagement with second-hand markets and valuing the product lifecycle.

Finally, **Masters** exhibits a comprehensive, intuitive approach, browsing entire shops efficiently and relying on extensive knowledge spanning multiple categories. They map second-hand hotspots, navigate markets effortlessly, and participate actively as buyers, sellers, and donors, making second-hand shopping their primary marketplace while advising others on navigating the system.

Hence, our study shows consumers developing their ability to navigate second-hand markets, going from complete confusion to seeking second-hand markets that mimic regular retail, and eventually being able to filter cluttered

second-hand shops containing multiple and shifting product categories. We furthermore see an advancement in the understanding of product quality going from only purchasing one single product category in a selected material (e.g., wooden toys) to primitive comparisons of price and quality of identical products, to comparison of similar products, to comparisons of more abstract product quality indicators such as materials and manufacturing.

This contributes valuable knowledge for second-hand consumers, as they can adopt strategies from higher expertise levels if they aim to improve their shopping for pre-owned items. Moreover, to foster a more circular economy, we must lower the barriers to entry in second-hand markets. By recognising what successful second-hand shoppers do and what challenges less experienced shoppers face, second-hand markets can adapt more readily to various skill levels and reduce these entry barriers. We suggest further studies of the challenges that second-hand consumers at different expertise levels face, and whether more expertise levels exist.

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References

Acharya, A. S., Prakash, A., Saxena, P., & Nigam, A. (2013). Sampling: Why and how of it? *Indian Journal of Medical Specialities*, *4*(2). https://doi.org/10.7713/ijms.2013.0032

Bardhi, F. (2003). Thrill of the hunt: Thrift shopping for pleasure. *Advances in Consumer Research*, *30*(Journal Article), 375–376.

Bohlin, A. (2019). 'It will Keep Circulating': Loving and Letting Go of Things in Swedish Second-hand Markets. *Worldwide Waste*, *2*(1), 3. https://doi.org/10.5334/wwwj.17

Cervellon, M., Carey, L., & Harms, T. (2012). Something old, something used: Determinants of women's purchase of vintage fashion vs second-hand fashion. *International Journal of Retail & Distribution Management*, *40*(12), 956–974. https://doi.org/10.1108/09590551211274946

Chi, M. T. H. (2013). Two Approaches to the Study of Experts' Charactaristics. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge Handbook of Expertise and Expert Performance* (pp. 21–30). Cambridge University Press.

Cooper, T. (2005). Slower consumption reflections on product life spans and the "throwaway society". *Journal of Industrial Ecology*, *9*(1-2), Article 1-2. https://doi.org/10.1162/1088198054084671

Edbring, E. G., Lehner, M., & Mont, O. (2016). Exploring consumer attitudes to alternative models of consumption: Motivations and barriers. *Journal of Cleaner Production*, *123*(Journal Article), Article Journal Article. https://doi.org/10.1016/j.jclepro.2015.10.107

Frahm, L. B., Boks, C., & Laursen, L. N. (2024). It's Intertwined! Barriers and Motivations for Second-hand Product Consumption. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-024-00441-y

Frahm, L. B., Laursen, L. N., & Christensen, B. T. (2024). *Creating a mess! Design strategies for managing visual complexity in second-hand shops*. Design Research Society, Boston. https://doi.org/10.21606/drs.2024.773

Frahm, L. B., Laursen, L. N., & Tollestrup, C. (2023). Everyone does it: Product-related Resell Strategies of Professional Second-hand Retailers. *PROCEEDINGS 5th PLATE Conference : The 5th Product Lifetimes and the Environment Conference in Aalto University, Espoo, Finland, 31 May – 2 June, 2023*, 303–309. https://vbn.aau.dk/en/publications/d0ca1bf9-3bb2-4815-83b8-9e205a0670b7

Gregson, N., & Crewe, L. (2003). Second-hand cultures. In *Materializing culture*. Berg. https://doi.org/10.2752/9781847888853

Gregson, N., Crewe, L., & Brooks, K. (2002). Shopping, space, and practice. *Environment and Planning D: Society and Space*, *20*(5), Article 5. https://doi.org/10.1068/d270t

Guiot, D., & Roux, D. (2010). A second-hand shoppers' motivation scale: Antecedents, consequences, and implications for retailers. *Journal of Retailing*, *86*(4), Article 4. https://doi.org/10.1016/j.jretai.2010.08.002

Hanington, B., & Martin, B. (2019). *Universal methods of design: 125 ways to research complex problems, develop innovative ideas, and design effective solutions* (Expanded and revised edition.). Rockport Publishers. https://www.vlebooks.com/vleweb/product/openreader?id=none&isbn=9781631597497

Harboe, G., & Huang, E. M. (2015). Real-World Affinity Diagramming Practices: Bridging the Paper-Digital Gap. *Proceedings of the 33rd Annual ACM Conference on Human*

Factors in Computing Systems, 95–104. https://doi.org/10.1145/2702123.2702561

Henseling, C., Blättel-Mink, B., Clausen, J., & Erdmann, L. (2010). Contribution of Online Trading of Used Goods to Resource Efficiency: An Empirical Study of eBay Users. *Sustainability*, *2*(6), Article 6. https://doi.org/10.3390/su2061810

Hur, E. (2020). Rebirth fashion: Secondhand clothing consumption values and perceived risks. *Journal of Cleaner Production*, *273*(Journal Article), Article Journal Article. https://doi.org/10.1016/j.jclepro.2020.122951

Kim, S., & Woo, H. (2021). Big data analysis of trends in the second-hand apparel market: A comparison between 2014 and 2019. *Research Journal of Textile and Apparel*, *26*(2), Article 2. https://doi.org/10.1108/RJTA-12-2020-0139

Lawson, B., & Dorst, K. (2009). *Design Expertise*. Routledge.

Militello, L. G., & Hutton, R. J. B. (1998). Applied cognitive task analysis (ACTA): A practitioner's toolkit for understanding cognitive task demands. *Ergonomics*, *41*(11), 1618–1641. https://doi.org/10.1080/001401398186108

Mugge, R., de Jong, W., Person, O., & Hultink, E. J. (2018). 'If It Ain't Broke, Don't Explain It': The Influence of Visual and Verbal Information about Prior Use on Consumers' Evaluations of Refurbished Electronics. *The Design Journal*, *21*(4), Article 4. https://doi.org/10.1080/14606925.2018.1472856

Mugge, R., Safari, I., & Balkenende, R. (2017). Is there a market for refurbished toothbrushes? An exploratory study on consumers' acceptance of refurbishment for different product categories. *PLATE: Product Lifetimes And The Environment*, *Journal Article*, Article Journal Article.

Parsons, E. (2002). *People or Profits? The challenges of managing in charity retail*. Institute for Retail Studies, University of Stirling. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=fce67ce27c9f45d78600a5f28301e5224fbbc123

Parsons, E. (2005). Dealing in secondhand goods: Creating meaning and value. *ACR European Advances*, Article Journal Article. https://www.proquest.com/conference-papers-proceedings/dealing-secondhand-goods-creating-meaning-value/docview/3168056160/se-2?accountid=8144

Smith, P. (2023). Secondhand apparel market worldwide 2021-2027. In *Statista* (Vol. 2024, Issue Feb 9,). https://www.statista.com/statistics/826162/apparel-resale-market-value-worldwide/

Steward, S. (2020). What does that shirt mean to you? Thrift-store consumption as cultural capital. *Journal of Consumer Culture*, *20*(4), Article 4. https://doi.org/10.1177/1469540517745707

van den Berge, R., Magnier, L., & Mugge, R. (2021). *A poorly educated guess: Consumers' lifetime estimations, attitudes towards repairability, and a product lifetime label* (No. Journal Article). Article Journal Article. PLATE - Product Lifetime And The Environment. https://doi.org/10.31880/10344/10181

Zaman, M., Park, H., Kim, Y.-K., & Park, S.-H. (2019). Consumer orientations of second-hand clothing shoppers. *Journal of Global Fashion Marketing*, *10*(2), Article 2. https://doi.org/10.1080/20932685.2019.1576060

Research paper
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Guilty (or invisible) materiality in everyday object relations?

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Keywords: Material relations; Materiality; Everyday life studies; Stuff; Sustainable consumption.

Abstract: In today's context, demanding radical change even on the scale of our daily behaviour, this article builds on research into guilty materiality to better understand obstacles to changing our everyday material relations. "Guilty materiality" refers to why materiality and material relations may be stigmatised, invisibilised, ignored and avoided.
Daily material relations self-documented by 82 university-level design students provide the tangible basis for exploring and highlighting obstacles and ambiguities in daily-life artefact relations and their materiality. Our study focuses only on what is touched by the cohort, constituting a limited number of artefact encounters. The main analysed material is individual maps produced by students visualising their daily consumption habits.
While the long-term aim of this research is to help identifying leverage points and action areas related to current practices and also mindsets, this paper also presents and explores the pertinence of the proposed methodology in this context. This research discusses, refines and adds to an existing list of triggers/influencing mechanisms that may act as obstacles to more environmentally-relevant everyday material relations.

Introduction

"*We live in a world overflowing with our own productions, a world in which objects beseige us, suffocate us*…" wrote Claudia Dona in 1988. This sentiment is reinterated by Daniel Miller (Miller 2008): "*We live today in a world of ever more stuff - what seems a deluge of goods and shopping*". Nearly twenty years before Dona, Jean Baudrillard was already lamenting the "*madness, this frenzied world of trinkets, of gadgets…their number, their redundance, their superficiality*…" There is little doubt that we have a problem with the quantity of objects, products, trinkets, gadgets we encounter in our everyday lives that Miller terms "stuff". And as these quotes illustrate, our awareness of this problem is not new. If we are aware of the issue, why has everyday behaviour in relation to stuff remained relatively stable?
Miller (2010) notes that "*Stuff is ubiquitous and problematic . But whatever our environmental fears or concerns over materialism, we will not be helped by either a theory of stuff, or an attitude to stuff, that simply tries to oppose ourselves to it*…" Nevertheless, previous research (Green & Treilhou, 2021) suggests that there are indeed a number of factors that may influence our daily relationships with stuff, and these factors may act as obstacles to changing behaviour. Termed "guilty materiality", the themes explored form a basis for looking at why materiality and material relations may be stigmatised, invisibilised, ignored and avoided.
In the current context, we need to encourage radical change, even on the scale of our daily behaviour. This article therefore aims to build on this research into "guilty materiality" to better understand the obstacles to changing our everyday material relations.
This study looks at both *1)* relations to things *2)* and relations with the materiality of things. Materiality is understood in the context of this research as being constitutive of, and underlying, the artefact, giving structure and confering its qualities (Burlot 2024). The notion of "invisibility" is therefore explored both in relation to everyday objects as entities, and in relation to their materiality.
Detailed daily material relations self-documented by a cohort of university-level design students provide the tangible basis for exploring and highlighting the obstacles and ambiguities in behaviour related to daily-life artefacts and their materiality.

Methodology

Any exploration of everyday material relations can potentially include a very large number of artefacts. In a widely commented study on 32

Californian households from 2001 - 2005, the average family owned 300,000 things, and even in the smallest household of the study 2260 objects were visible to researchers (UCLA: *Life at Home*).
The nature of our study reduces the number of artefact involved. Rather than North American households, our study is based on individual material experiences of French students, the majority of whom were living in student lodgings at the time. Equally, using a protocol inspired by the work of Paola Zucotti, and her "Everything We Touch project, our study focuses only to what is touched by the cohort, therefore further limiting the number of artefact encounters.

school	year	study year	class total	study cohort
Nîmes University	2017	5yr	11	9
Rubika	2017	2nd	15	11
ENSAAMA	2021	4th	23	21
Nîmes University	2023	5th	11	8
Rubika	2024	2nd	27	10
ENSAAMA	2024	3rd/4th	9	5
Nîmes University	2024	5th	10	9
Rubika	2025	2nd	20	9
TOTAL			126	82

Table 1. Schools, year, level and number of students involved in the study

This research is based on self reporting and reflection by eight different groups of students in higher education design courses in three different French teaching establishments (the university of Nîmes, the ENSAAMA (Higher National School for Applied Arts), Paris and the Rubika Design School in Valenciennes. The students are from years 2 to 5. The period covered by the eight different individual studies is from 2017 to 2025. An overview of the cohort is given in Table 1. As students in product, UX and social design, the cohort can be considered as already sensitised to environmental issues and also potentially more sensitive to products and materials. Whilst the bias related to the nature of the cohort needs to be taken into account, we consider that it does not limit the value of the study.

The exercise carried out by all eight student groups is a four step process. This involved noting everything touched during one day, reflecting on this list, categorising/sorting, and visualising material interactions as an annotated/reorganised map. The students were introduced to the exercise immediately before carrying out their touch/list activity.

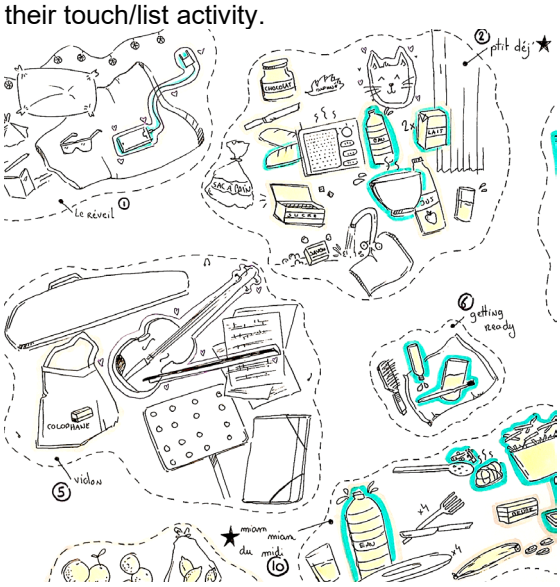


Figure 1. Extract from student map (N.Bodart, 2024)

The exercise was not a stand-alone activity, and was part of a number of different teaching modules, due to the relevance of this type of autoethnography exercise (Schouwenberg & Kaethler, 2021). The nature of the teaching modules related to this study are noted in Table 2.
The main analysed material for this study is individual maps produced by students visualising their daily consumption habits. Figure 1 shows an extract from a student map with a sorting system by zones and colour highlighting for other forms of categorisation. The maps are all illustrated documents containing both images (photos or sketches) of the objects touched and text notes.
A second source of information is the comments by students on the exercise and additional notes and comments added to their maps.
Despite the homogenous nature of the cohort, each of the 8 individual cohorts generated lists with important divergence in the number of objects noted. We can thus compare potentially exhaustive inventories and those which may

school/year	total exercise duration	sort/ map time	included in what teaching module?
Nîmes,2017	24hrs	4hrs	User research tools
Rubika,2017	1 week	2 days	Basic design
ENSAAMA,'21	2 weeks	1 week	Creative speed projet on Material relations
Nîmes, 2023	24hrs	4hrs	Systems approaches for Transitions
Rubika,2024	2024	2nd	Basic design
ENSAAMA,'24	2 weeks	1 week	DfS & Design for transitions
Nîmes,2024	24hrs	4hrs	Systems approaches for Transitions
Rubika,2025	1 week	2 days	Basic design

Table 2. Duration of exercises and related teaching modules

be incomplete within each student group, particularly in relation to things that may
be invisibilised. Differences observable across the whole cohort are considered to be less rigourous as the exercises were carried out by students in different schools, at different levels of study, and with probable (slight) variations in the task descriptions.
It is important to highlight a certain number of ethical issues and also limitations and biases in the study. From an ethical standpoint, it was important for the students to be aware of the authors' research, and that these exercises could be part of their research. The ongoing research carried out by the authors was discussed with all student groups before, and during the listing and mapping exercise. Previous research and findings were also shared and discussed with student groups after this exercise phase. As the materials were discussed and viewed in a classroom setting, students were asked to make exhaustive lists and maps, but also were encouraged to exclude any elements that they considered too personal or intimate. The maps were analysed only by the co-authors in order to respect the approval of students for their use in this research. Any maps/extracts used for communication purposes in relation to this research are shown with renewed approval from the students concerned.
One of the limitations of this study relates to reproductability. This study of illustrated maps is made possible by the specific nature of the student cohort, able to produce readable visual artefacts ("maps") from lists of what they have touched. It is important to note that the exercise is not necessarily easy, even for this cohort. Nevertheless the difficulties are more related to the length of time needed to sort, iterate and illustrate than doing the illustration itself. Based on self reporting, there may be issues of subjective interpretation of the instructions, and students clearly may chose to not list/show certain objects touched for moral, cultural, religious or even legal reasons. We can confirm that drawn (rather than photogrpahic) representations allow the students to include more objects in their maps, while respecting their intimacy. In discussions, students appeared to be much more comfortable with this type of map, which may be more relevant for future studies.

Analysis

Invisibility of things

The first level of analysis of the student maps focuses on simply what things are present and what are absent in these illustrations. In the 73 maps analysed from the first seven student groups (see Table 1) the most obvious omissions seem to concern food, single use objects and particularly packaging, different forms of paper and individual items of clothing. Chargers, cables were also missed from a number of lists and subsequent illustrations.
During the exercise with the most recent cohort the mapping process was followed by a revaluation of what had been missed. The missing items were added to the illustrations in text or sketches. This confirmed the objects mentioned above but also enables us to generate a number of object families:

- things on us/wearing (clothes, jewellery, sometimes the mobile phone)
- parts of the touched environment (cushions, chairs, blanket/throw - things not touched by our hands)
- things as a means to do something (chargers, spatula/stirring spoons, scissors…)
- single use/disposable things (yoghurt pots, wipes, cotton pads, paper, toilet paper, ready meal food containers and also actual fruit, vegetables…)

The activities by the student cohorts related to cooking and eating contain perhaps the highest number of "blind spots". The social practice theory framework might be useful in this context (Kuijer, 2014, Rinkinen, Jalas & Shove, 2015). Nevertheless our study focusing on the "stuff" mediating these practices highlights that many of the material elements involved go unnoticed. Interestingly there is notable irregularity in what

is missed, with often one object identifying an action that was carried out; diary, notebook, list but no pen, or cooking pan but no spoon, spatula or food cooked.
The notion of mediation (Rosenberger & Verbeek, 2015), after Ihde) may explain some omissions when the object as a means to do something is part of an embodied relation. The famous example of Heidegger of the hammer "ready-to-hand" illustrates how a tool becomes invisible in the action of use. (In the case of our study pens, chargers, spatulas, mixing/stirring spoons.)
The invisibility of single use and short life objects, and also of food could be linked to the notion of transitory things and consumerisation (Fromm, 1976). It is perhaps worth noting that short life objects have their origin in the theories (almost exactly one hundred years ago) of "Consumer Engineering" of Earnest Elmo Calkins (1932); suggesting "Consumer engineering must see to it that we use up the kind of goods we now merely use", and the notion of positive "Creative Waste" of Christine Frederik in "Selling Mrs Consumer" 1929.
The study by Ripoll (2023) looking at human comportmental obstacles to behaviour change highlights the human tendency to place emphasis on the short term, and short term gratification which may also help explain the absence of single/short-life objects.
Our study does not enable us to determine if this invisible short term consumption is or has become purely automatic, or as Stuart Walker suggests (Walker, 2017) capable of generating feelings of dissatisfaction and therefore perhaps avoidance. Certain student texts/comments support the idea of displeasure in relation to waste, and to non-durable, short-life objects.
Finally it may be worth noting that beyond the "consumption" explanation, the absence of food could also be linked to the absence of clothing and things on our bodies. This might raise questions around the status of our bodies in everyday interactions.

Presence of materiality

Students were encouraged to consider different ways they might group, categorise and make sense of their lists of objects. These categorisations give insights into how students reflected on the list they generated, and how they wanted to organise and make sense of their lists. The initial categorisations by the majority of students are by activities, or "moments" of the day, but most maps included other forms of grouping/sense making. Other recurring classifications concern attachment, need, what is indispensable, what I like/love.
Surprisingly despite the process encouraging a reflection on the things touched, and the fact that students (re)observed these objects, only a minority suggest consideration of the materiality of things. Only 1/3 of categorisations make any clear reference to materiality (22 out of 73 analysed).
Out of 73 student classifications, less than five use actual materials as a way to group objects. What could be termed the "stuff" they are made of (Markosian, 2015) is in all but three cases the visible external materiality. Only three students comment on contents, material inside or complexity, or of objects as forms of "container".
Other references to materiality, present in equally small numbers, relate to sensorial material qualities (stickiness, softness, smells, sounds made by), to weight, to volume and to the resistance/fragility of materials.
Interestingly for some students a classification or group based on material qualities occurs only when the objects do not fit into a clear activity or moment category, therefore things defying habitual classification.

Ambiguous materiality

Despite the relatively small number of references to materiality in our study, a number of observations can be made which highlight a form of ambiguity in relation to materials and materiality.
In an article on "Clutter" (Baker, 1995) this type of excess stuff in our homes is described as matter out of control, and therefore reflecting our lack of control. A small number of student comments and categorisations support this notion of mattter "out of control"; things that are "always falling", things that are "not cooperative", things that "I lose all the time".
A related family is of objects that are, or might be, misused or could be misappropriated; a number of students have a category of things that "I'm always fiddling with". Just two students comment on sound-related fiddling, no
ticing or playing with the sounds objects can make.
Related to the alternative use theme, object materiality is evaluated by a small number of (only female) students for their potential for use to "defend yourself in an attack situation". Here the weight, angular forms, grip etc and therefore materiality seem to be considered.
The notion of durability highlights another aspect of the ambiguity of materiality. While some

students comment on not liking single use and short life objects, others classifying keepable and disposable objects show surprising choices - a computer is disposable, but the fabric case is not. Sneakers are considered disposable.
While notions of pleasure/displeasure are present in student categorisations these are largely in relation to pleasurable activities, with only a very few refering to sensorial pleasure (soothing, smell, comforting). There is little evidence of either satisfying or dissatisfying material qualities.

Discussion

Verbeek & Kockelkoren (1998) argue that designers seem to be Platonists, failing to see things as *material entities*. The initial analysis of student maps reported in this article seems to suggest that this may still be the case. We may question if our cohort is infact less concerned by materiality than the wider population, but this is beyond the scope of the current research. It nevertheless is of concern that future designers may not be sufficiently conscious of material entities.
Analysis of the student maps and comments gives support to a number of the themes previously identified which may contribute to negative perceptions leading to invisibility or avoidance of material objects and their materiality. See Table 3.
A number of these themes are also partially confirmed by the current research, but are not sufficiently characterised, and also necessitate longer presentation than is possible here.
The themes confirmed and those partially confirmed do enable us to identify larger families which may be relevant for future research, namely relations to the family of transitory, unidentified, soon to be waste “stuff“. A second family that deserves attention, especially for designers, concerns material confusion, knowledge, durability and toxicity and therefore perhaps the need for normalising materiality relations.

Implications and further research

The invisibility of material things in our everyday interactions certainly appears to be confirmed here.

too much	things overflowing, flooding, becoming unmanageable	**?**
stuff	unidentified material, unseen	YES
waste	things without value	YES
short lived	seen as transitory	YES
inept materials	unadapted to life-cycles, wrong materials/use	?
material confusion	and lack of material knowledge	YES
toxic materials	and lack of information and reaction	?
toxic behaviour	and behaviour dictated by things	?
anti-social	object relations detract from human relations	
morally wrong	we should aim for “being” rather than “having”	?
entrapping	objects can entangle or trap us	?
restrict movement	treadmill effects, restricting personal mobility	
materialism	desiring things for themselves	?
spying	objects can spy on us, and collect information	
hoarding	pathological behaviour	
clutter	matter out of control, reflecting our lack of control	YES

Table 3. themes which may negatively influence material object relations (based on Green, Treilhou, 2020). (Shading and YES/? indicates those confirmed/partially confirmed in this paper)

Whether this can be linked to the even more evident invisibility of materiality, and notions of avoidance and/or guilt is not yet proved. We can nevertheless identify a lack of positive associations/pleasure in relation to individual things or their materiality. Equally certain reasons for avoidance of things and materiality - termed “guilty materiality“ in previous research appear to be supported.
While the long-term aim of this research is to provide a step towards identifying leverage points and action areas related to current practices and also mindsets, this paper also presents and explores whether the proposed methodology may be valuable in this context. The everything we touch protocol followed by

sorting and mapping is a fastidious and time consuming exercise, but one which has produced rich analysable supports. It is also, in the case of this specific cohort, an exercise that is generally very positively received.
The results show a high level of heterogeneity, even within a seemingly homogenous cohort, The research here takes advantage of the heterogeneity of reactions and interpretations to the exercise as an analysable material, through a process of comparison. This heterogeneity also nevertheless highlights the need to remain cautious about conclusions or generalisations on material behaviour and indicates the need to consider domestic material relations as potentially ideosyncratic and diverse.
Further research may need to go into more depth, and perhaps the use of a more rigorous version of this protocol with motivated self-reporting participants, who might potentially be recruited through exercises such as those used here.

Conclusion

The basis of this research is the relatively simple protocol of "everything I touched" accompanied by the classification of the objects concerned by the people involved. This process nevertheless provides information and raises questions that go beyond the simple symbolic, emotional or ideological attachment to everyday objects.
This research discusses, refines and adds to an existing list of mechanisms that may act as obstacles to more environmentally-relevant everyday material relations. Our findings suggests a high level of invisibility of material things in everyday interactions. The materiality of these objects (understood as the constitutive/underlying materials and structure and therefore physical qualities) appears to be even less perceived in everyday practices. Together these observations highlight ongoing everyday activity and perceptions that appear difficult to reconcile with the need to become more aware of our material-related behaviour. These findings need to validated through further and more in-depth research.

References

Baker, S. (1995) To go about noisily: clutter; *writing and design, in Emigre* No35, Summer

Baudrillard, J. (1970) *La Société de Consommation*, Editions Denoel, Folio Essais, Paris

Binswanger, M. (2006) Why does income growth fail to make us happier? Searching for the treadmills behind the paradox of happiness. *The Journal of Socio-Economics 35*, pp366 - 381 DOI: 10.1016/j.socec.2005.11.040

Burlot, D, (2024) Materials, materialities, making. Histoire de l'art, no. 93: Materials, materialities, making. In: ArtHist.net, Apr 28, 2023 (accessed Dec 8, 2024), <https://arthist.net/archive/39180>.

Dona, C. (1988) Invisible Design, in *Design After Modernism*, ed; Thackara, p152 - 159

Fromm, E (1976) *To Have or To Be*, 2013, Bloomsbury Academic, London

Green, C. & Treilhou, S. (2020) Guilty Materiality. why we play down material relations. In *DC (S) Design Culture(s), Cumulus Roma, June 16 - 19, Roma*, 2020 (2021)

Heidegger, M. *Being and Time*, (1927) trad. Macquarrie & Robinson, Blackwell, Oxford, 1962 (Sein und Zeit)

Hodder, I. (2014) The Entanglements of Humans and Things: A Long-Term View, *New Literary History*, Volume 45, Number 1, Winter 2014, pp. 19-36 DOI: 10.1353/nlh.2014.0005

Kuijer, L. (2014) Implications of Social Practice Theory for Sustainable Design, doctoral thesis, TU Delft, NL.

Lee J. (2014) The True Benefits of Designing Design Methods. *Artifact, Volume III, Issue 2 DOI: 10.14434/artifact.v3i2.3951*

Life at Home in the 21st Century, UCLA research, 2001 - 2005, commented on in newsroom.ucla.edu/magazine/center-everyday-lives-families-suburban-america (accessed Dec 8, 2024)

Markosian, N. (2015) The Right Stuff, *Australasian Journal of Philosophy* 93 (4):665-687 (2015) https://doi.org/10.1080/00048402.2014.999001

Miller, D. (2008) *The Comfort of Things*, Polity Press, Cambridge

Miller, D. (2010) *Stuff*, Polity Press, Cambridge

Rinkinen, J., Jalas, M. & Shove, E. (2015) Object Relations in Accounts of Everyday Life, in *Sociology 1-16 - Special Issue on Sociologies of Everyday Life*

Ripoll, T. (2023) *Pourquoi je prends ma douche trois minutes de trop?*, Editions Sciences Humaines, Auxerre, France)

Rosenberger, R., & Verbeek, P. P. C. C. (2015). A field guide to postphenomenology. In R. Rosenberger, & P.-P. Verbeek (Eds.), Postphenomenological Investigations: Essays on Human-Technology Relations (pp. 9-41). (Postphenomenology and the Philosophy of Technology). Lexington Books.Postphenomenological Investigations: Essays on Human-Technology Relations, Lexington, p.9-41

Schouwenberg, L. & Kaethler, M. Eds.(2021) The Auto-Ethnographic Turn in Design, Valiz, Amsterdam

Verbeek P-P, & Kockelkoren P, (1998), The Things That Matter, in *Design Issues*, Vol 14. Number 3, Autumn

Walker, S. (2017) The object of nightingales: design values for a meaningful material culture, in the Routledge Handbook of Sustainable Product Design, ed. Chapman, p53 - 68, Routledge, UK

Zucotti P. (2015) *Every Thing We Touch: A 24-Hour Inventory of Our Lives*, Viking, UK

DOI: 10.2752/175470812X13281948975459

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The Consumption Economy – Finding Value in Our Clothing

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Keywords: Consumption Practices; Values; Ethical Beliefs; Second-hand Market; Consumers.

Abstract: The fashion industry is one of the largest global polluters, with its linear 'take-make-dispose' supply chain model driving unsustainable consumption patterns. With over 100 billion garments produced annually, the industry contributes significantly through over-production and consumption in the multi-billion dollar industry. **Overarching Question:** This study investigates consumer consumption practices to understand the true ethical beliefs and values of individuals in relation to fashion purchasing, use, and disposal. Consumption practices are rarely explored by understanding consumer deeper thoughts and perceptions in second-hand retail, despite garments having an average lifespan of 3.3 years, many clothing items are unused, with 26% of garments in the UK remaining unworn (SCAP, 2021).**Sub Question:** The effects of the high and low value of clothing in the second-hand economy need to be investigated with the collection of empirical data of consumption practices. Predominantly unseen activity in Consumer-to-Consumer (C2C) transactions remains underexplored, executed through digital and online selling platforms. **Sub Questions:** This study examines consumer's ethical belief systems that influence second-hand purchasing behaviour. Exploring participants' motivations when engaging in second-hand markets in physical and online spaces, it highlights the complexities of consumer belief systems that shape their purchasing behaviour. The findings emphasise the importance of values and beliefs playing an integral role in the second-hand market landscape—challenging traditional consumption models and shedding light on potential avenues for innovation in a circular fashion future.

Introduction

The fashion industry significantly impacts the environment, ranking as the sixth-largest polluting sector globally (EEA, 2023). With over 100 billion garments produced annually (Chan, 2024), it relies on a linear "take-make-dispose" supply chain model (Ellen MacAurther Foundation, 2023). This approach drives the relentless production of clothing, saturating markets with used products. The industry's rapid production cycles, fuelled by seasonal trends, result in the frequent obsolescence of garments, contributing to unsustainable consumption patterns (Niinimäki, 2015).

Previous studies by Niinimäki (2015) highlight how consumer values and beliefs influence their purchasing behaviour, demonstrating that garment design should be approached through a value-creation system. Adegeest (2016) states that clothing durability has declined dramatically over the past century, alongside this, research indicates that a significant portion of wardrobes remains unused; for example, 26% of clothing owned by UK consumers, which is estimated to be 31 items per person, is left unworn (Palmer, 2022). These unused garments often sit unworn for years during their "use phase" (Klepp et al., 2020). When no longer, consumers typically donate, pass on, or resell their clothing (Gregson et al., 2007). This aids the circulation of garments to be sold in second-hand systems, which indicates many new routes that lead to the demise of low-priced items scoured across digital platforms and in the charity retail sector.

The Consumption Economy Contextual Review

Previous research into consumer behaviour has predominantly examined ethical decision-making and purchasing practices within first-hand markets (Auger & Devinney, 2007; Belk et al., 2005; Hur, 2020; Vladimirova et al., 2023). Consumer purchasing behaviours in second-hand spaces have been debated by key authors, for instance, Gregson and Crewe (2003), were able to approach their research

through an anthropological lens. In contrast to this, Horne and Maddrell (2002) often focus on societal, and economic impact across the value chain. However, consumer purchasing behaviour in this paper aims to explore consumption practices within the second-hand market, specifically analysing consumers' ethical beliefs and values when reselling from a Consumer-to-Consumer (C2C) perspective. While consumer purchasing behaviours provide insight into broader consumption patterns, the dynamics of C2C transactions in this emerging market remain largely unexplored in academic research.

The study of values and ethics is vital to understanding sustainable fashion consumption, as they incorporate a wider discussion to see the problems surrounding fast fashion in a more holistic setting, and can help gain traction with a wider audience (Niinimäki, 2015). In contrast, when clothing is made in a localised economy this can increase value and bring awareness to traditional production (Fletcher, 2010). In these efforts, practitioners are encouraged to create value around their textile craft, which excludes mass-manufactured multiples. Furthermore, designers, traditionally focused on product aesthetics, are increasingly being encouraged to consider sustainability from the outset by collaborating with key stakeholders to develop products and services that support circular economies (Liedtke et al., 2013).

While the second-hand economy has grown due to increased accessibility via technology, it remains under-researched in certain areas, such as C2C transactions, which often go undetected. Barriers to second-hand clothing (SHC) consumption, including concerns over cleanliness, accessibility, and social perceptions, remain significant (Hur, 2020). However, online platforms have made second-hand purchasing increasingly common, suggesting that consumer behaviour is influenced more by convenience than by concerns about transparency (Hur, 2020; Vladimirova et al., 2023). This paper will investigate the dynamics of second-hand consumption, by understanding consumers' values and ethical beliefs, by uncovering purchasing behaviour, by engaging with them, particularly in online and physical contexts. Consumers' value systems are connected to beliefs of bad and good, right and wrong, and this gives consumers a sense of direction, followed by a series of behaviours (Paehike, 2000). The knowledge gaps this paper will identify how consumer values and beliefs play an integral role in second-hand purchasing. By Identifying the overarching research question and the sub-questions the literature reveals that consumption practices influence how products and services are marketed and consumed, ethically or otherwise (Armstrong et al., 2015). Consumption practices play a key role and European apparel consumption is the fourth-largest contributor to climate change and greenhouse gas emissions (EEA, 2023). Encouraging consumers to have alternative consumption patterns by reassessing their current systems and sustainable behaviours

Methodology

The study sought to understand consumer beliefs and values, investigating the cognitive processes behind their decision-making and identifying the key drivers that motivate them to buy second-hand items. An indicative qualitative methodological framework was developed to address three critical research questions:

Overarching Research Question: How do consumer values and beliefs play an integral role in second-hand purchasing?

Sub Questions

- What are the effects of high and low-value of clothing in the second-hand economy?
- How do consumer belief systems interact with second-hand spaces to elicit high consumption?

This study is a qualitative research approach which explores participants' core belief systems, motivations, and actions with second-hand markets. A sample strategy is used to recruit participants who are actively engaged in second-hand clothing consumption, to ensure diverse perspectives from both physical charity shops and digital online platforms. This study draws upon a comparative analysis of consumer principles which instigate purchasing motivations through these key retail personas.

Sample Strategy: The participants in this study were chosen on their engagement with second-hand purchasing, recruitment-facilitated activity in online second-hand platforms, consistent engagement with second-hand clothing social media groups, and regular attendance to purchase in charity retail shops. A sample size of 10 Generation Z consumers was selected as study participants, due to 41% of this demographic being most likely to impulse buy on second-hand digital platforms, in comparison to 34% of millennials and 32% of Generation X (Djafarova & Bowes, 2021). The primary data would use semi-structured interviews to serve as the collection method, enabling participants to articulate their ethical considerations and purchasing motivations. This set of interviews analysed how individual consumption behaviours contribute to the broader second-hand supply chain.

Interview Process: the interviews were designed to explore perspectives on second-hand consumption, focusing on their purchasing behaviour in a digitalised second-hand market space. The charity retail integrates business-to-consumer (B2C) transactions, and this instigates consumers to act akin to trading action as their values in second-hand markets are aligned with their ethical beliefs. Specific questions probed the cognitive processes behind their choices, which reflected their beliefs and values. Participants were encouraged to reflect on how sustainability, personal values, and economic factors influence their decisions to buy pre-owned items.

The semi-structured format allows for in-depth discussion to be drawn upon but allows flexibility to explore emerging themes that appear in interviews with the participants. In the final step, participants were able to identify the product life cycle of garments they owned This step aimed to identify potential correlations between their expressed beliefs and values and the ways they treated and managed their clothing. By integrating these layers of inquiry, the study sought to uncover how consumer values and behaviours align with the broader goals of sustainability and extended garment lifespans in the second-hand markets. All interviews were audio-recorded with participant consent and were transcribed for analysis. A thematic approach was used to highlight recurring patterns and key insights, allowing for a structured examination of consumer values, behaviour and ethical beliefs. This process enabled a rigorous interpretation of data, which could draw upon some key findings to exemplify key themes in second-hand consumption.

Discussions and Findings

The study was investigated through semi-structured interviews, to explore participants' ethical behaviours and understand whether their beliefs influenced their practices within second-hand markets. By identifying consumers' ethical beliefs, valuable insights were gained into the principles that guide their purchasing decisions. This research holds importance for stakeholders, academics, and industry professionals, as it sheds light on aspects of second-hand clothing consumption and consumer motives and this type of purchasing behaviour.

The interview data revealed that participants do not rely on a single source for clothing purchases, instead employing a range of methods such as online shopping, retail, auctions, and second-hand markets. The discussion provided evidence of consumers' altruistic behaviours, with their purchasing choices reflecting personal values and lifestyle preferences. Furthermore, it indicates that a primary factor influencing consumer purchasing behaviour is the desire to align purchases with individual beliefs, with various consumption methods aligning closely with their lifestyle choices.

When comparing values between the first- and second-hand economy, one participant stated "when a brand is more sustainable, I am more likely to purchase it first-hand because they are doing good rather than bad, so the brand's ethics have contributed to correct ways to buy directly from that brand". This finding indicates how consumers are to negotiate a common misconception with only purchasing first-hand and reflects an ongoing philosophical debate on their ethical choices when it comes to purchasing first-hand and second-hand retail. This key finding also challenges the assertion by Geiger and Keller (2018) that altruism is the main driver of sustainable fashion consumption. This group of participants were chosen because they were active shoppers in second-hand clothing markets. In contrast to this,

Casais and Faria (2022) highlighted that social values and economic factors shape the gap between consumer intentions and actions. Additionally, when considering the second-hand market in the context of the charity retail sector, it was noted that: "buying second-hand is a great option, there are lots of charity shops in my hometown, and it is easier on the conscience". This brings attention to how the economic status of an area can determine the high consumption of low-quality clothing. For instance, many small towns within the U.K. are seeing more charity retail shops opening in low-income districts across the UK high streets. Additionally, Generation Z, often constrained by lower incomes, struggles to afford sustainable fashion brands, a challenge noted by Rex (020). Therefore, the younger generation is motivated to pursue second-hand consumption as a way of being sustainable.

The investigation was able to demonstrate how the social media platform Depop creates a sense of community with similar values and beliefs by mirroring platforms like Instagram by integrating social elements and purchasing behaviour. This has contributed to the rise of 'Depop Girlies' – a term which describes influencers within Generation Z who engage in reselling second-hand clothing at a significant markup (Harting, 2022). The finding highlights, how capitalising on second-hand fashion is curated through consumers being able to create value on certain products, as their role as a seller for capital gain, whilst other items with low-value qualities to the product remain within the charity retail sector, which is fed into their waste management system.

There are now many ways for clothing to ebb and flow through second-hand retail markets, and Generation Z is increasingly aware of garment resale value for financial gain. In this study, participants reflected on the best ways to discard garments, and this plays a significant role in their purchasing behaviour as one of the participants was able to reflect, "When thinking about how to get rid of this item, I will probably sell it on Depop. Nevertheless, it will be given to charity if it is too damaged." This garment removal behaviour distinguishes how the reselling phase and the disposal phase are closely tied to one another in C2C (consumer-to-consumer) second-hand markets. Value creation at this stage is determined by the seller and highlights how economic and societal trends can shift the value of products and this is pursued in a realm of sustainable purchasing through second-hand markets.

An interesting observation came from Participant 5, who referred to items in a charity shop as 'new', highlighting the varied interpretations of what new means in the context of second-hand purchasing. This is mirrored in debates within literature, where value is considered a multi-layered concept, with many meanings which are specific to the context. Mostly, value is known for being defined as socially recognised importance: the weight that society gives to an object or an issue (Hirscher et al., 2018). Value in second-hand commodities is widely debatable and is perceived by a host of actors, stakeholders, donors, customers and beneficiaries, each operating through different regimes of values (Elsden et al., 2019). This study affirms how key concepts of the definition are widely debated, therefore defining the low and high value of textile creates a more accurate approach which this study goes on to explore.

Conclusions

To conclude the study, the investigation was able to explore the behaviour of consumer consumption practices in second-hand clothing markets to understand consumers' true ethical beliefs and values when purchasing, use and disposal. Values can be determined by first identifying on a scale the low and high value of items, and this plays a multifaceted role when it comes to depicting certain belief systems in second-hand purchasing. Firstly, the value of garments is demonstrated through consumers' garments, for instance, time can determine if certain items of clothing will gain value while others may lose value.

When items are to retain high-value, textiles can retain different types of value after a length of time, for example, because of how it has been designed and constructed, kept for sentimental reasons, or archived as artefacts, mended or embellished. High value is created through all these characteristics by creating an element of care and appreciation. This also demonstrated how ethical beliefs are to be consistent in high-valued items and how a strong sense of second-hand ownership can be passed on to the next buyer of this item. On the other hand, when items show low value, they usually encompass signs and characteristics of

garments which can be found in low-cost fashion markets. This has overseen a change in buying and wearing habits, as similar patterns in the data highlighted the shift and cognitive bias for garments that had been designed on a low-value creation system, and mimicked agile supply chain systems of a trajectory of planned obsolesce predicted market. This has been described as clothing usually purchased in multiples and discarded quickly in the post-consumer phase as it is perceived to be of little value (Fletcher, 2010). Discouraging consumers from retaining value in clothing has the consequence of a detachment from their clothing, it is only beneficiary for the garment's very short life before it is disposed of and replaced with another item that will share the same lifespan as its predecessor.

When clothing enters second-hand realms the charity retail sector here in the U.K. experiences high amounts of low and high-valued items, it is implicit that the direction the garment may travel in the supply chain is dependent on its previous life span. Passing clothing onto charity is a form of doing something good for the individual and the thought process is the feeling the garment is being sent in the right direction to live its second life where it can be worn once again. The findings in this study were able to identify how their purchasing behaviour indicates how active second-hand shoppers explored their value propositions in second-hand purchasing behaviour in this ongoing study.

As explained by Elsden et al., (2019) some things are said to be 'priceless' and cannot be reduced to an abstract, exchangeable or single value, whereas the consumer's beliefs and values are embedded and entwined in a complex series of behaviours. The participants in this study were conflicted with the fashion companies' sustainability morals and their belief systems on their knowledge surrounding second-hand purchasing. When defining value and beliefs in consumers craftsmanship of a garment plays an important role, as there is a personal relationship with the garment, and this is lost when consumers do not understand the craftsmanship that has gone into making a garment.

References

Adegeest, D.-A. (2016, August 18). *Loose Threads: The shrinking lifespan of high street fashion*. FashionUnited. https://fashionunited.uk/news/fashion/loose-threads-the-shrinking-lifespan-of-high-street-fashion/2016081821460

Armstrong, C. M., Niinimäki, K., Kujala, S., Karell, E., & Lang, C. (2015). Sustainable product-service systems for clothing: Exploring consumer perceptions of consumption alternatives in Finland. *Journal of Cleaner Production*, *97*, 30–39. https://doi.org/10.1016/j.jclepro.2014.01.0

Auger, P., & Devinney, T. M. (2007). Do What Consumers Say Matter? The Misalignment of Preferences with Unconstrained Ethical Intentions. *Journal of Business Ethics*, *76*(4), 361–383. https://doi.org/10.1007/s10551-006-9287-y

Belk, R., Devinney, T., & Eckhardt, G. (2005). Consumer Ethics Across Cultures. *Consumption Markets & Culture*, *8*(3), 275–289. https://doi.org/10.1080/102538605001604

Casais, B., & Faria, J. (2022). The Intention-Behavior gap in Ethical Consumption: Mediators, Moderators and Consumer Profiles Based on Ethical Priorities. *Journal of Macromarketing*, *42*(1), 100–113. https://doi.org/10.1177/027614672110548

Chan, E. (2024, January 4). *Wait, Do I Actually Need To Pay Tax When Reselling Clothes Online?* British Vogue. https://www.vogue.co.uk/article/tax-rules-selling-clothes-online

Djafarova, E., & Bowes, T. (2021). 'Instagram made Me buy it': Generation Z impulse purchases in fashion industry. *Journal of Retailing and Consumer Services*, *59*, 102345. https://doi.org/10.1016/j.jretconser.2020.102345

EEA. (2023, February 27). *EU exports of used textiles in Europe's circular economy—European Environment Agency* [Briefing].https://www.eea.europa.eu/publications/eu-exports-of-used-textiles

Ellen MacAurther Foundation. (2023). *Fashion and the circular economy*. https://www.ellenmacarthurfoundation.org/fashion-and-the-circular-economy-deep-dive

Elsden, C., Symons, K., Bunduchi, R., Speed, C., & Vines, J. (2019). Sorting Out Valuation in the Charity Shop: Designing for Data-Driven Innovation through Value Translation. *Proceedings of the ACM on Human-Computer Interaction*, *3*(CSCW), 109:1-109:25. https://doi.org/10.1145/3359211

Fletcher, K. (2010). Slow Fashion: An Invitation for Systems Change. *Fashion Practice*, *2*(2),

259–265. https://doi.org/10.2752/175693810X12774625387594

Geiger, S. M., & Keller, J. (2018). Shopping for Clothes and Sensitivity to the Suffering of Others: The Role of Compassion and Values in Sustainable Fashion Consumption. *Environment and Behavior*, *50*(10), 1119–1144. https://doi.org/10.1177/0013916517732l0

Gregson, N., & Crewe, L. (2003). *Second-Hand Cultures*. Bloomsbury Publishing (UK). https://doi.org/10.2752/9781847888853

Gregson, N., Metcalfe, A., & Crewe, L. (2007). Identity, Mobility, and the Throwaway Society. *Environment and Planning D: Society and Space*, *25*(4), 682–700. https://doi.org/10.1068/d418t

Harting, L. (2022, February 24). *The gentrification of the 'Depop girly'*. Epigram. https://epigram.org.uk/2022/02/24/the-gentrification-of-the-depop-girly/

Hirscher, A.-L., Niinimäki, K., & Joyner Armstrong, C. M. (2018). Social manufacturing in the fashion sector: New value creation through alternative design strategies? *Journal of Cleaner Production*, *172*,4544–4554. https://doi.org/10.1016/j.jclepro.2017.11.0

Horne, S., & Maddrell, A. (2002). *Charity Shops: Retailing, Consumption and Society*. Routledge. https://doi.org/10.4324/9780203167458

Hur, E. (2020). Rebirth fashion: Secondhand clothing consumption values and perceived risks. *Journal of Cleaner Production*, *273*, 122951. https://doi.org/10.1016/j.jclepro.2020.1229

Klepp, I. G., Laitala, K., & Wiedemann, S. (2020). Clothing Lifespans: What Should Be Measured and How. *Sustainability*, *12*(15), Article 15. https://doi.org/10.3390/su12156219

Liedtke, C., Buhl, J., & Ameli, N. (2013). Designing value through less by integrating sustainability strategies into lifestyles. *International Journal of Sustainable Design*, *2*, 167–180. https://doi.org/10.1504/IJSDES.2013.0571

Niinimäki, K. (2015). Ethical foundations in sustainable fashion. *Textiles and Clothing Sustainability*, *1*(1), 3. https://doi.org/10.1186/s40689-015-0002-

Paehike, R. C. (2000). *Environmental Values and Public Policy*. Scribd. https://www.scribd.com/document/404233145/Paehlke-2000-Environmental-Values

Palmer, I. (2022, October 7). *Nation's wardrobes hold 1.6 billion items of unworn clothes* People open to new ways of shopping*. WRAP. https://wrap.org.uk/media-centre/press-releases/nations-wardrobes-hold-16-billion-items-unworn-clothes-people-open-new

Rex, H. (2020, September 4). *Is Depop Gentrifying Secondhand Shopping?* https://www.refinery29.com/en-gb/depop-secondhand-gentrification

SCAP. (2021). *Sustainable Clothing Action Plan | WRAP*. https://wrap.org.uk/resources/guide/textiles/sustainable-clothing-action-plan#

Vladimirova, K., Henninger, C. E., Alosaimi, S. I., Brydges, T., Choopani, H., Hanlon, M., Iran, S., McCormick, H., & Zhou, S. (2023). Exploring the influence of social media on sustainable fashion consumption: A systematic literature review and future research agenda. *Journal of Global Fashion Marketing*, *0*(0), https://doi.org/10.1080/20932685.2023.2237978

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Behind the Stars: Consumer Personality and Review Composition for New and Refurbished Products

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Keywords: Refurbished; Consumer; Attributes; Psychology; e-waste.

Abstract: The rapid growth of e-commerce and technological advancements has amplified the production of electronic waste (E-waste). Refurbished products offer a sustainable alternative by extending product lifecycles, yet consumer behavior toward these products remains underexplored in many regions, including India. This study investigates key product attributes and psychological characteristics of consumers, analyzing 2,189 refurbished and 4,967 new product reviews using text mining and linguistic analysis tools. The findings highlight significant differences in consumer preferences, with refurbished product consumers prioritizing Battery health, Service-related aspects, packaging, and hygiene, while new product buyers emphasize features and aesthetic factors. Psychological differences are evident as refurbished product consumers exhibit a more positive tone and goal-driven reasoning while the new product consumers show more structured analytical evaluation. Using Constructive Decision-Making Theory (CDMT), the study explains how consumers of refurbished products construct satisfaction by reinforcing their choices post-purchase. The findings offer insights for refurbishers, policymakers, and marketers to foster trust and adoption of refurbished products through marketing strategy, standardized practices, and certifications while aligning with consumers' decision-making process.

Introduction

E-waste is now an environmental issue. Globally, several countries have started paying serious attention to addressing it (Aboelmaged, 2021; Borthakur, 2020). Circular business models are gaining popularity as a solution to the growing e-waste problem. Unlike the take-make-waste model, the Circular Economy (CE) model is regenerative (Araujo-Morera et al., 2021). According to CE, all the value chain activities involved in a business should be oriented towards reducing, reusing, and recycling (3Rs) resources. Refurbishing is one such circular business model that aims to increase the longevity of the product and material(Geissdoerfer et al., 2020). Through the process of refurbishing, used products are revitalized to a certain standard, which may or may not be at par with the new product quality (Thierry et al., 1995) From the consumer's perspective while designing a refurbished product, understanding the needs, exploring market trends, comprehending competitors' actions, and designing actionable based on feedback from all stakeholders is crucial for gaining an advantage(Teece, 2007). Many scholars have studied the quality and characteristics that shape consumer expectations of new products (Anderson et al., 1994; Oliver, 1980) but, there are very few studies that enhance the understanding of these factors for refurbished products. Although some studies have explored consumer perceptions of refurbished products in developed countries (Alyahya et al., 2023; Wallner et al., 2024) there is a notable lack of research on this topic within the Indian context. Further, while extensive literature is available on the psychological characteristics that influence consumers while purchasing a new product, there is a noticeable gap in identifying the psychological characteristics of consumers that influence purchase decisions of refurbished products. Even more scant is the literature that compares consumer behavior between refurbished and new products. This research aims to address this gap by answering the following questions

RQ1: What are the factors that drive purchasing decisions for refurbished products amongst Indian consumers? How do these factors compare to those of new products?

RQ2: How do Indian consumers of refurbished and new products construct their satisfaction,

and what psychological factors influence this process?

This study makes three contributions to refurbished product literature. First, it is the first study to apply the Constructive Decision Making Theory (CDMT) to explain the satisfaction of refurbished product consumers. Second, It leverages Linguistic Inquiry and word count (LIWC) to obtain insights into the cognitive and emotional responses of refurbished and new product consumers.
Thirdly, it identifies key product attributes valued by Indian consumers, bridging the gap in the literature that largely focuses on developed markets.

Literature Review

The extant literature on refurbished products identifies several factors that influence the purchase of refurbished products. These factors are primarily grouped into product attributes, consumer characteristics, and seller engagement. Table 1 summarizes the key factors identified from the literature.
Refurbished products are often rejected as a consequence of a negative trade-off between perceived risks and benefits(Van Weelden et al., 2016). One of the prime reasons why people don't choose to buy refurbished products is the because of hygiene and contamination risk (Abbey et al., 2015; Singhal et al., 2019; Wallner et al., 2022b, 2022a). However, when deciding to purchase refurbished products, consumers categorize the product's features into primary, secondary, and innovative functions, which subsequently guide their decision-making process.
The willingness to pay (WTP) is lower for refurbished products (Harms & Linton, 2016) owing to the perception of lower quality and higher risk (Esmaeilian et al., 2021; Van Weelden et al., 2016). The purchase intention toward refurbished products is also dependent on factors related to the consumer. For instance, environmentally conscious consumers are more likely to purchase refurbished products (Mugge et al., 2017; Wallner et al., 2022a, 2024). Further, value-conscious consumers would be incentivized to buy refurbished products(Wallner et al., 2024). Seller engagement also plays a crucial role when consumers buy refurbished products. As per prior research, in the risk-return tradeoff, low price, strong seller reputation, and warranties can help lower the perceived risk of purchasing a refurbished product (Agostini et al., 2021; Sharifi & Shokouhyar, 2021; Van Weelden et al., 2016; Wallner et al., 2024)

Even though these factors have given us considerable insights, most studies have focused on purchase intention as the dependent variable. Often purchase intentions don't get converted into actions leading to an intention-action gap (Khor & Hazen, 2017; Wallner et al., 2022) thereby resulting in limitations. To comprehend the actual consumer behavior, it is critical to understand the post-purchase stage(Nasiri & Shokouhyar, 2021).Hence this paper utilizes online customer reviews (OCR) to understand consumer behavior.
According to several studies on consumer behavior, post-purchase satisfaction is a psychological process where consumers validate their purchase decisions *(Festinger & Urry, 1957; Oliver, 1980)*. In addition to sharing their experiences, consumers write reviews to justify their decisions, legitimize tradeoffs, and construct their satisfaction on factors other than physical product features (Dholakia et al., 2004; Hennig-Thurau et al., 2004; Li et al., 2023).
This is consistent with the Constructive Decision-Making Theory (CDMT), which posits that consumers build their judgments using context, available knowledge, and cognitive effort rather than having a predetermined set of preferences(Bettman et al., 1998).
CDMT states that consumer choices are context-dependent and influenced by several factors, such as social influence, available alternatives, marketing messages, etc. Secondly, consumers select options that align with their objectives. These objectives could be either minimizing effort, maximizing the accuracy of the result, reducing the negative impact of the decision, or ensuring the ease of justifying their decision. Thirdly, consumers will shift between rational (analytical) and intuitive (heuristic) approaches to decision-making depending on the complexity of the task. Because the consumption choices are constructed, CDMT provides a lens to explain why consumer reviews reflect the process of validating purchase decisions other than product performance.
To quantitatively assess how these psychological processes manifest in customer reviews of new and refurbished products, this study employs Linguistic Inquiry and Word Count (LIWC) analysis. LIWC is a robust text

Key Research Variables	Theme/Parameter	Reference
Price	Product Attributes	(Ghosh et al., 2023; Sharifi & Shokouhyar, 2021)
Product features (Primary, Secondary and Innovative features)	Product Attributes	(Ghosh et al., 2023; Nasiri & Shokouhyar, 2021; Seifian et al., 2023; Sharifi & Shokouhyar, 2021; Wallner et al., 2024)
Consumer motivation (Environmental motivation and financial motivation)	Consumer attributes	(Nasiri & Shokouhyar, 2021; Seifian et al., 2023; Wallner et al., 2024)
Consumer characteristics (Value consciousness, Disgust sensitivity, Environmental concern)	Consumer attributes	(Wallner et al., 2022b, 2024)
Seller Related (Warranty, Reputation, Packaging)	Seller's Engagement	(Seifian et al., 2023; Wallner et al., 2024)

Table 1. Factors from Literature Review

analysis tool to analyze the emotional, cognitive, and structural aspects of written language (Boyd et al., 2022). LIWC has been found effective in extracting psychometric traits from text(Pal et al., 2023), making it a suitable tool for evaluating consumer reviews.

Method

The data for this study was gathered from the Amazon India website (www.amazon.in). Reviews of both new as well as refurbished versions of the same headphones (e.g. JBLC100 SI, JBL C50Hi, Sony WI-C100 etc.) were scraped for text analysis using rvest package in R. This approach allows direct comparison between the two product categories. For the study, headphones were selected as they make up a substantial portion of small waste electrical and electronic equipment (WEEE). These often remain unused, and hence present an opportunity for reuse and integration into the circular economy (Shittu et al., 2022).

Reviews from India, written in the English language were selected for analysis. The final dataset consists of 2,189 reviews of refurbished products and 4,967 reviews of new products spanning between March 2015 to May 2024.
The selected review text underwent a series of preprocessing steps to ensure consistency and accuracy. Different packages from the R library were used for the process. Thereafter a lexicon was developed to code the reviews. This step followed an iterative method using a hybrid of deductive and inductive approaches to create a robust dictionary (Fereday et al., 2006; Proudfoot, 2023) as shown in Figure 1

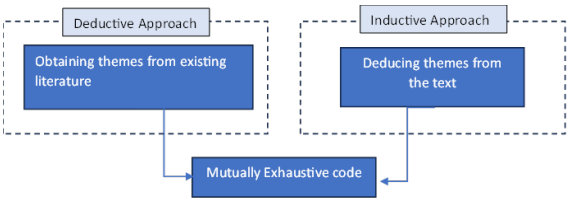


Figure 1. Lexicon Development

The lexicon outlined above was applied to the reviews to identify 13 key attributes that the consumers of refurbished products prioritize (the lexicon is available on request). A Chi-square test, was conducted to compare the distribution of these 13 attributes in the reviews of Refurbished and new products to address RQ1.
To explore the psychological dimensions of post purchase satisfaction (RQ2), the study employed the Linguistic Inquiry and Word Count (LIWC-22) tool. Eight variables were selected, which represent emotional and cognitive dimensions that are commonly associated with consumer behavior.
The sequence of steps has been illustrated in Figure 2

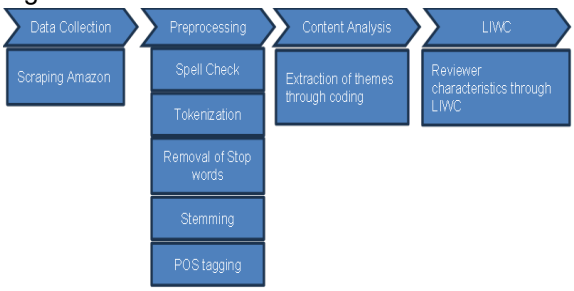


Figure 2. Process

Results

Key Attributes of Refurbished Products

Table 2 below presents the frequency of reviews mentioning each attribute for both refurbished and new products derived from the coding process mentioned above.

Theme	Variable	No of reviews	
		Refurbished	New
Product Related	P1-Sound Quality	1006	3210
	P2-Usage related	253	1144
	P3-Accessories	349	1478
	P4-Design Features	146	1020
	P5-Battery	331	619
	P6-Price	152	788
Seller Related	S1-Product_Service_related	578	1337
	S2- Warranty_related	78	266
	S3- Packaging	146	138
	S4- Unhygenic	16	8
Customer Related	C1-Brand consciousness	524	1746
	C2-Value /Price Consciousness	401	1221
	C3-Usecase	214	1054

Table 2. Key factors Identified from reviews of Refurbished Products

Comparison between Refurbished and New product Reviews

The Chi-square test yielded significant results ($\chi 2$ =449, p=0.000). The Mosaic plot of residuals Figure 3 clearly distinguish the distribution of these factors in the reviews of both product categories. Standardized residuals > |2| indicate attributes that are significantly overrepresented or underrepresented in each category.

Attributes Over Represented in Refurbished product Reviews

Battery health, Service-related aspects, packaging and hygiene overrepresented in reviews of refurbished products. These results are consistent with the body of research that indicates refurbished product consumers place a high value on longevity, functionality, post-purchase service, and hygiene ((Ghosh et al., 2023; Seifian et al., 2023; Wallner et al., 2022b, 2024).

Attributes over Represented in new product Reviews

Consumers purchasing new products tended to discuss design features, usage related aspects, use cases and price more. Even though the prevalent marketing message is that the refurbished products are sold at lower prices (Alyahya et al., 2023; Mugge et al., 2017), price was underrepresented in refurbished product reviews. The negative residual for price in refurbished product reviews (-4.37) suggests that while price is discussed, as against for a new product consumer, it is not the primary factor driving satisfaction or dissatisfaction in refurbished purchases.

Instead, refurbished consumers focus more on perceived value and quality rather than absolute cost.

Attributes Equally Represented in Both New and Refurbished Reviews (Fundamental Consumer Requirements)

Despite the observed differences, four attributes—sound quality, warranty, brand consciousness, and value consciousness—showed no significant difference between new and refurbished product reviews.

This suggests that these are fundamental expectations for consumers, irrespective of whether they buy a new or refurbished product. For all consumers, Sound quality is a core requirement and warranty serves as a risk-reduction mechanism that consumers demand in both categories. These findings suggest that product sellers must meet these fundamental expectations.

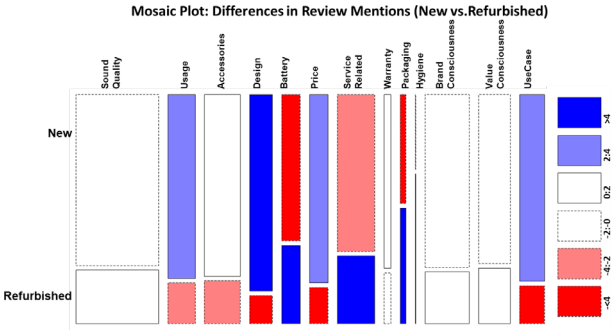


Figure 3. Mosaic Plot of Residuals

Comparison of Psychological differences between Refurbished and New product consumers.

Table 3 below shows the mean scores of different psychological markers from LIWC across product categories and the

corresponding significance values of the t-test for comparison of these scores. These scores against each variable represent the percentage of words in a text that corresponds to the variable.

Variable	Refurbished	New	p value
Analytic	42.2	45.0	0.002
Clout	13.0	14.4	0.048
Authentic	51.7	51.1	0.606
Tone	60.9	55.8	0.000
Social	4.0	4.1	0.306
Lifestyle	7.0	5.5	0.000
Drives	3.7	3.0	0.000
Cognition	11.2	12.0	0.001

Table 3. t- test results to compare mean scores from LIWC.

The t-tests clearly show that customers of new and refurbished products construct their satisfaction in very different ways.
Customers of refurbished products use adaptive reasoning to support their choices, whereas consumers of new products rely on structured evaluations.

Cognitive Processing

New product consumers have higher Analytic and Cognition scores, suggesting a more methodical, logical, and data-driven assessment procedure. This is in line with CDMT's expectation-driven framework. New product consumers evaluate products against pre-determined benchmarks(Bettman et al., 1998). New product consumers also have higher Clout score, indicating greater confidence and assertiveness in their decision-making.

Consumers of refurbished products on the other hand exhibit lower Analytic and Cognition scores, indicating more flexible and adaptive reasoning. Their lower Clout score points to greater uncertainty in their purchase, leading them to seek reassurance through post-purchase rationalization.

Emotional Reinforcement and Justification

Consumers who purchase refurbished products have higher Tone scores, indicating they are writing more optimistic reviews. This lends credence to the notion that they construct satisfaction after purchase by reinforcing their decision emotionally, a key post-purchase strategy described in CDMT. Since refurbished products are accompanied by inherent uncertainty, consumers compensate for potential shortcomings by emphasizing positive experiences. This behavior aligns with Cognitive Dissonance theory which says consumers justify their decisions post-purchase to minimize psychological discomfort *(Festinger & Urry, 1957)*.

Lifestyle and Goal-Oriented Framing

Refurbished product reviews have higher Lifestyle and Drives scores. This suggests that the consumers integrate their purchases into broader personal goals and motivations. Customers of refurbished products present their purchase as a deliberate, goal-driven choice, whether out of resourcefulness or financial prudence. According to CDMT in such cases, consumers construct satisfaction by coordinating their decisions with their long-term goals and self-concept (Bettman et al., 1998).

Social and Authentic Expression

There is no significant difference between the Authenticity and Social scores, indicating that both consumer groups express their opinions with comparable sincerity and that social engagement and communicative intent in reviews are similar.

Implications

The findings from our study offer actionable implications for the Refurbishers and Policymakers.

Reducing Pre-purchase uncertainty to increase adoption

Given that battery health, Service-related aspects, and packaging aspects are over-represented in product reviews, businesses should implement proactive strategies to reduce consumer hesitation. Assuring quality checks, post-purchasing service guarantees and ensuring packaging like new products can reduce customer hesitation.

Reinforcing Satisfaction through emotional and Goal-based messaging

Since Refurbished product customers rely on post-purchase rationalization, businesses must reinforce positive decision-making after purchase.
Post-purchase engagement through e-mails reaffirming that the purchase decision of refurbished product as a smart choice can

enhance satisfaction construction. Featuring consumer testimonials with real buyer stories can validate purchase decisions. Helping consumers justify and rationalize their decisions will reduce the cognitive load and encourage adoption.
New product consumers respond better to feature-driven ads, while refurbished consumers need trust-building messaging upfront to encourage adoption.
Through certification programs for refurbished goods, policymakers could promote adoption and further lower consumer perceptions of risk.

Conclusion

The findings of this study contribute to the academic discourse on consumer behavior in circular economy markets by highlighting how Indian consumers evaluate and construct satisfaction for refurbished products.
The over-representation of battery health, service, and packaging-related aspects in reviews indicates, that trust and quality assurance can play a significant role in encouraging the adoption of refurbished products. The findings indicate that consumers prioritize perceived value, risk mitigation, and product dependability over price as factors influencing their decision to buy refurbished goods.
Applying CDMT provides a deeper understanding of how customers dynamically construct satisfaction. Refurbished product buyers use goal-driven reasoning (higher Lifestyle and drives score) and post-purchase justification (higher tone), in contrast to consumers of new products who use structured evaluation (higher analytic and cognitive scores).

These differences suggest that to encourage the adoption of refurbished products, companies and policymakers should take a two-pronged approach. To reduce the perception of risk, they ought to implement tactics like quality assurance, professional packaging, and post-purchase service. To present refurbished goods to customers as clever and resourceful options, marketing narratives should provide positive reinforcement, align the message with the goals of the consumers such as making smart and resourceful purchases, and make it easier for consumers to justify the purchase.

Limitations and Scope for Future Research

While the study provides valuable insights, it is subject to limitations. Firstly, there may be platform bias because the reviews were gathered from just one e-commerce site (Amazon India). Secondly, some characteristics, like hygiene considerations, may not be adequately present in reviews. This is because these deterred the consumers from purchasing the product whereas this study only looks at the post-purchase phase. Future research could overcome this limitation by using survey or experimental techniques to record pre-purchase obstacles and contrast them with post-purchase assessments, Lastly, while the study highlights how consumers construct satisfaction, future research can incorporate how these differences influence the ratings, repurchase intentions, brand perceptions, etc. Examining these aspects could provide further insight into the role of psychological factors in encouraging the adoption of refurbished products.

References

Abbey, J. D., Meloy, M. G., Blackburn, J., & Guide, V. D. R. (2015). Consumer markets for remanufactured and refurbished products. *California Management Review*, *57*(4), 26–42. https://doi.org/10.1525/cmr.2015.57.4.26

Aboelmaged, M. (2021). E-waste recycling behaviour: An integration of recycling habits into the theory of planned behaviour. *Journal of Cleaner Production*, *278*. https://doi.org/10.1016/j.jclepro.2020.124182

Agostini, L., Bigliardi, B., Filippelli, S., & Galati, F. (2021). Seller reputation, distribution and intention to purchase refurbished products. *Journal of Cleaner Production*, *316*. https://doi.org/10.1016/j.jclepro.2021.128296

Alyahya, M., Agag, G., Aliedan, M., & Abdelmoety, Z. H. (2023). Understanding the factors affecting consumers' behaviour when purchasing refurbished products: A chaordic perspective. *Journal of Retailing and Consumer Services*, *75*. https://doi.org/10.1016/j.jretconser.2023.103492

Anderson, E. W., Fornell, C., & Lehmann, D. R. (1994). Customer Satisfaction, Market Share, and Profitability: Findings From Sweden. In *Journal of Marketing* (Vol. 58). https://doi.org/10.1177/002224299405800304

Araujo-Morera, J., Verdejo, R., López-Manchado, M. A., & Hernández Santana, M. (2021). Sustainable mobility: The route of tires through the circular economy model. In *Waste Management* (Vol. 126, pp. 309–322). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2021.03.025

Bettman, J. R., Luce, M. F., & Payne, J. W. (1998). Constructive consumer choice processes. *Journal of Consumer Research*, *25*(3), 187–217. https://doi.org/10.1086/209535

Borthakur, A. (2020). Policy approaches on E-waste in the emerging economies: A review of the existing governance with special reference to India and South Africa. In *Journal of Cleaner Production* (Vol. 252). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.119885

Boyd, R. L., Ashokkumar, A., Seraj, S., & Pennebaker, J. W. (2022). *The Development and Psychometric Properties of LIWC-22*. https://www.liwc.app/contact.

Dholakia, U. M., Bagozzi, R. P., & Pearo, L. K. (2004). A social influence model of consumer participation in network- and small-group-based virtual communities. *International Journal of Research in Marketing*, *21*(3), 241–263. https://doi.org/10.1016/j.ijresmar.2003.12.004

Esmaeilian, B., Onnipalayam Saminathan, P., Cade, W., & Behdad, S. (2021). Marketing strategies for refurbished products: Survey-based insights for probabilistic selling and technology level. *Resources, Conservation and Recycling*, *167*. https://doi.org/10.1016/j.resconrec.2021.105401

Fereday, J., Adelaide, N., Australia, S., & Eimear Muir-Cochrane, A. (2006). *Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development*.

Festinger, L., & Urry, C. (1957). *A Theory of Cognitive Dissonance*.

Geissdoerfer, M., Pieroni, M. P. P., Pigosso, D. C. A., & Soufani, K. (2020). Circular business models: A review. In *Journal of Cleaner Production* (Vol. 277). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.123741

Ghosh, A., Pathak, D., Bhola, P., Bhattacharjee, D., & Sivarajah, U. (2023). Analysing product attributes of refurbished laptops based on customer reviews and ratings: machine learning approach to circular consumption. *Annals of Operations Research*. https://doi.org/10.1007/s10479-023-05758-9

Harms, R., & Linton, J. D. (2016). Willingness to Pay for Eco-Certified Refurbished Products: The Effects of Environmental Attitudes and Knowledge. *Journal of Industrial Ecology*, *20*(4), 893–904. https://doi.org/10.1111/jiec.12301

Hennig-Thurau, T., Gwinner, K. P., Walsh, G., & Gremler, D. D. (2004). Electronic word-of-mouth via consumer-opinion platforms: What motivates consumers to articulate themselves on the Internet? *Journal of Interactive Marketing*, *18*(1), 38–52. https://doi.org/10.1002/dir.10073

Khor, K. S., & Hazen, B. T. (2017). Remanufactured products purchase intentions and behaviour: Evidence from Malaysia. *International Journal of Production Research*, *55*(8), 2149–2162. https://doi.org/10.1080/00207543.2016.1194534

Li, L., Yao, B., Li, X., & Qian, Y. (2023). What motivates customers to publish online reviews promptly? A text mining perspective. *Journal of Electronic Business & Digital Economics*, *2*(1), 24–44. https://doi.org/10.1108/jebde-09-2022-0034

Mugge, R., Jockin, B., & Bocken, N. (2017). How to sell refurbished smartphones? An investigation of different customer groups and appropriate incentives. *Journal of Cleaner Production*, *147*, 284–296. https://doi.org/10.1016/j.jclepro.2017.01.111

Nasiri, M. S., & Shokouhyar, S. (2021). Actual consumers' response to purchase refurbished smartphones: Exploring perceived value from product reviews in online retailing. *Journal of Retailing and Consumer Services*, *62*. https://doi.org/10.1016/j.jretconser.2021.102652

Oliver, R. L. (1980). A Cognitive Model of the Antecedents and Consequences of Satisfaction Decisions. *Journal of Marketing Research*, *17*(4), 460–469. https://doi.org/10.1177/002224378001700405

Pal, S., Biswas, B., Gupta, R., Kumar, A., & Gupta, S. (2023). Exploring the factors that affect user experience in mobile-health applications: A text-mining and machine-learning approach. *Journal of Business Research*, *156*. https://doi.org/10.1016/j.jbusres.2022.113484

Proudfoot, K. (2023). Inductive/Deductive Hybrid Thematic Analysis in Mixed Methods Research. *Journal of Mixed Methods Research*, *17*(3), 308–326. https://doi.org/10.1177/15586898221126816

Seifian, A., Shokouhyar, S., & Bahrami, M. (2023). Exploring customers' purchasing behavior

toward refurbished mobile phones: a cross-cultural opinion mining of amazon reviews. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-023-03804-x

Sharifi, Z., & Shokouhyar, S. (2021). Promoting consumer's attitude toward refurbished mobile phones: A social media analytics approach. *Resources, Conservation and Recycling*, *167*. https://doi.org/10.1016/j.resconrec.2021.105398

Singhal, D., Jena, S. K., & Tripathy, S. (2019). Factors influencing the purchase intention of consumers towards remanufactured products: a systematic review and meta-analysis. *International Journal of Production Research*, *57*(23), 7289–7299. https://doi.org/10.1080/00207543.2019.1598590

Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, *28*(13), 1319–1350. https://doi.org/10.1002/smj.640

Thierry, M., Salomon, M., Luk, J., & Wassenhove, V. (1995). Strategic Issues in Product Recovery Management. *California Management Review*, *37*(2), 114–136.

Van Weelden, E., Mugge, R., & Bakker, C. (2016). Paving the way towards circular consumption: Exploring consumer acceptance of refurbished mobile phones in the Dutch market. *Journal of Cleaner Production*, *113*, 743–754. https://doi.org/10.1016/j.jclepro.2015.11.065

Wallner, T. S., Haslbeck, J. M. B., Magnier, L., & Mugge, R. (2024). A network analysis of factors influencing the purchase intentions for refurbished electronics. *Sustainable Production and Consumption*. https://doi.org/10.1016/j.spc.2024.03.009

Wallner, T. S., Magnier, L., & Mugge, R. (2022a). *Buying new or refurbished? The influence of the product's durability and attractiveness, contamination risk and consumers' environmental concern on purchase intentions of refurbished and new products*.

Wallner, T. S., Magnier, L., & Mugge, R. (2022b). Do consumers mind contamination by previous users? A choice-based conjoint analysis to explore strategies that improve consumers' choice for refurbished products. *Resources, Conservation and Recycling*, *177*. https://doi.org/10.1016/j.resconrec.2021.105998

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Turning Trash into Treasure is Hard Work! How the Activities of Consumers and Reuse Enablers Extend Product Lifetimes

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Keywords: Product circulation; Reuse enabler; Consumer; Second-hand product; Product divestment.

Abstract: This paper explores the process of transferring second-hand products from one home to another. It focuses on three key participants: the consumer who is divesting products from their home, the consumer who purchases pre-owned items, and the second-hand and reuse enablers that facilitate this circulation of products. Current literature tends to concentrate solely on one of these groups—either consumers divesting products, second-hand and reuse enablers, or consumers buying pre-used items. This fragmented approach leaves gaps in understanding the complete process of product circulation. To address this knowledge gap, our study examines the entire process, starting from the moment a consumer decides to part with a product until that product finds a new owner. We conducted interviews with 20 consumers who are divesting products, 11 second-hand and reuse enablers, and 20 consumers who purchase pre-owned items. Our research identified three main product circulation processes and eight sub-processes: Donation, Commission Sale, and Sell-It-Yourself. Each circulation process involves a long series of activities carried out by the consumer divesting the product, the reuse enabler, or the consumer buying the item. By comparing these processes, we highlight that successful circular product exchanges require significant effort from all participants. Additionally, we demonstrate how the responsibility for these activities shifts depending on the chosen process, revealing the challenges associated with circular product transactions and how reuse enablers can support recirculation. This research contributes to a deeper understanding of the circular economy and its current struggles and opens discussions on how to overcome these challenges.

Introduction

One promising approach to address climate change effectively is the transition from a linear to a circular economy, in which products and materials are kept in circulation and product lifetimes are extended (den Hollander et al., 2017; Ellen MacArthur Foundation, n.d.). Circular economy strategies encompass a range of actions, including maintenance, reuse, refurbishment, remanufacturing, and recycling. Among these, product reuse is considered particularly impactful, as it preserves products at the current integrity level (Ellen MacArthur Foundation, n.d.). It typically entails that a product reaches a new consumer when the current one no longer needs it.

While direct product exchanges between consumers, such as gifts or more spontaneous second-hand sales, can facilitate reuse, intermediary actors often play a crucial role in enabling these transactions. Examples of such intermediaries include online marketplaces, second-hand retailers, and flea markets, all of which help facilitate product circulation. These intermediaries, referred to here as 'reuse enablers,' serve as connectors between individuals looking to divest used products and those seeking to acquire them. As such, reuse enablers must cater to the needs of both groups to effectively support sustainable product recirculation.

How consumers handle unwanted products affects product lifetimes: decisions like retaining, recycling, or passing items to new users determine whether products continue in use (Cruz-Cárdenas & Arévalo-Chávez, 2018; Sarigöllü et al., 2021). Divestment choices offer various personal benefits and costs, influencing which path consumers choose (Cruz-Cárdenas & Arévalo-Chávez, 2018). Transferring items to others often involves additional tasks, which can make circulation seem inconvenient or even deter it entirely (Selvefors et al., 2019). For those looking to divest, reuse enablers are

crucial to making recirculation more attractive and convenient than less sustainable options.

Reuse enablers also have a crucial role in addressing buyer concerns. Research highlights common barriers to second-hand shopping, including perceptions of disorganization, unpleasant odours, or uncleanliness (Bardhi, 2003; Bardhi & Arnould, 2005; Frahm, Boks, et al., 2024; Frahm, Laursen, et al., 2024). Although these views are changing (Mitchell & Montgomery, 2010), many shoppers still avoid second-hand items due to hygiene concerns, unpleasant shopping environments, and fears of social stigma (Armstrong et al., 2015; Frahm, Laursen, & Boks, 2023; Gullstrand Edbring et al., 2016; Hur, 2020; Wallner et al., 2022). Competing with new product sellers, reuse enablers must work to overcome these barriers, making second-hand shopping more appealing and thereby supporting more sustainable consumption patterns.

Prior studies on reuse enablers have often classified them by scope and revenue model (Yrjölä et al., 2021). Some reuse enablers support product recirculation without monetary exchange between consumers, such as through donations or direct gifting (Paden & Stell, 2005). Others rely on financial transactions—ranging from direct sales at flea markets, and online platforms to sales through intermediaries like second-hand retailers, auctions, consignment shops, and pawn shops (Lane et al., 2009; Paden & Stell, 2005; Sarigöllü et al., 2021). These descriptions, however, primarily emphasize business models and operational functions, offering limited insight into what the process of divesting and acquiring products second-hand entails for the consumers.

Studies on consumers divesting their goods, the operations of reuse enablers, and consumers purchasing second-hand items are typically treated as separate areas of analysis. However, together, these elements form an interconnected process essential for product circulation. Moreover, an underexplored concept in this context is consumption work—the labour involved in the purchasing, use, reuse, and disposal of products (Wheeler & Glucksmann, 2015). The nature of this consumption work within circular economy practices is crucial, as it may significantly influence the development and viability of the "circular consumer" and can be a key to understanding the 'attitude-behaviour' gap (Hobson et al., 2021). Despite its importance, consumption work remains a largely neglected area in the current literature and in broader discussions on reuse (Hobson et al., 2021).

While previous research has addressed how reuse enablers attract consumers by aligning with trends, maintaining cleanliness, repurposing items, or crafting engaging store environments (Frahm, Laursen, & Tollestrup, 2023; Gregson & Crewe, 2003; Parsons, 2005), few studies consider the ways reuse enablers facilitate connections between consumers divesting and consumers buying. This paper seeks to fill that gap by examining the different roles and linked activities in product circulation processes. By investigating the entire reuse process—with a particular emphasis on the consumption work it entails—this study aims to contribute a more holistic understanding of the consumers divesting, the reuse enablers, and the consumers purchasing pre-used. Furthermore, the study aims to develop the understanding of how these activities contribute to product circulation and the process of extending product lifetimes.

Methodology

This study is based on secondary data collected through several independent research studies. The three studies shed light on the concerns and activities performed by each of the three actors (see Figure 1). In combination, the studies contribute to answering the question of how the work required to recirculate products



Figure 1. The perspective that each of the studies contribute with.

is divided between consumers divesting, reuse enablers, and consumers buying.

The first study involved semi-structured interviews with 20 Swedish households, focusing on currently unused products retained within the household and how these products were divested. This study provided valuable insights into the various activities consumers engage in when divesting products, as well as their concerns during the process. Additional data from interviews with 20 Danish second-hand consumers (Study 2) offered insights into the activities and concerns of buyers of second-hand products, while data from interviews with 11 Danish second-hand retailers (Study 3) shed light on the value-adding and selling activities carried out by reuse enablers. Some complementary data was collected from various reuse enablers in both Sweden and Denmark, about the reuse enablers' service offerings and the process of divesting and acquiring products.

The analysis of reuse enablers is based on the premise that the appeal of circular consumption alternatives largely depends on how they fit into consumers' everyday lives (in line with Selvefors et al., 2019). Therefore, understanding what consumers do when interacting with different reuse enablers is crucial (cf. Hobson et al., 2021). To compare reuse enablers, we analysed the division of activities between the divesting consumer, the reuse enabler, and the buyer. This involved mapping out all the activities involved in a product exchange process for each reuse enabler and identifying "who does what", starting from when a consumer decides to divest a product and ending as the second-hand product enters a new home. The analysis also included the activities performed by the reuse enablers, mapping the value-adding activities.

A selection of reuse enablers to include in the study was made based on literature (e.g Paden & Stell, 2005; Yrjölä et al., 2021), and the authors' own experiences and awareness of different conduits, to include a variety of actors with different business models and offerings to the consumers. The selected reuse enablers included physical stores like charity shops and flea markets, but also various online based services (see Figure 3 for a full overview).

Results and Analysis

Product exchange processes consist of a long series of activities that vary between different reuse enablers, an overview of all activities found in the analysis is presented in Figure 2. These activities need to be performed for products to be recirculated. They are differently distributed between consumers divesting products, consumers purchasing products, and the reuse enablers depending on the conduit. Figure 3 illustrates the division of activities between the actors throughout the product exchange process for each type of enabler. Some of the activities always need to be carried out to make the product exchange possible (indicated by a full line around the activity), while others, though not critical, are frequently performed (indicated by a dashed line around the activity).

The sheer number of activities required was often perceived as being too much work, which often prevented or made recirculation more challenging. In addition, specific activities like preparing products for sale and dealing with buyers were often considered as hard work by divesting consumers. For consumers looking to divest products this hard work often worked as a barrier, preventing them from moving products along. Similarly, for reuse enablers there is both varied and hard work involved in handling and reselling second-hand products. For example, reuse enablers work hard to counteract the prejudice about smelly or dirty charity shops by cleaning products before bringing them into the store. The work involved in recirculating products is often challenging, especially for the consumers divesting, as they do not have the same routine and experience as the reuse enablers.



Figure 2. Product exchange activities.

Since certain reuse enablers share similar characteristics, they can be grouped into three primary categories: donations, commission sales, and sell-it-yourself. Each category will now be discussed in detail.

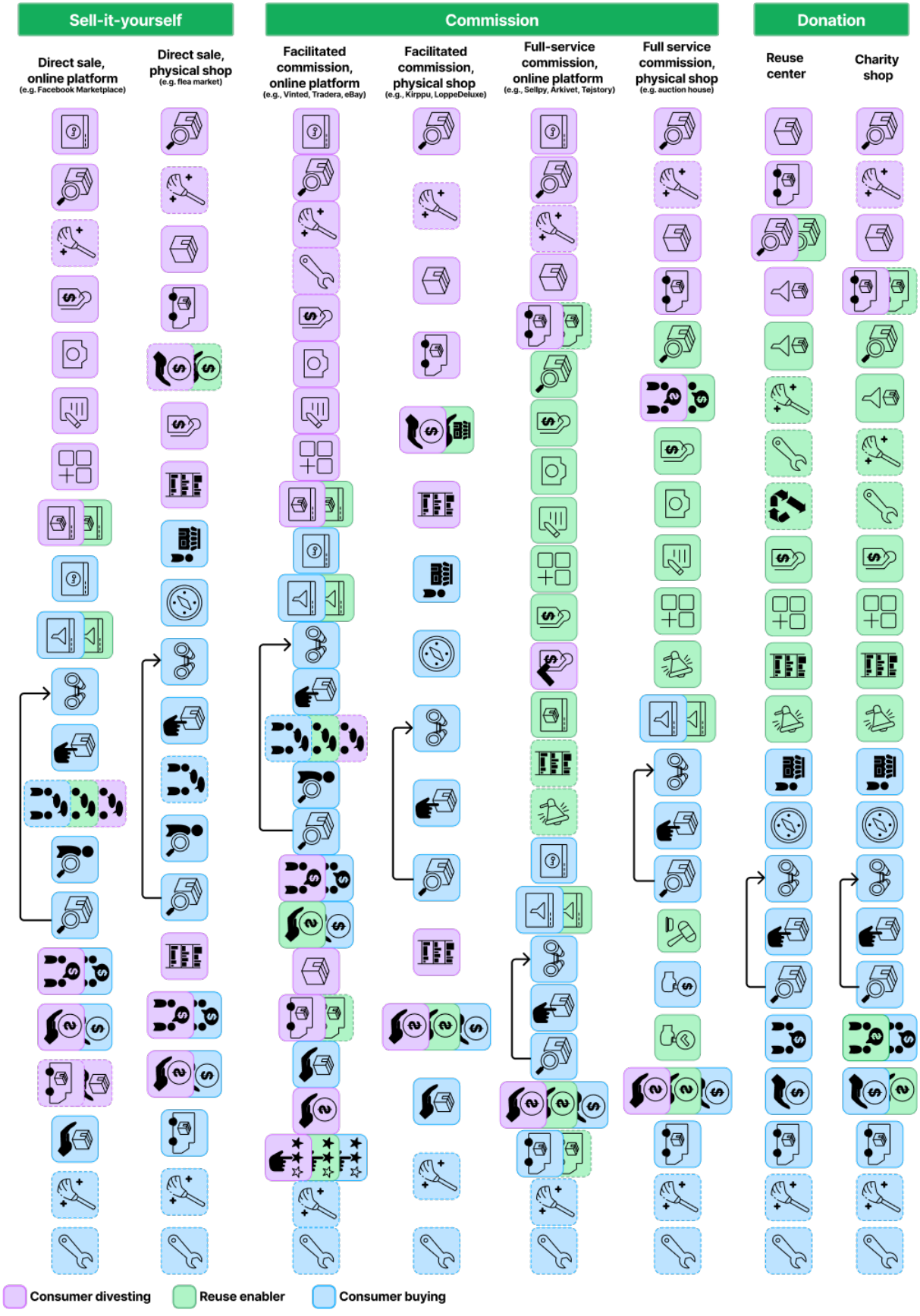


Figure 3. Division of activities between actors.

Donation

The donation process is characterized by a relatively low level of effort required from consumers who are divesting their items. Donating products to charity requires few activities and divested products can be handled in bulk which eases divestment. The divesting consumer receives no financial compensation; instead, all revenue from the resale goes to the reuse enabler, typically a charity shop or a reuse centre. The reuse enabler takes on the bulk of the work to recirculate the product. This includes re-valorisation efforts, such as cleaning, and sometimes minor repairs or upcycling, to make the items more appealing for resale, as well as the selling activities.

There is no direct interaction between the consumer divesting the item and the consumer purchasing it. Thus, the buying consumer has no way to assess the item's previous owner. This separation creates a distinct handover point, with minimal overlap in activities or interactions between the divesting and buying consumers and the reuse enabler. The absence of the original owner in this process simplifies price negotiations and may even contribute to a "neutral" feel to the product, as it is less affected by the previous owner's influence. This neutrality may enhance the appeal of the product to new consumers, making it feel more universally accessible and free from prior associations.

Commission Sales

In the commission sales category, there is greater overlap in activities among all participants—the divesting consumer, the buying consumer, and the reuse enabler. The reuse enabler receives a commission on each sale, with the monetary amount varying based on the level of service provided. *Full-service commission sales* yield a higher percentage for the reuse enabler compared to *facilitated commission sales*, where the reuse enabler's role is more limited.

The commission sales category thus includes two sub-categories. In *Full-Service Commission* (e.g., auction houses, full-service online platforms), the reuse enabler takes physical possession of the product, assuming a more involved role that includes setting sale terms and typically engaging with the divesting consumer on aspects like pricing and conditions of sale, which are often considered challenging by divesting consumers.

The reuse enabler manages a series of preparatory activities to prepare the product for sale, including advertising and coordinating with the buying consumer.

This interaction creates a more integrated experience for the buying consumer, while the divesting consumer's role becomes largely passive after the product is handed over. Notably, there is no direct contact between the divesting and buying consumers, and the buying consumer cannot evaluate the product's previous owner. In *Facilitated Commission* (e.g., physical commission shops, commission-based online platforms), the reuse enabler plays a more passive role, mainly providing a physical or digital platform where divesting and buying consumers can connect directly. The reuse enabler does not handle the product directly but instead facilitates the transaction by providing a secure space for the exchange. In this model, the divesting consumer takes responsibility for all aspects of the sale, including re-valorisation, advertising, and negotiations. Taking on this work is often considered challenging but is often worth it as they receive a larger part of the price. They remain actively involved throughout the entire process, unlike in full-service commission sales. The buying consumer has a limited ability to assess the divesting consumer, often relying on ratings, display quality, or other indirect indicators of the seller's reliability.

Overall, commission sales offer secure transactions and allow the reuse enabler to play either an active or passive role depending on the type of commission.

Sell-it-yourself

In the sell-it-yourself category, the consumer divesting the product assumes full responsibility for most aspects of the exchange, including re-valorisation, advertising, selling, and the final handover to the buying consumer. This type of reuse enabler significantly shifts the workload to the divesting consumer, who performs many of the activities typically managed by a reuse enabler in other sales processes. This is often seen as challenging, especially as the divesting consumers perform these actions infrequently and may lack the routines and competences required.

A unique characteristic is that transactions between the consumer divesting and the consumer buying rely heavily on mutual trust. Since the reuse enabler typically is not involved

in the financial exchange, there is no third-party security to guarantee the transaction's safety. Instead, the reuse enabler's role is mostly about providing a platform, either physical or online, where divesting and buying consumers can connect.

Throughout the process, the divesting consumer remains active, managing each step from product presentation to payment and handover. This arrangement conveys a high level of interaction between the consumer divesting and the consumer buying, as their activities are closely linked. The consumer divesting also benefits financially, receiving the full payment (or close to it) for the sale.

Overall, the sell-it-yourself category offers divesting consumers the chance to maximize earnings but requires them to manage most of the process themselves, making it a more self-reliant approach to product exchange. Nevertheless, these reuse enablers play an important role in making divested products accessible to a large pool of potential buyers and making a wide range of products accessible to consumers looking for something on the second-hand market.

Overall Comparison

When comparing different reuse enablers, it is evident that consumers who divest products receive a larger portion of the payment when they take on more responsibilities. By assuming tasks such as product re-valorisation, advertising, and selling, the divesting consumer can increase their share of the sale.

From the perspective of the buying consumer, the activities they must perform are relatively consistent across various reuse enablers. While the buying consumer may pay different prices for the same product depending on the platform, the number of activities required does not change significantly. This raises the question of what the consumer is actually paying for if it is not to be relieved of any work. Although not captured in this analysis, it is likely that the price difference is related to the overall shopping experience, which can vary greatly depending on the reuse enabler. Factors such as the selection of products, their condition, the layout of the shop, and the way items are displayed all contribute to the buyers' experience. These elements are, in turn, influenced by the activities carried out by the reuse enabler (or sometimes the consumer divesting). While these activities may not significantly reduce the buyer's workload, they can greatly enhance the shopping experience when carried out skilfully.

Discussion

This research highlights the substantial work involved in product circulation, both for consumers divesting products, the reuse enablers, and consumers purchasing them. For the consumers divesting products, reuse enablers can decrease the effort needed by taking over activities that the divestors otherwise would have to carry out themselves. In relation to the buyers, the reuse enablers not only provide a place to find second-hand products but also carry out activities to enhance the shopping experience.

While this analysis presents a complex landscape of available product circulation conduits, it only offers a partial view. Both consumers looking to divest and those seeking to buy products might struggle to understand the differences between various reuse enablers, and this complexity deepens when consumers must select a reuse enabler based on their specific needs. For divestors, high-value items may warrant a more work-intensive conduits to maximize profitability. However, for disposing of multiple lower-value items, other less work-intense conduits may be more suitable. Similarly, buyers' needs can vary. Are they shopping for enjoyment and browsing for unique finds, or are they seeking a specific product at a good deal? This distinction will influence which reuse enabler that is most suitable to satisfy their needs. Throughout the interview data that forms the basis for this study, there are indications that navigating the landscape of reuse enablers presents a significant challenge for both divestors and buyers. An important area for future research would thus be to explore this challenge further, with the long-term goal of making it easier for consumers to participate in product circulation markets and, hence, a circular economy.

Another valuable avenue for future research is the shopping experience and how it varies across different reuse enablers. A deeper exploration of how reuse enablers shape the overall shopping experience could not only reveal strategies for selling second-hand products at the highest possible price but perhaps also provide insights into how lower-value products can be effectively sold (or circulated) at all.

In conclusion, the presented analysis of the activities that are carried out by consumers

divesting products, reuse enablers, and consumers buying second-hand products illustrates the diverse and hard work involved in product recirculation for all participants. It sheds light on how reuse enablers bridge the gap between divesting and buying consumers and reveals how different types of reuse enablers affect the division of labour among these actors. This understanding can serve as a foundation to further support consumers in the second-hand market, for instance by introducing less work-intensive options. In turn, this can facilitate the recirculation of used products and extend product lifetimes.

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References

Armstrong, C. M., Niinimäki, K., Kujala, S., Karell, E., & Lang, C. (2015). Sustainable product-service systems for clothing: Exploring consumer perceptions of consumption alternatives in Finland. *Journal of Cleaner Production*, *97*, 30–39. https://doi.org/10.1016/j.jclepro.2014.01.046

Bardhi, F. (2003). Thrill of the Hunt: Thrift Shopping For Pleasure. *ACR North American Advances*. https://www.semanticscholar.org/paper/Thrill-of-the-Hunt%3A-Thrift-Shopping-For-Pleasure-Bardhi/bad7080a44bf8f9e8e9ed362a1c14d553f70b8f0

Bardhi, F., & Arnould, E. (2005). Thrift shopping: Combining utilitarian thrift and hedonic treat benefits. *Journal of Consumer Behaviour*, *4*, 223–233. https://doi.org/10.1002/cb.12

Cruz-Cárdenas, J., & Arévalo-Chávez, P. (2018). Consumer Behavior in the Disposal of Products: Forty Years of Research. *Journal of Promotion Management*, *24*(5), 617–636. https://doi.org/10.1080/10496491.2018.1405514

den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. *Journal of Industrial Ecology*, *21*(3), 517–525. https://doi.org/10.1111/jiec.12610

Ellen MacArthur Foundation. (n.d.). *Circular economy introduction*. Retrieved 14 November 2024, from https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Frahm, L. B., Boks, C., & Laursen, L. N. (2024). It's Intertwined! Barriers and Motivations for Second-hand Product Consumption. *Circular Economy and Sustainability*.

Frahm, L. B., Laursen, L. N., & Boks, C. (2023). *Smells Like Grandparents: Consumers' Barriers and Motivations to Second-hand Shopping*. PLATE. https://www.researchgate.net/publication/371911958_Smells_Like_Grandparents_Consumers'_Barriers_and_Motivations_to_Second-hand_Shopping

Frahm, L. B., Laursen, L. N., & Christensen, B. T. (2024). Creating a Mess!: Design Strategies for Managing Visual Complexity in Second-hand Shops. In *Proceedings of DRS2024 Boston: Resistance, Reflection, Recovery, Reimagination. Design Research Society International Conference*. Design Research Society. https://doi.org/10.21606/drs.2024.773

Frahm, L. B., Laursen, L. N., & Tollestrup, C. (2023). *Everyone does it: Product-related Resell Strategies of Professional Second-hand Retailers*. PLATE. https://www.researchgate.net/publication/371911955_Everyone_does_it_Product-related_Resell_Strategies_of_Professional_Second-hand_Retailers

Gregson, N., & Crewe, L. (2003). *Second-Hand Cultures*. Berg Publishers.

Gullstrand Edbring, E., Lehner, M., & Mont, O. (2016). Exploring consumer attitudes to alternative models of consumption: Motivations and barriers. *Journal of Cleaner Production*, *123*, 5–15. https://doi.org/10.1016/j.jclepro.2015.10.107

Hobson, K., Holmes, H., Welch, D., Wheeler, K., & Wieser, H. (2021). Consumption Work in the circular economy: A research agenda. *Journal of Cleaner Production*, *321*, 128969. https://doi.org/10.1016/j.jclepro.2021.128969

Hur, E. (2020). Rebirth Fashion: Secondhand clothing consumption values and perceived risks. *Journal of Cleaner Production*, *273*, 122951. https://doi.org/10.1016/j.jclepro.2020.122951

Lane, R., Horne, R., & Bicknell, J. (2009). Routes of reuse of second-hand goods in Melbourne households. *Australian Geographer*, *40*(2), 151–168. Scopus. https://doi.org/10.1080/00049180902964918

Mitchell, M. and Montgomery, R. (2010), "An Examination of Thrift Store Shoppers,"

Marketing Management Journal, Fall, pp. 94-107

Paden, N., & Stell, R. (2005). Consumer Product Redistribution: Disposition Decisions and Channel Options. *Journal of Marketing Channels*, *12*(3), 105–123. https://doi.org/10.1300/J049v12n03_06

Parsons, E. (2005). *Dealing in Second-hand Goods: Creating Meaning and Value*.

Sarigöllü, E., Hou, C., & Ertz, M. (2021). Sustainable product disposal: Consumer redistributing behaviors versus hoarding and throwing away. *Business Strategy and the Environment*, *30*(1), 340–356. https://doi.org/10.1002/bse.2624

Selvefors, A., Rexfelt, O., Renström, S., & Strömberg, H. (2019). Use to use – A user perspective on product circularity. *Journal of Cleaner Production*, *223*, 1014–1028. https://doi.org/10.1016/j.jclepro.2019.03.117

Wallner, T. S., Snel, S., Magnier, L., & Mugge, R. (2022). Contaminated by Its Prior Use: Strategies to Design and Market Refurbished Personal Care Products. *Circular Economy and Sustainability*, 1–22. https://doi.org/10.1007/s43615-022-00197-3

Wheeler, K., & Glucksmann, M. (2015). *Household Recycling and Consumption Work: Social and Moral Economies*. Springer.

Yrjölä, M., Hokkanen, H., & Saarijärvi, H. (2021). A typology of second-hand business models. *Journal of Marketing Management*, *37*(7–8), 761–791. https://doi.org/10.1080/0267257X.2021.1880465

Research paper
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Exploring Emotional Attachments in Children's Toy Relationships: A Generative Co-Design Approach to Design for Sustainability

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Keywords: Design for Sustainability; Toy Consumption; Emotional Durability; Product Longevity; Generative Design Research.

Abstract: The existing production and consumption system is causing significant plastic waste in the toy market. Unfortunately, most toys are discarded within six months of purchase, often due to the limited opportunities for extending the lifespan of toys through repairing, reusing, or recycling. To address this issue, this study explores the potential of emotional durability as a strategy to promote sustainable consumption in the toy industry. Utilizing the Emotional Durability Design Nine Framework as a theoretical foundation, this study emphasizes creating long-lasting emotional connections between children and their toys through various dimensions such as narratives, identity, relationships, and evolvability. A mixed-method approach is employed to engage children aged 10 to 12 in reflecting on their emotional attachments to toys, starting with semi-structured interviews with five children to identify their favorite toys, which they have kept for an extended period, and the factors influencing their attachment. Following that, cultural probes in the form of an activity set are designed to explore the stories associated with these toys and tested with four children. Finally, the refined version of the activity set is conducted in the classroom environment with 30 children. Findings indicate that personal memories, the desire for personalization, and the ability to repair or modify toys significantly influence children's attachment and the longevity of their toys. By integrating emotional durability into toy design, the study highlights its potential to encourage sustainable consumption practices and reduce waste in the toy industry, which may also encourage children to see toys as valuable, long-term companions rather than disposable items.

Introduction

The linear consumption model, which dominates global production, involves using and discarding products. As a result of this model, toys, often produced from plastic material, are part of a fast-moving consumer goods market that promotes frequent replacement (UNEP 2014). Research indicates that the majority of toys end up in landfills within six months, significantly contributing to the accumulation of plastic waste (Qian et al., 2020; Clark, 2007). However, due to the complex and mixed use of materials in toys, it is rare to convert toy waste into raw materials for various purposes (Qian et al., 2020).

Circular economy principles focus on reducing waste and prolonging the lifespan of products through design interventions that enable repair, reuse, and recycling (Bocken et al., 2016). However, since the toy market is primarily concerned with low-cost disposable products, it is challenging to address these principles. As a result, addressing this issue requires a shift from a linear consumption model to sustainable consumption, in which both producers and consumers can play a significant role in extending product life spans by establishing a strong person-product relationship (Mugge et. al, 2005; Kamptner,1991). This can be achieved by focusing on emotional durability, where consumers, especially children in this case. This approach would enable them to build long-term attachments with their toys while encouraging them to keep these products longer.

The Emotional Durability Design Nine Framework

The Emotional Durability Design Nine Framework proposed by Haines-Gadd et al. (2018), provides a comprehensive approach to designing products that foster long-lasting emotional connections with users. The framework comprises nine themes: *narratives, consciousness, identity, relationships,*

evolvability, materiality, integrity, imagination, and *conversations*. Each of these themes explores a different way in which a product can engage the user and create a meaningful experience that goes beyond its primary functional value. For instance, the *narrative* theme emphasizes the importance of a product's history and the stories it carries, while *identity* allows users to personalize and enhance their attachment. In toy design, these elements are critical because children often develop attachments to toys through storytelling, imaginative play, and personalization. By integrating features that allow children to connect emotionally with their toys, designers can help extend the life of these products, reducing the tendency for early disposal.

The Emotional Durability Design Nine Framework (Haines-Gadd et al., 2018) is particularly relevant in the context of toys, as it helps explain how specific design features can prolong a toy's lifespan by encouraging children to form deeper emotional bonds with them. It provided a critical theoretical foundation for this research, offering structured insights into the design and sustained emotional attachment to products over time. Within the context of the research, this framework was adopted by particularly focusing on the dimensions, such as *narratives, identity, relationships,* and *evolvability*, which was useful in guiding both the design of the activity set and the analysis of the data gathered from the participants involved in the research.

Methodology

Sampling and Participants

In this study, children aged 10 and 12 were recruited based on their social, cognitive, and motor development. Ethical approval for this research was obtained from The Middle East Technical University (METU UEAM) Applied Ethics Research Center before participant recruitment. As stated in Piaget's Cognitive Developmental Theory, children around 10 to 12 years old are transitioning from the concrete operational stage (ages 7–11) to the formal operational stage (11+), enabling them to establish, express, and verbalize connections with their toys (Berk, 2006). Their capability for social bonding, analytical thinking, and physical involvement improved their engagement with toys in ways that promote emotional durability, making this group appropriate for investigating how sustainable toy design may foster long-term relationships.

Stages of the Research

This research employed a mixed method, incorporating *generative design research* and *participatory co-design* approaches, to obtain comprehensive insights into children's behaviors and the underlying reasons for their preferences. This is achieved through the use of exploratory research techniques such as cultural probe kits (Hanington & Martin, 2012). Figure 1 illustrates the division of the field research into three stages.

Phases	Method	Aim of the Method
Preliminary Phase	Semi-Structured Interviews	Gaining an understanding of children's favorite toys and the type of toys they have been carrying with them for a long time.
Pilot Research	Cultural Probe	Learning more about the stories behind children's favorite toys and evaluating usability and how much they enjoy during completing the diaries.
Final Research	Cultural Probe (as a classroom activity)	Gaining an in-depth understanding of children's favorite toys and their emotional connections with their toys during completing the revised version of diaries.

Figure 1. Stages of Field Research.

Initially, *semi-structured interviews* were conducted with three girls and two boys aged between 10-11 to gain an understanding of children's favorite toys and the type of toys they have been carrying with them for a long time; secondly, *cultural probe* in the form of *activity set* was designed based on the Emotional Durability Design Nine Framework (Haines-Gadd et al., 2018) and the results of the semi-structured interviews, and then conducted with two girls aged 10 and 11 to learn more about the stories behind children's favorite toys and evaluating the usability and joyfulness of the cultural probe. Finally, as part of the primary research, the activity set was revised according to the findings of the pilot study and refined version was shared with 30 children, including 15 girls and 15 boys aged 10-12, recruited from both private and public schools to gain a comprehensive understanding of children's favorite toys, such as plush toys, educational toys, dolls, action figures, vehicles and sports toys, and their emotional connections with them, examining the reasons behind why they keep some toys while discarding others (see Table 1). During the main research, all sessions were held in the classroom environment (see Figure 2) as a classroom activity to facilitate a comfortable and familiar environment. Each

child was also encouraged to bring in their favorite toy to the activity sessions. Through these hands-on interactions, how they cared for their toys, which elements they felt most attached to, and what aspects of their toys they would modify if given the chance, were observed. This approach allowed for a deeper understanding of how emotional bonds are formed and maintained in the context of toy use.

Participant Number	Age	Toy Category	Age of the Toy
Pilot 1	10	Plush Toy	2
Pilot 2	11	Plush Toy	8
P1	12	Plush Toy	8
P2	12	Sports Toy	N/A
P3	11	Plush Toy	6
P4	11	Plush Toy	9
P5	11	Plush Toy	10
P6	11	Plush Toy	2
P7	11	Plush Toy	5
P8	11	Doll	6
P9	11	Plush Toy	10
P10	11	Action Figure	2
P11	11	Plush Toy	8
P12	11	Plush Toy	2
P13	11	Sports Toy	2
P14	10	Plush Toy	N/A
P15	11	Educational Toy	5
P16	11	Plush Toy	5
P17	11	Action Figure	9
P18	11	Sports Toy	N/A
P19	10	Action Figure	3
P20	10	Plush Toy	3
P21	11	Educational Toy	N/A
P22	12	Plush Toy	7
P23	11	Vehicle	3
P24	12	Doll	7
P25	11	Vehicle	2
P26	12	Vehicle	8
P27	12	Educational Toy	2
P28	12	Plush Toy	5
P29	12	Plush Toy	3
P30	12	Plush Toy	3

Table 1. The list of the participants based on their favorite toy categories and the length of time they have owned them.



Figure 2. The cultural probe is utilized as a classroom activity.

Development of the Cultural Probe in the Form of Activity Set

A unique generative design research method, in the form of an activity set (Sanders et al., 2012), was developed to gather data from children about their emotional connections with their toys (Özkürkçü, 2024). Before designing the activity set as a generative method, a comprehensive literature review on the research methods such as Contextual inquiry (Druin, 1999), Mission from Mars (Dindler et al., 2005), and Kid Reporter (Bekker et al., 2003), was conducted to explore the relevant co-designing methods, tools, and techniques with children in a way that could be engaging for children. As a result, the activity set was designed to be engaging and interactive, allowing children to reflect on their favorite toys and explore why they are valuable for them. Initially, the concept of the activity set was inspired by the Mission from Mars approach (Dindler et al., 2005), in which children were encouraged to take off into space on a spacecraft called Memorium (see Figure 3). Within the context of class activity, 30 activity sets were shared with the children. The content of those was analyzed through thematic coding, with the theoretical framework guiding the structure of the analysis. This approach facilitated a systematic exploration of emotional durability by categorizing the data according to each dimension. The data analysis in this research included voice recordings and visual data from activity set sessions. The data was transcribed and analyzed using the Miro Board interface. Key parts were highlighted, and related themes were identified based on participants' responses. An Excel document was prepared to categorize participant information, including age, gender, toy

category, and features they love, dislike, or want to change. The data analysis aimed to improve the evaluation and interpretation of the verbal and visual information gathered.

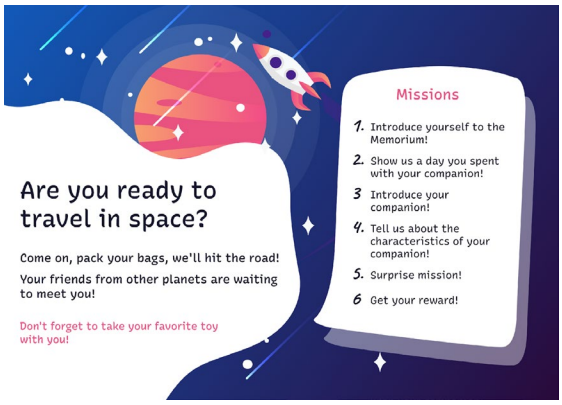


Figure 3. Introductory page of the cultural probe representing takeoff in space on Memorium.

To participate in the spacecraft and experience space travel between different planets, the children were required to complete specific tasks. These tasks included explaining the stories they had been together from the beginning, personalizing them according to their preferences, and expressing a desire to repair or modify them. The purpose of these activities was to uncover the emotional factors that underlie product attachment.

Before participating in the classroom activity, parents were required to complete the consent form, and the children were asked to bring their favorite toys. The first phase of the activity included an overview of the exercises, which included: i) an introduction to the spaceship; ii) a day with a preferred toy; iii) a general presentation of the preferred toy; iv) a features-focused introduction of the preferred toy; and v) a dream toy concept. Subsequently, children were asked for their verbal consent to participate in the study, and the tape recording began upon their approval.

As part of the "Mission on Mars: Introduce yourself to the Memorium!" activity, children were prompted to provide essential personal information, like their names, ages, interests, and hobbies. The objective of the activity was to familiarize the children with the activity and to gather information about them by allowing them to introduce themselves to the spacecraft. The design of the activity was intended to resemble progression through different levels, similar to progressing through stages in a board game, rather than directly asking the set of questions in a list view (Figure 4).



Figure 4. "Mission on Mars: Introduce yourself to the Memorium!" activity.

During the "Mission on Jupiter: Show us a day you spent with your companion!" activity, the children were instructed to illustrate and articulate their interactions with their cherished toys, and also a sticker set was provided by the researcher to motivate them to complete the activity. This activity provided valuable insights into the significance of the toy in daily routines and activities, allowing the researcher to explore the "relationship" dimension, regarding "establishing a ritual or habit" as outlined in the Emotional Durability Design theoretical framework (Haines-Gadd, 2019; Haines-Gadd et al., 2018). For instance, Participant 1 drew a typical day with his cherished plush toy and highlighted the moments when his companion was present. As shown in Figure 5, he spends the entire day with his plush toy.

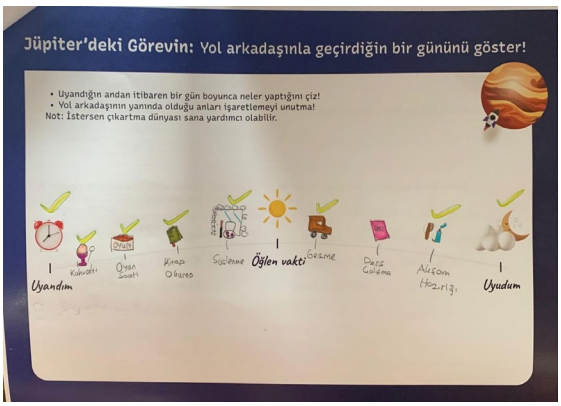


Figure 5. Participant 1's "Mission on Jupiter: Show us a day you spent with your companion!" activity.

In the "Mission on Saturn: Introduce your companion" activity, the children were asked to

provide details regarding their favored toy, encompassing its name, duration of ownership, reasons for selection, and the toy's significance in their lives, to collect general information about their favorite toys. In Figure 6, Participant 24 introduced her plush toy "Verda", which she had owned for seven years. Verda with her curly hair, "containing everything" was seen as a source of confidence and capable of surviving in difficult conditions. In addition, reflecting on the *narrative* theme, where a toy's story and personal memories enhanced the emotional attachment, she explained the day they met each other as on the day her first tooth came out, the tooth fairy brought her a gift (meaning her mother).

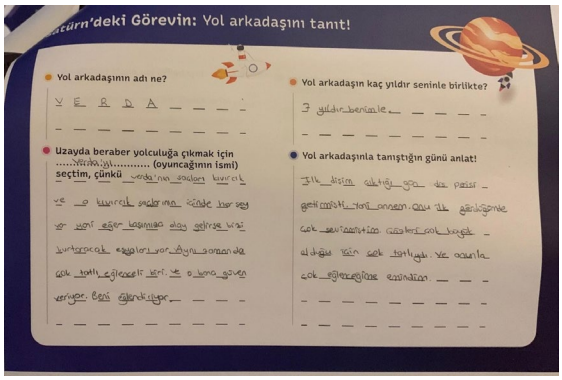


Figure 6. Participant 24's "Mission on Saturn: Introduce your companion!" activity.

The following content of the activity set will be the basis for the findings and insights regarding the main themes that emerged from the analysis. In the "Mission on Uranus: Tell us about the characteristics of your companion!" activity, children were instructed to provide details about their favorite toy and its characteristics, including both favorable and unfavorable aspects. They were also asked to demonstrate these features on the toy to facilitate a comprehensive understanding of their preferences. For instance, Participant 1 illustrated his cherished plush toy, marking his favorite characteristics with a green sticker and his disliked characteristics with a red sticker. Also, he explained the reasons for his favorites, including too cute, ideal size for portability, and also the disliked features, including unstableness and some scratches on his eyes (Figure 7). This aligned with the *relationship* theme, specifically, the subtheme of *fixing or maintaining the product*, since highlighting scratches indicated a desire to care for or fix the toy, establishing an emotional connection through maintenance and care.

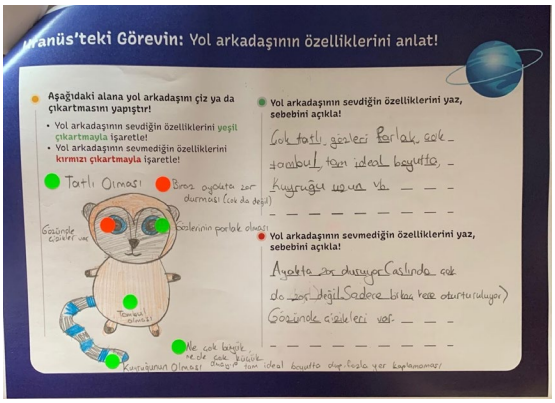


Figure 7. Participant 1's "Mission on Uranus: Tell us about the characteristics of your companion!" activity.

On the other hand, related to the relationship theme, Participant 23 preferred to repair his favorite vehicle by detaching the broken parts and replacing those with new ones (Figure 8) in order not to lose his cherished item.

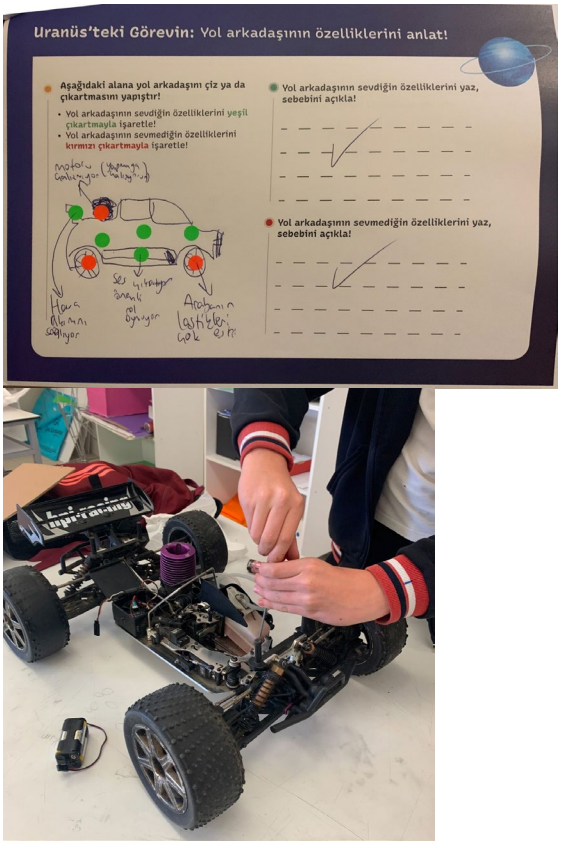


Figure 8. Participant 23's "Mission on Uranus: Tell us about the characteristics of your companion!" activity and repairing his cherished vehicle.

During the "Mission on Neptun: Time for change!" activity, children were prompted to express their concepts of a dream toy, including any preferred modifications or alterations, as well as the reasons and methods for implementing these changes. This enabled both the researcher and the children to investigate their preferences and concepts for their dream toys, also linked with the *identity*, *relationship*, and *evolvability* themes as outlined in the Emotional Durability Design theoretical framework (Haines-Gadd, 2019; Haines-Gadd et al., 2018). For instance, Participant 24 expressed a desire to personalize the doll's appearance, aligning with the *identity* theme. She indicated that she wanted to change Verda's "simple and boring" clothes for something more stylish, as well as change her hair color, to improve her fashion sense. To connect Verda's look with her own style, Participant 24 drew a "before and after" change on the activity sheet (Figure 9), demonstrating how personalization promoted personal connections via shared identity.

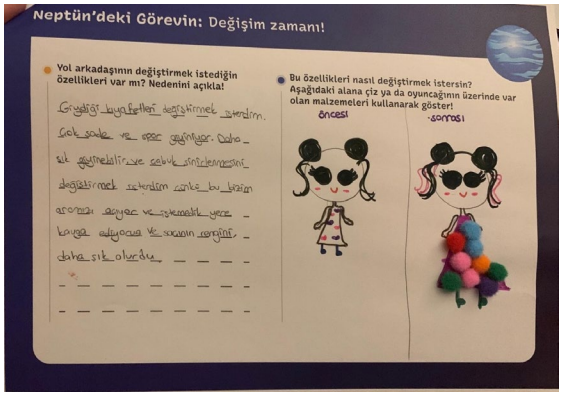


Figure 9. Participant 24's "Mission on Neptun: Time for change!" activity.

On the other hand, Participant 8 expressed a desire to personalize her cherished doll (Figure 10) by adding a scarf that matches her outfit and giving it magical abilities: "I wish it had a wand and could do magic." This was also in line with the *identity* theme, as she highlighted tailoring the doll with some distinct characteristics that represented her creative desires.

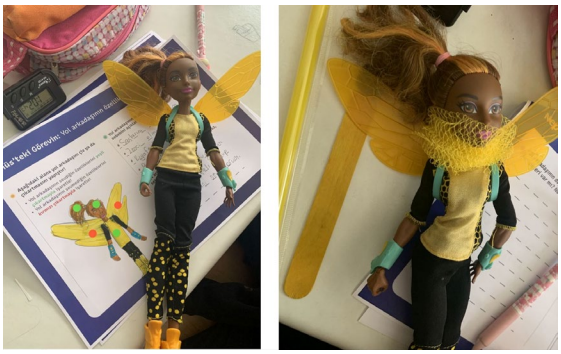


Figure 10. Participant 8's "Mission on Neptun: Time for change!" activity.

Participant 22's desire for her plush toy Snoopy to have stronger, more durable limbs highlighted the *evolvability* theme, which emphasized the adaptability of products to meet evolving user demands over time. When she wished to put extra stuffing in Snoopy's arms for comfort, she demonstrated how toys might be modified to enhance functioning as preferences change (Figure 11).

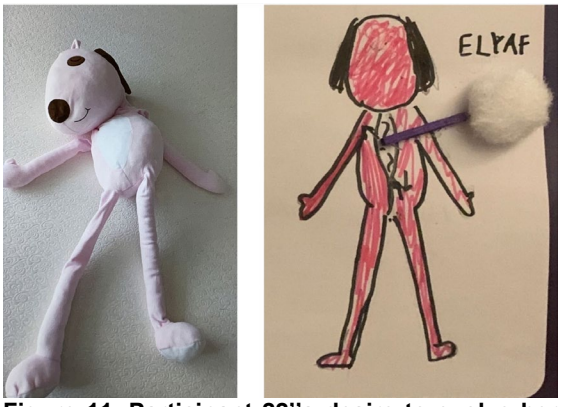


Figure 11. Participant 22''s desire to evolve her plush toy.

Another example linked to the *evolvability* theme was given by Participant 19, who described his action figure as a cherished toy because it could transform across various play scenarios, such as changing from a whale to a robot, which evolved to match children's changing preferences and developmental needs over time (Figure 12).



Figure 12. Participant 19's "Mission on Neptun: Time for change!" activity.

Conclusion

This study demonstrated the potential of emotional durability as a strategy for promoting sustainable consumption in the toy industry. The study encouraged children to engage in activities that reflect their emotional attachments to toys by integrating the Emotional Durability Design Nine Framework (Haines-Gadd et al., 2018) as the theoretical basis for developing the activity set. The activity set included tasks such as storytelling about the toy's origin, personalizing or repairing the toy itself or the drawing of the toy, and imagining how they might evolve or modify their toys. The findings revealed that certain emotional dimensions were more prominent in promoting toy longevity. Children often attach emotional value to toys linked to personal memories, such as gifts from family members or toys associated with special life events, highlighting *narratives* as a key factor. *Identity* was also significant, as children expressed a strong desire to personalize their toys, which deepened their attachment to their belongings. On the other hand, the *relationship* was another key dimension influencing their connection, as several participants mentioned that they repair or want to repair broken toys. Additionally, *evolvability*, the ability of toys to change and adapt over time, was found to be crucial in maintaining long-term engagement, as children valued toys that could grow with their interests. While implementing the activity set as a classroom activity for generative co-design sessions provided valuable insights into children's relationships with their toys and supported its effectiveness in fostering interest and motivation, several limitations emerged. Initially, some children did not bring their toys to the classroom due to fear of damage. Contrary to expectations, few children had personalized or repaired their toys, aiming instead to preserve them. For these limitations, the toolkit can be developed further with additional 2D and 3D components and accessories to help children reflect on changes that they would like to make or simply build their dream toy that may also reflect or integrate those features for personalization, repair, and upgrade. Future research could encourage children to bring toys they wish to modify or create their dream toys, offering additional perspectives on attachment and personalization by implementing warm-up activities. In addition to these future research suggestions, it would also be valuable to explore the role of parents in toy purchasing decisions, as these can significantly influence the connection children form with their toys. Finally, longer study durations and multiple sessions including the whole lifespan of toys (design, production, use, and post-use) could also provide a deeper understanding of building emotional connections for actively involving children in the design process.

Acknowledgments
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References
Bekker, M., Beusmans, J., Keyson, D., & Lloyd, P. (2003). KidReporter: a user requirements gathering technique for designing with children. *Interacting with computers, 15*(2), 187-202.

Berk, L. E. (2006). *Child Development.* Boston: Pearson.

Bocken, N. M., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of industrial and production engineering, 33*(5), 308-320. https://doi.org/10.1080/21681015.2016.1172124

Clark, E. (2007). *The real toy story: Inside the ruthless battle for America's youngest consumers.* Simon and Schuster.

Dindler, C., Eriksson, E., Iversen, O. S., Lykke-Olesen, A., & Ludvigsen, M. (2005). Mission from Mars: a method for exploring user requirements for children in a narrative space. In *Proceedings of the 2005 conference on Interaction design and children* (pp. 40-47). DOI: 10.1145/1109540.1109546

Druin, A. (1999, May). Cooperative inquiry: developing new technologies for children with children. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (pp. 592-599). https://doi.org/10.1145/302979.303166

Haines-Gadd, M. (2019). *Emotional durability design nine: Developing a tool for product longevity* (Doctoral dissertation, University of Brighton).

Haines-Gadd, M., Chapman, J., Lloyd, P., Mason, J., & Aliakseyeu, D. (2018). Emotional durability design nine—A tool for product longevity. *Sustainability, 10*(6), 1948. https://doi.org/10.3390/su10061948

Hanington, B., & Martin, B. (2012). *Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions.* Rockport Publishers.

Kamptner, N. L. (1991). Personal possessions and their meanings: A life-span perspective. *Journal of Social Behavior and Personality, 6*(6), 209. Unique identifier: 1992-01081-001

Mugge, R., Schoormans, J. P. L., & Schifferstein, H. N. J. (2005). Design strategies to postpone consumers' product replacement: The value of a strong person product relationship. *The Design Journal, 8*(2), 38-48. https://doi.org/10.2752/146069205789331637

Özkürkçü, E. (2024). *Exploring the Dimensions of Emotional Durability and Longevity in Toy Design for Sustainability* (Master's thesis, Middle East Technical University (Turkey)).

Sanders, E. B. N., & Stappers, P. J. (2012). *Convivial toolbox: Generative research for the front end of design.* Bis.

Qian, K., & Fennessy, L. (2020). Undo-Replay: re-scripting unsustainable toy consumption through value transference.

UNEP. (2014). *UNEP 2014 Annual Report.* Retrieved from https://www.unep.org/resources/annual-report/unep-2014-annual-report

Research paper
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Selling repurposed furniture: An exploratory study into consumer perception

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Keywords: Urban Upcycling; Circular Design; Furniture; Aesthetics; Consumer Perception.

Abstract: Repurpose is becoming more popular as a circularity strategy. This circularity strategy is specifically promising in the case of furniture. One of the challenges of upscaling repurpose is the negative consumer perception of repurposed products. Studies up to date pertain to consumer perception of refurbished products and products using recycled content. In this study we investigate (1) to which extent the motives mentioned within literature play a role when it comes to consumers' perception of repurposed furniture and (2) to what extent the visibility of past identity of repurposed furniture and storytelling play a role in consumer perception. The result indicate that aesthetic and functional quality are highly valued. Storytelling seems to be a secondary motive for customers to consider a repurposed product. We further identified three categories of repurposed furniture (i.e., visibly repurposed, non-visibly repurposed and unique look) that appeal to different consumer segments. While further research can be done into the demographic profiles, these categories can be used by designers/makers to make repurposed products that better appeal to their envisioned customer base.

Introduction

As part of the transition towards a circular society, upcycling, a process in which products and materials that are about to be disposed, are instead repaired, refurbished or repurposed or remanufactured in a way that increases their value (Singh et al., 2019), is gaining growing attention of both researchers and practitioners. Out of all the different circularity strategies, repurpose delays recycling or disposal of end-of-life consumer products by using discarded products or their parts in new products with a different function and/or in a different context, thereby retaining value added during previous production and use processes (Potting et al., 2017; van Hees & Oskam, 2021; Lepelaar et al., 2022).
Repurpose is specifically promising in the case of furniture, as annually large volumes of furniture are being discarded and incinerated while these volumes still retain a high residual value (Sung, 2017) and there are opportunities for localized and flexible production in the furniture industry (Hjelmgren et al., 2015).
Even though repurpose deals with some challenges such as streams of discarded materials having varying quality and limited availability (Leede et al., 2021; Lepelaar et al., 2022) this strategy is being embraced commercially (Sung, 2015) and is seen by scholars as a promising circular business model strategy (Lüdeke-Freund et al., 2018).
Yet, from the different strategies that can be employed to contribute to circularity, repurpose is currently the least explored by scholars (Berglund et al., 2023; de Leede et al., 2021; Lüdeke-Freund et al., 2019).

One of the challenges in upscaling repurpose is the negative perception consumers have about repurposed products e.g., lack of good quality products, high price and limited access (Singh et al., 2019). Yet, a positive image of circular products could contribute to the acceptance of repurposed products (Calvo-Porral & Lévy-Mangin, 2020). Studies that have looked at motives influencing consumer perception of circular products focus on strategies such as refurbishment (Mugge et al., 2017; Van Weelden et al., 2016), and the use of recycled content in products (Essoussi & Linton, 2010) and to a lesser extend repurpose (Yu & Lee, 2019). Mugge et al. (2017) provide the most comprehensive list of motives including familiarity with the concept of refurbishing, the product category, financial benefit, functional quality, aesthetic quality, warranty, degree to which a product is personal e.g., prescription glasses, and contamination. Apprehension

when it comes to contamination mainly arises due to concerns about hygiene, utility and territory (e.g., this product belongs to someone else) (Baxter et al., 2014).
Yu & Lee (2019) in addition mention social value and emotional value. Essoussi & Linton (2010) conclude that consumers are willing to pay less for products that make use of recycled content as they perceive them to have lower quality due to a higher functional risk. Lack in trust of product performance of circular products negatively influences product perception (Yu & Lee, 2019). Providing consumers with a story about the past identity of repurposed products can aid in positive consumer perception (Kamleitner et al., 2019). Table 1 gives an overview of the most mentioned motives that influence consumer perception.
Within literature there are no studies looking into consumer perception of repurposed furniture, specifically. Hence, in this study we investigate (1) to which extent the motives mentioned within literature play a role when it comes to the perception of repurposed furniture in practice and (2) to what extent the visibility of past identity of repurposed furniture and storytelling play a role in consumer perception.

Motives	**Definition (the degree at which the consumer…)**	**Sources**
Familiarity with (circularity) concept	… is familiar or understand the circularity concept being applied	Mugge et al. (2017); Sung (2017)
Financial benefit	… perceives that the price difference between a new and refurbished product is large enough to benefit from	Mugge et al. (2017); Van Weelden et al. (2016)
Functional quality	… perceives the physical performance or functional obsolescence of the product	Mugge et al. (2017); Yu & Lee (2019); Sung (2017); Singh et al. (2019)
Emotional quality	.. perceives the product to be able to arouse feelings (e.g., enjoyment, feeling good)	Yu & Lee (2019); Sung (2017)
Social benefits	… perceives that the product will increase their status or self esteem	Yu & Lee (2019)
Aesthetic quality	… perceives the product to be beautiful	Mugge et al. (2017); Yu & Lee (2019)
Personalization quality	… perceives that the product needs personalization (e.g., prescription glasses) or can be used as form of self-expression	Mugge et al. (2017); Yu & Lee (2019); Park & Lin (2020)
Environmental benefit	… perceives the product to provide an environmental benefit	Van Weelden et al. (2016); Yu & Lee (2019); Sung (2017)
Uniqueness	… perceives the product as one of a kind or innovative	Park & Lin (2020)
Warranty	… product comes with a guarantee that you can bring it back in case it does not function as promised	Mugge et al. (2017)
Contamination	… perceive the product to be contaminated due to previous use	Mugge et al. (2017); Baxter et al. (2014)
Storytelling	providing a story of the past identity of the repurposed product	Kamleitner et al. (2019)

Table 1 Motives influencing consumer perception of circular products

Motives	Sample statements
Aesthetic quality	I did not think the product looked pretty I think the product looked pretty
Storytelling	The storytelling about the product appealed to me
Financial benefit	I think it's too expensive It was cheaper than buying a new item
Functional quality	I'm doubting about the functionality The product offers a functionality that I needed
Warranty	I'm doubting about the warranty
Contamination	I think it's dirty/I did not like the thought that someone else had used (part of) the product previously
Emotional quality	The product that I bought or got repurposed retained emotional value
Environmental benefit	I'm doubting about the product lifetime I value sustainability (I rather do not buy new interior products)
Uniqueness	The product was made from a unique material It's a unique product that is not being made somewhere else

Table 2 Motives and sample statements

Method

Survey

A survey and in-depth interviews were conducted. The survey was spread through online channels such as LinkedIn and via the partners of the research project Urban Upcycling from the Amsterdam University of Applied Sciences. The goal of the survey was to get more insights into the motives influencing consumer perception of repurposed furniture. In the survey participants were asked whether they were familiar with the repurpose concept, as familiarity of the circularity concept could influence consumer perception (Mugge et al., 2017). Participants were also asked whether they had bought repurposed furniture and how long ago. Subsequently, participants were presented with statements describing why they did or did not buy repurposed furniture. The statements were based on motives identified within literature (see table 2). We also provided room for participants to share their own motives. The survey was open for responses from May until November 2023.

In-depth Interviews

The survey was followed up by in-depth one-on-one interviews with 7 participants. Part of these participants also participated in the survey. We ensured that there was a variety in age and background amongst the participants. With the interviews we aimed to further investigate how the degree of visibility of repurposed material and storytelling played a role in consumer perception of the products. In the interviews, participants were first asked to share more about themselves and their affinity with sustainability and we explained the repurposed concept. Second, participants were presented with 12 products within the product categories: lamps, stool and accessories — four products in each category (see Appendix A). We chose these three categories as these categories include products that all consumers have in their house and that are being purchased a couple of times in a lifetime. We selected products that differed in terms of their visual appearance, specifically how visible the repurposed component and materials were in the product. In the first round, we provided only the images of each of the products. In the second round, as a means of storytelling, we provided the background information of the products i.e., company name, description of the product and what it was made of. We asked the participants to rank the products based on how likely it was that they would buy them in case they had to style them in a completely new space. We did not provide the absolute prices of each product but instead gave an indication using icons as to focus on the visual appearance of the product and storytelling. Table 2 gives an overview of one product per category. Both the survey as well as the interviews were conducted in Dutch. Hence, mainly people who live in the Netherlands and who are speaking Dutch participated in the survey. The interviews were analyzed using the annotated portfolio as described by Sauerwein et al. (2018).

Lamp



From: The Talk Of The Town design



Stool



From: Circulair Warenhuis



Accessories



From: Super Local

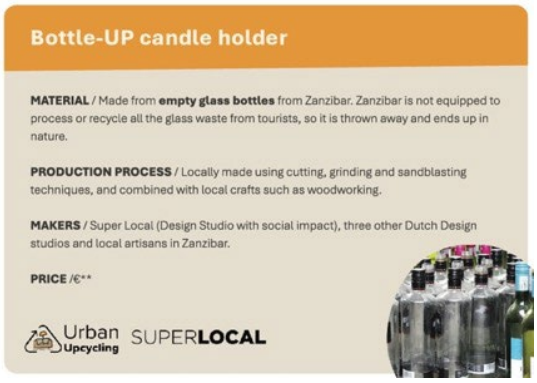


Table 3 Example of the product-images and background information that were shown to participants. See the Appendix for the full set of product-images.

Results

Survey

Demographic participants
We recorded a total of 231 responses. Four responses were excluded, because the respondent did not agree with the conditions of the survey. In addition, we excluded 65 responses as they did not complete the full survey, leaving us with 162 responses. The ages of the respondents varied from 18 to 65+ (92%). 32% of the participants identified as men and 60% of women and the rest selected other categories (e.g., non-binary or preferred not to say). 81% of the respondents were academically educated e.g., university of (applies sciences) and lived (67%) and worked (66%) in a city as opposed to a village. Half of the respondents (n=83) shared that they had bought repurposed furniture in the past, of which almost half (46%) bought living room furniture (e.g., a couch, coffee table, lamps or tv cabinet). A ranking of other types of furniture included office (10%), outdoor (10%), bedroom (8%) kitchen (5%). 82% of repurposed products were bought between 2023 and five years prior to that.

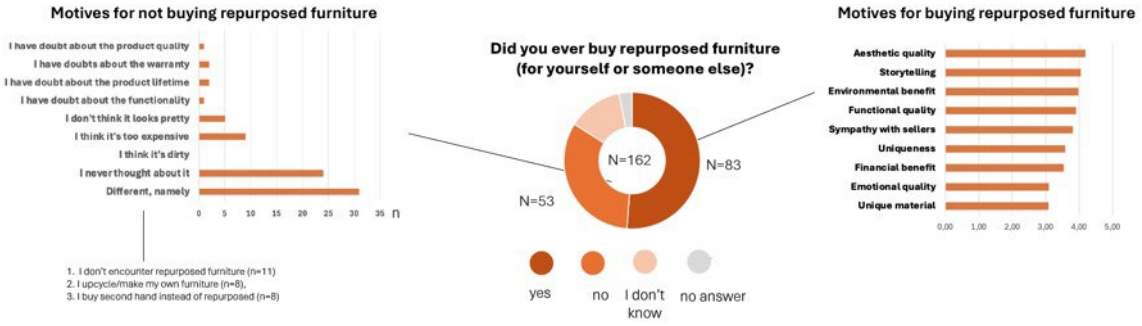


Figure 1 Infographic consumer motives to (not) buy repurposed furniture

The motives

For purchasing repurposed furniture
The respondents who had bought upcycled furniture (n=83, 51%) valued statements about why they would buy repurposed products in the following order: (1) aesthetics, (2) storytelling and (3) sustainability and, (4) functionality. Respondents identified less with the statements related to the origins of the materials, the emotional value connected to the product or sympathizing with the designers of the product, see figure 1.

For not purchasing repurposed furniture
Of the respondents who never bought repurposed furniture before (n=53, 33%) indicated that they had never considered buying repurposed furniture (32%), thought it was too expensive (12%) and did not think it was beautiful (7%). Motives related to the life span of the product, warranty, (perceived) product quality and product contamination were chosen to a lesser extent. Next to that, a large portion (41%) provided their own explanation. These explanations can be categorized as: not encountering repurposed furniture (n=11), upcycling their own furniture (n=8), buying second hand instead of repurposed (n=8), limited offerings (n=5) and logistics hassle to get the furniture from the store to the house (n=1). These respondents provided the following prerequisites to consider buying repurposed furniture in the future: availability at regular (large) stores, improved visibility of repurposed products, more marketing and advertisement, less expensive, improved aesthetic appearance e.g., not so apparently repurposed, and clean products.

Repurpose in the future
71% of the respondents indicated that they were open to buying repurposed furniture in the future. Motives given were related to sustainability (e.g., using less resources, better for the environment), unique design of repurposed furniture price and third lower price.

Visual appearance

During the in-depth interviews, the participants did not rank the products remarkably differently before and after providing the background information (table 3). What seemed to be leading in ranking the products was the aesthetics appeal. The participants mostly mentioned a product's look as reason for ranking the product at a certain place. Positive aesthetic valuations (e.g., this product… looks pretty, fits my interior style, looks unique) equaled high rankings, while negative valuations (e.g., the product looks ugly, cheap, looks contrived or chaotic). While a couple of the participants perceived the products that visibly looked repurposed as unattractive, there were some participants who valued this look as sustainable (e.g., you can see that materials are being repurposed). In addition, certain product designs seemed to be interpreted as generic and were related to mass produced furniture. Participant 6 said: "This is a certain style that I associate with Leenbakker [explanation: a large furniture store in the Netherlands]. I mean I see this type of furniture more often". In addition, color choice as well as printing on products appealed to varying degrees to the participants.

Before providing background information

	#1 favorite	#2	#3	#4 least favorite
Lamps				
1 Fietslampje (The Upcycle)				7
2 Willemsbrug lamp (The Talk of the Town design)	1	2	4	
3 BALK (Blooey)	3	1	3	
4 Hook'd (Tolhuijs)	3	4		
Stools				
1 Wolkpoefje (Nienke Hoogvliet X Circulair Warenhuis)	1	2	3	1
2 Bull Kruk (Studio Hamerhaai)	1	2		3
3 BB01 STOOL (Blooey)	2	3	1	2
4 Reupholstered stool (Meublowski)	3		2	2
Accessories				
1 Mand (Household Hardware)	3		2	2
2 The Grandma's Pillow (Rescued)		1	2	4
3 Bottle-UP candle holder (SuperLocal)	3	1	3	
4 Circulair wandrek FENCY (Tolhuijs)	1	3	1	1

After providing background information

	#1 favorite	#2	#3	#4 least favorite
Lamps				
1 Fietslampje (The Upcycle)			1	6
2 Willemsbrug lamp (The Talk of the Town design)	1	3	3	
3 BALK (Blooey)	3	1	2	1
4 Hook'd (Tolhuijs)	3	3	1	
Stools				
1 Wolkpoefje (Nienke Hoogvliet X Circulair Warenhuis)	1	1	3	2
2 Bull Kruk (Studio Hamerhaai)	1	2	1	3
3 BB01 STOOL (Blooey)	2	2	1	2
4 Reupholstered stool (Meublowski)	3	1	2	1
Accessories				
1 Mand (Household Hardware)	1		3	3
2 The Grandma's Pillow (Rescued)		2	3	2
3 Bottle-UP candle holder (SuperLocal)	3	1	1	1
4 Circulair wandrek FENCY (Tolhuijs)	3	3		1

Table 4 Ranking of repurposed products before and after storytelling. Best rated (green) – product(s) that was/were cumulatively ranked the highest on place #1 and #2. Worst rated (red) – product(s) that was/were cumulatively ranked the highest on #3 and #4.

Functionality
Another motive that was mentioned was functionality. When it comes to functionality specifically, the stools benefitted from perceived (multi)functionality, while the lamps and some of the accessories were assessed based on practical features (e.g., is the cable length of the lamp long enough so it can reach the socket).

Storytelling
Even though aesthetic quality and functional quality seemed to be leading (e.g., participant: "I primarily make my choice based on looks and secondly based on the story"), some participants valued the history behind the repurposed waste stream. For example, participant 4 got excited after reading about the sourcing of the materials that were used to make the Willemsbrug lamp (see Appendix A). Participant 4: "[the Willems Bridge in Rotterdam] is a real icon for people living in Rotterdam". Participants also valued the products being (hand)made locally in a city they had a connection with. Participant 3: "handmade in Utrecht. And I'm from Utrecht." For one product, the background information negatively affected the ranking. When participants learned that the material was sourced from old German bunkers some of them viewed the product more negatively.

Contamination and price
Contamination and price were mentioned to a lesser extent. Contamination concerns were only raised when textiles were used e.g., how clean is the textile used to make the product and how dirty will the textile get while it's being used in my house. Last, even though absolute prices were not mentioned, one of the participants mentioned that she could not see herself buying one of the accessories as she imagined it to be more expensive than buying it at the thrift store.

Discussion
Within literature aesthetic quality (Mugge et al., 2017) is mentioned as one of the motives influencing consumer perception of circular products. Both the survey as well as the interviews showed that in the case of repurposed products consumers highly value the aesthetic quality of a product. When it comes to the aesthetic quality some participants valued visibility of the repurposed materials as it came across as sustainable to them. Yet, other participants valued a generic look as this looked like mass-produced products being sold in larger furniture stores. This could indicate that consumers might value a level of sophistication in product design and material processing, when it comes to repurposed products. In addition, while storytelling could help establish an extra connection between the consumer and the product through referencing the product's past identity (Kamleitner et al., 2019), the result of the studies indicated that this did not always positively influence the participant's perception. Storytelling only seemed to have a positive influence when the participant already positively aesthetically valued the product and had a connection with the source of waste stream or the location where the product was made. Third, contamination concerns mainly arose when textiles were used. While mentioned within literature, surprisingly warranty was not really indicated as an important factor in consumer perception. This could be because the consumer did not have to make a buying decision and did not see the prices within the study.

From the interviews three categories of repurposed products arose: (1) visibly repurposed products, whereby consumers see which components or materials have been repurposed, (2) non-visibly repurposed products and (3) repurposed products with a unique look in terms of shape. This last category of products can benefit from storytelling when it is made locally, or the materials are sourced from a place that appeals to the consumer base. Further research should investigate demographic segmentation according to applied visibility strategy in product design and the place where the product is sold to the consumer.

Limitations in this study include the limited number of participants of the survey and interviews and the representation of various consumer segments within this small sample. Another limitation is providing participants with a selection of specific repurposed products. While this selection was made carefully, it can be seen as arbitrary as another group of researchers could have come to a different selection. Hence, further research should be

done when it comes to other product categories and samples of other specific products to assess to what extent the findings can be generalized. Furthermore, future research could include looking into how repurpose strategies could meet the consumer's need for aesthetic and functional value and financial benefits.

Conclusion

Upscaling the practice of selling repurposed furniture proves to be challenging in practice. One of the challenges in upscaling repurpose is the negative perception of consumers of repurposed products. This paper aims to provide insights into motives that influence consumer perception of repurposed furniture. The results show that aesthetic and to a lesser extent functional quality are a prerequisite for consumers to even consider repurposed furniture. Storytelling can be seen as secondary to aesthetic and to functional quality. It further shows that repurposed products can be divided into three larger categories (i.e., visibly repurposed, non-visibly repurposed and unique look) that appeal to different consumer segments. Further research needs to be done to assess the demographic profiles that fit each segment. With this knowledge designers/makers in the field can more strategically design products that better appeal to their envisioned customer base.

References

Baxter, W. L., Aurisicchio, M., & Childs, P. R. N. (2014). Materials, use and contaminated interaction. *Materials and Design*, *90*, 1218–1227. https://doi.org/10.1016/j.matdes.2015.04.019

Berglund, M., Bystedt, S., Eklöf, D., Bosch, M. Van Den, & Wever, R. (2023). *Chair a Story – What Repurpose-Driven Design can contribute to upcycling more dining room chairs The ReTuna eco-system Case Selections: Chairs*. *June*.

Calvo-Porral, C., & Lévy-Mangin, J.-P. (2020). *The Circular Economy Business Model: Examining Consumers' Acceptance of Recycled Goods*.

de Leede, A., Lepelaar, M., Groote, N., & Vorsselen, J. Van. (2021). *Repurpose Driven Design - A practice-based evaluation of design methods for repurposing*. *May*.

Essoussi, L. H., & Linton, J. D. (2010). New or recycled products: How much are consumers willing to pay? *Journal of Consumer Marketing*, *27*(5), 458–468. https://doi.org/10.1108/07363761011063358

Hjelmgren, D., Salomonson, N., & Ekström, K. M. (2015). Upcycling of pre-consumer waste – opportunities and barriers in the furniture and clothing industries. In Karin M. Ekström (Ed.), *Waste Management and Sustainable Consumption: Reflections on consumer waste* (pp. 187–198). Routledge, Taylor & Francis Group, Earthscan.

Kamleitner, B., Thürridl, C., & Martin, B. A. S. (2019). A Cinderella Story: How Past Identity Salience Boosts Demand for Repurposed Products. *Journal of Marketing*, *83*(6), 76–92. https://doi.org/10.1177/0022242919872156

Lepelaar, M., Oskam, I., van Hees, M., de Leede, A., van Vorsselen, J., Diemeer, M., & Groote Schaarsberg, N. (20022). *Repurpose kennis en kansen voor upcycling van afgedankte producten, onderdelen en materialen*.

Lüdeke-Freund, F., Gold, S., & Bocken, N. M. P. (2019). A Review and Typology of Circular Economy Business Model Patterns. In *Journal of Industrial Ecology* (Vol. 23, Issue 1, pp. 36–61). Blackwell Publishing. https://doi.org/10.1111/jiec.12763

Mugge, R., Safari, I., & Balkenende, R. (2017). Is there a market for refurbished toothbrushes? An exploratory study on consumers' acceptance of refurbishment for different product categories. *Plate Product Lifetimes and The Environment 2017 (Research in Design Series; Vol 9)*, 293–297. https://doi.org/10.3233/978-1-61499-820-4-293

Park, H. J., & Lin, L. M. (2020). Exploring attitude–behavior gap in sustainable consumption: comparison of recycled and upcycled fashion products. *Journal of Business Research*, *117*, 623–628. https://doi.org/10.1016/j.jbusres.2018.08.025

Sauerwein, M., Bakker, C., & Balkenende, R. (2018). Annotated Portfolios as a Method to Analyse Interviews. *Proceedings of DRS*, *3*, 1148–1158. https://doi.org/10.21606/dma.2017.510

Singh, J., Sung, K., Cooper, T., West, K., & Mont, O. (2019). Challenges and opportunities for scaling up upcycling

businesses – The case of textile and wood upcycling businesses in the UK. *Resources, Conservation and Recycling*, *150*(December 2018), 104439. https://doi.org/10.1016/j.resconrec.2019.104439

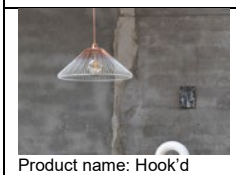
Sung, K. (2015). *A Review on Upcycling: Current Body of Literature , Knowledge Gaps and a Way Forward*. *17*(4), 28–40.

Sung, K. (2017). *Sustainable production and consumption by upcycling*. *May*, 2–283.

Van Weelden, E., Mugge, R., Bakker, C., (2016). Paving the way towards circular consumption: Exploring consumer acceptance of refurbished mobile phones in the Dutch market. *Journal of Cleaner Production*, *113*, 743–754. https://doi.org/10.1016/j.jclepro.2015.11.065

Yu, S., & Lee, J. (2019). The effects of consumers' perceived values on intention to purchase upcycled products. *Sustainability (Switzerland)*, *11*(4). https://doi.org/10.3390/su11041034

Appendix A

Lamps		Stools		Accessories	
 Product name: Fietslampje	**Company**: The Upcycle **Waste stream:** Old bicycle lamps **Picture from**: Jeremy Kooyman	 Product name: Wolkpoefje	**Company:** Nienke Hoogvliet collaboration with Circulair Warenhuis **Waste stream:** Old dish cloths **Picture from:** Circulair Warenhuis (archive)	 Product name: Bottle-Up kaarsenhouder	**Company:** Super Local **Waste stream:** Wine bottles **Picture from:** Jeroen van der Vielen
 Product name: Willemsbrug lamp (klein)	**Company:** The Talk of The Town design **Waste stream:** Old steel parts of the Willemsbrug in Rotterdam **Picture from:** TTOTT design	 Product name: Bull kruk	**Company:** Studio Hamerhaai **Waste stream:** Picture from: Studio Hamerhaai	 Product name: Autoband mand XL	**Company:** Household Hardware **Waste stream:** Old tires **Picture from:** Household Hardware
 Product name: Balk Lampje	**Company:** ONZE / Blooey **Waste stream:** Old road signs **Picture from:** ONZE, Remko Verhaagen	 Product name: BB01 Stool	**Company:** ONZE / Blooey **Waste stream:** Reclaimed construction steel from demolished bunkers / Powder coated steel **Picture from:** Blooey, Remko Verhaagen	 Product name: Grandma's Pillow	**Company:** Rescued **Waste stream:** Old wool blankets **Picture from:** Rescued
 Product name: Hook'd	**Company:** Tolhuijs design **Waste stream:** Powdercoated hooks **Picture from:** Tolhuijs	 Product Name: Re-upholstered stool	**Company:** Meublowski **Waste stream:** Old stool **Picture from:** Meublowski	 Product name: Fency	**Company:** Tolhuijs Design **Waste stream:** Waste material from a fence manufacturer **Picture from:** Tolhuijs

Tabel 5 Full overview of products shown to the participant during the one-on-one interviews

Extended Abstract
6th PLATE 2025 Conference
Aalborg, Denmark, 2-4 July 2025

The Hidden Cost of Cheap: Are We Paying More for Short-Lived Goods?

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Keywords: sustainable consumption; cost of ownership; product lifetimes; economic benefits; repair

Introduction

There is a vast array of brands and models of the same product type available on the market, each with a wide range of quality, durability, longevity, and repairability. This raises a critical question: do higher-priced products last longer and ultimately cost less in the long term, or, in other words, do we end up paying more when opting for cheaper but less durable alternatives? From a sustainability perspective, making products more durable and repairable plays a vital role in extending their lifespans, reducing production frequency, and alleviating environmental pressures (Cooper, 2005; van Nes & Cramer, 2006). At the same time, price remains one of the most significant factors influencing purchase decisions (Bault & Rusconi, 2020). More sustainable products are often perceived as more expensive, leading to the belief that sustainable consumption may only be feasible for wealthier consumers (Raha & Mallya, 2022). However, in the long-term perspective, less expensive products may prove costlier due to shorter lifespans, more frequent replacements, and higher associated environmental costs.

The link between product costs and actual long-term expenditures remains poorly understood (we were not able to identify existing studies outside of the automotive field), and this study represents the first empirical effort to explore this connection using real-world data for consumer products. Building on the established Total Cost of Ownership (TCO) framework (Faludi & Ritsma, 2024), this study quantifies the annual ownership costs of products by incorporating their purchase price, expected service lifespan, and repair costs and frequencies. Recent data on the lifespans and repair patterns of various consumer electronics (Amatuni et al., 2023) significantly enhance this framework. By integrating these data sources with complementary consumer surveys and retail data from Action stores in the Netherlands, we offer a pioneering assessment of optimal "economical" prices, highlighting that the cheapest option does not always deliver the lowest total costs over time.

Methods

This study has three main objectives:

1. To measure TCO across various models and product categories.
2. To examine the relationship between higher prices, product longevity, and potentially lower TCO, which has not been adequately studied with real-world consumption patterns.
3. To determine the “optimal product price” for each category, balancing either minimal total costs or the total material impacts. Consumers paying above or below these prices risk either overly frequent replacements or overpayment for disproportionately expensive goods missing potential economic or environmental efficiencies.

This study leverages recent consumer surveys with empirical data on product electronics lifespans, failure and repair rates (Amatuni et al., 2023), and actual purchase and repair statistics from our ongoing partnership with Action stores. Given that failure and repair data were collected at the product level rather than at a component level as outlined in the original TCO framework, we adopt a simplified formula:

$$TCO = \frac{Cp + Pf \cdot ((1 - Pr) \cdot Cp + Pr \cdot Cr)}{LT}$$

where TCO represents the Total Cost of Ownership, calculated as the annualized costs of owning a product. Cp is the purchase price of the product, LT is its expected service lifespan in years, Pf is the probability of failure during LT, Pr is the likelihood of a successful repair

attempt, and Cr is the cost of repair. Using this formula, we assess the TCO for each product by gathering data on prices (from multiple market sources), lifespans, and repair probabilities (from published studies and our additional survey with Action consumers). To address uncertainties in input data, we aimed to base each parameter on at least five survey sources and evaluate outcomes across best- and worst-case scenarios to be able to track and depict the uncertainty of the final results.

Results & discussion

Within this preliminary assessment, by comparing TCOs (the sum of the upfront price of a new product with its total repair costs along use time) for two product groups (smartphones and vacuum cleaners) with a broad price spectrum, we observe the following:

Firstly, while existing repairability scores (such as iFixit and FRI) rank consumer electronics in terms of ease of repair, they do not indicate cost savings or replacement frequencies. In contrast, this study provides a clearer link between upfront prices, longevity, and long-term economic outcomes. For this purpose, we conducted two surveys (38-50 respondents per product) collecting data on purchase, repair and discard behaviour, estimating the total use times and the TCO for each device. Here, we depict the resulting scatterplots after data cleaning and removal of outliers. For each product category, we explore the relationship between the upfront price of the product (x-axis) and its eventual use time or the resulting annual cost of ownership considering the possible repair costs (y-axis).

For smartphones sold in Germany (Figure 1), there was no statistically significant correlation observed between price and longevity. If anything, lower-paying consumers even tend to use devices for longer.

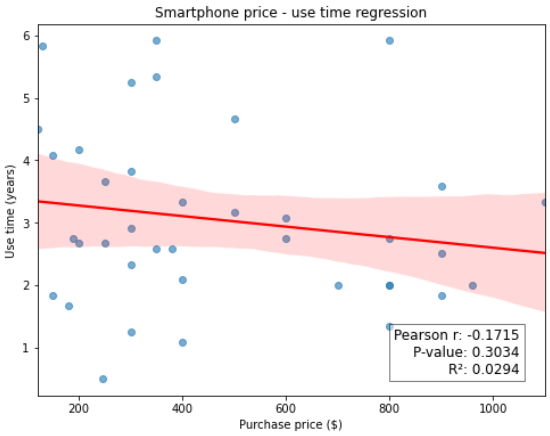


Figure 1: Relationship between upfront smartphone price in Germany and its resulting use time (n = 38). Linear model

At the same time, a higher upfront smartphone price is associated with a higher total annual cost of ownership in the long run (Figure 2).

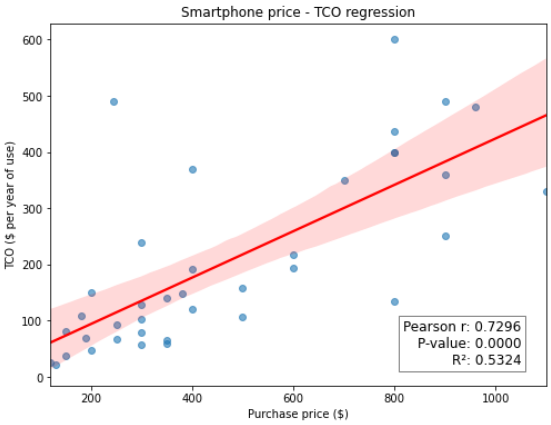


Figure 2: Relationship between upfront smartphone price in Germany and the resulting annual cost of ownership, TCO (n = 38). Linear model

For vacuum cleaners, considering the coefficient of determination R^2, quadratic regression fits the data better than the linear model, both for the use time and the annual cost of ownership. In particular, use time is extended with either the cheapest or the most expensive goods but not the ones in between (Figure 3).

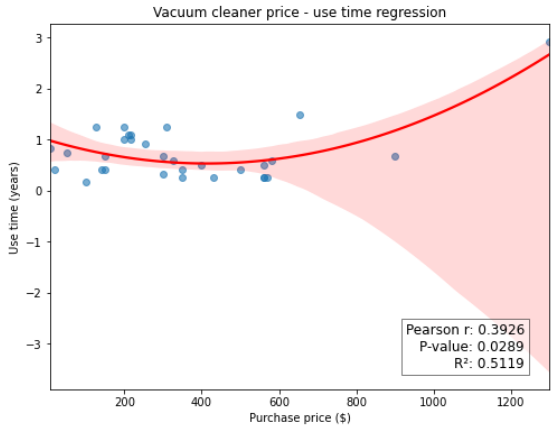


Figure 3: Relationship between upfront vacuum cleaner price in the US and its resulting use time (n = 31). Quadratic model

At the same time, there is also a moderate quadratic relationship observed that suggests that middle-cost goods cost the most in the long-run (Figure 4).

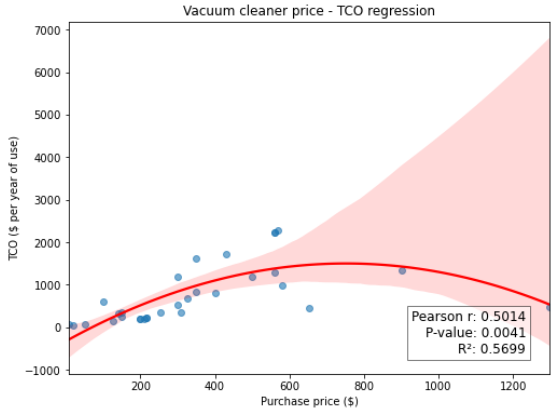


Figure 4: Relationship betIn ween upfront vacuum cleaner price in the US and the resulting annual cost of ownership (n = 31). Quadratic model

As a result, this preliminary assessment presents evidence against the common assumption of the gap between the most economical and the most sustainable consumption strategies. We show that for both products, replacement rates are rising with increasing prices and are later dropping again for vacuum cleaners. At the same time, expectedly, for both products, higher product price is associated with higher annual costs of ownership (TCO might rebound back for more expensive vacuum cleaners however).

In essence, contrary to expectations, we show that for selected categories, the cheapest products consistently offer the optimal balance of long-term cost-efficiency and sustainability.

Yet, results are expected to vary significantly across product categories, and within the later stage of this study, with a bigger sample size and a more diverse range of products, optimal economical and sustainable price ranges for each product category that minimize both consumer expenses and environmental impacts will be identified.

To conclude, this study is the first to empirically link product prices, use patterns, and repair data with long-term monetary and environmental outcomes. By identifying price points that align with sustainable consumption, this research offers valuable insights for consumers, retailers, and policymakers aiming to foster economic and environmental sustainability.

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References

Amatuni, L., Yamamoto, T., Baldé, C. P., Clemm, C., & Mogollón, J. M. (2023). Quantifying total lifetimes of consumer products: Stochastic modelling accounting for second-hand use and establishing an open-collaborative database. *Resources, Conservation and Recycling*, *197*, 107103. https://doi.org/10.1016/j.resconrec.2023.107103

Bault, N., & Rusconi, E. (2020). The Art of Influencing Consumer Choices: A Reflection on Recent Advances in Decision Neuroscience. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.03009

Cooper, T. (2005). Slower consumption: Reflections on product life spans and the “throwaway society.” *Journal of Industrial Ecology*, *9*(1–2), 51–67. https://doi.org/10.1162/1088198054084671

Faludi, J., & Ritsma, R. (2024). *The Total Cost of Ownership Score : Unifying Repair with Durability and Improving Objectivity , Completeness , and Scalability*. 471–481. DOI: 10.23919/EGG62010.2024.10631233

Raha, S., & Mallya, H. (2022). *Ensuring affordable, favourable and sustainable lifestyles for all*. 1–16.

van Nes, N., & Cramer, J. (2006). Product lifetime optimization: a challenging strategy towards more sustainable consumption patterns. *Journal of Cleaner Production*, *14*(15–16), 1307–1318. https://doi.org/10.1016/j.jclepro.2005.04.006

Extended Abstract
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Have prospects for product life-spans improved? A comparison of trends in household appliances and electronic goods over 25 years

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Keywords: Electronic goods; Product life-times; Obsolescence; Historical trends; WEEE.

Introduction

The lack of firm evidence on trends in the life-span of consumer durables is especially unfortunate in the case of household appliances and electronic goods due to the scale and environmental impact of e-waste (Balde et al., 2024). Although some limited international data on product life-spans was identified over 40 years ago (OECD, 1982), research to generate data systematically across all types of household appliances and electronic goods was only undertaken much later.

During the 1990s the impending Waste Electrical and Electronic Equipment (WEEE) Directive prompted manufacturers and retailers to seek better information about the waste created by their products. A multi-stakeholder project team was formed and commissioned a survey of 'end-of-life' household appliances and electronic goods, which addressed life-spans. Their report, *Prospects for Household Appliances*, revealed that 57% of such products in people's homes were under 5 years old and their average (mean) age when discarded ranged from 4 years (for small appliances, mobile phones and toys) to 12 years (for electric cookers). Almost one half of respondents expressed dissatisfaction with product life-spans (Cooper & Mayers, 2000; Cooper, 2004).

The circular economy debate has increased interest in product longevity and prompted further European Union legislation (e.g. the Ecodesign for Sustainable Products Regulation) and, in the UK, a parliamentary report on electronic waste (Environmental Audit Committee, 2020). Consequently, a second UK survey was undertaken, in 2023, to identify trends in the life-span of household appliances and electronic goods, and to explore consumers' expectations, attitudes and behaviour concerning acquisition, repair and disposal, including life-span labelling.

This Extended Abstract compares data from the two UK surveys on the ownership of household appliances and electronic goods, their life-spans, and the extent of rental, reuse, borrowing and sharing. Future outputs will draw upon the substantial new database to address themes such as consumer expectations, public policy, demographic influences, design influences and repair.

Methodology

The two UK surveys each adopted a consumer-based approach but with a slightly different method: in 1998 face-to-face doorstep interviews with householders were undertaken, while in 2023 respondents from a consumer panel completed online questionnaires. The final sample size in each case was over 800 householders, and representative of the UK population by gender, age, ethnicity, social grade and region.

The questions in 2023 were designed to obtain data comparable to that from 1998, although some were reworded and others added or removed to reflect the historical context and desired focus. Product categories were maintained as far as possible while allowing for technological developments. Due to greater disaggregation there were up to 43 categories in 2023, compared to 15 in 1998. Data were cleaned, weighted and analysed using SPSS; cross-tabulated data were tested for significance using t tests.

Aside from modifications to the method and product categories, key limitations to the research are that the data were self-reported by consumers and may rely on memory.

Results and discussion

There was a substantial increase in ownership of household appliances and electronic goods, from a mean of 25 products per household in 1998 to 42 in 2023. The greatest growth was in computers and peripherals (from under 1 per household to over 5), mobile phones (from under 1 to nearly 3) and small appliances (from over 6 to around 12). This reflects changes in technology (e.g. laptops, tablets) and greater affluence, although the revised method may have resulted in more small appliances being identified.

The mean life-span of discarded items varied by product category; in 2023 it was typically 8 to 10 years for products such as electric cookers, washing machines and fridge freezers, 5 years for small appliances and 4 years for mobile phones. There was significant variation between wired and cordless products: wired models of DIY power tools, vacuum cleaners/carpet cleaners and garden power tools typically lasted longer than cordless models.

There was evidence of declining life-spans in some, but not all, product categories. The mean life-span for vacuum cleaners/carpet cleaners, televisions and electric cookers declined, while it increased for landline telephones, substantially, and small appliances, slightly. In other product categories little change was evident or direct comparisons were problematic.

The findings enhance the scarce evidence on historical life-span trends (Oguchi et al., 2010). International comparisons are not easy due to different data collection methods, product categorisation and waste management practices, and many national studies with life-span data have not addressed all types of household appliances and electronic goods. Rare exceptions from the Netherlands and Germany (cited in Bakker et al., 2014 and German Environment Agency, 2017) have suggested a downward trend, but a Japanese study concluded that life-spans have increased (Oguchi & Daigo, 2017). Further research is required.

Our survey also explored product acquisition. The proportion of second-hand items, whether purchased or given, was substantially higher in 2023 than 1998. By contrast, despite government interest in a shift from product ownership to rental, in 2023 fewer respondents reported that they had recently rented items (typically DIY power tools, garden power tools, washing machines, or vacuum cleaners/carpet cleaners) than in 1998.

There was, however, evidence from 2023 of borrowing and sharing by around a fifth of respondents (typically garden power tools, DIY power tools, vacuum cleaners/carpet cleaners, and monitors or printers/copiers/scanners). This indicates a certain degree of resource efficiency and social cohesion. Comparable data were not collected in 1998.

Conclusions

Ownership of household appliances and electronic goods in the UK, especially second-hand items, grew between 1998 and 2023, while rental declined. There is extensive borrowing and sharing.

The decrease in life-spans revealed in several product categories may have negative impacts on consumers and the environment, although the slight increase for small appliances may be beneficial. The trend towards cordless products is significant, as wired models typically last longer. The growth in product ownership and a failure to increase life-spans, overall, suggest that the consumption of household appliances and electronic goods remains environmentally unsustainable.

Our study exposed the methodological issues raised when collecting, analysing and comparing life-span data. It has provided valuable data to inform theoretical discussion concerning premature product obsolescence. International studies, with comparable data, are now needed to improve knowledge and understanding.

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References

Bakker C., Wang F., Huisman J. & den Hollander M. (2014). Products that go round: Exploring product life extension through design. *Journal of Cleaner Production*, 69, 10-16. https://doi.org/10.1016/j.jclepro.2014.01.028

Baldé, C.P. et al. (2024). *Global E-waste Monitor 2024*. Geneva/Bonn: International Telecommunication Union (ITU) and United Nations Institute for Training and Research (UNITAR). Retrieved from https://ewastemonitor.info/the-global-e-waste-monitor-2024/

Cooper, T. (2004). Inadequate life? Evidence of consumer attitudes to product obsolescence. *Journal of Consumer Policy*, 27(4), 421–449. https://doi.org/10.1007/s10603-004-2284-6

Cooper, T. & Mayers, K. (2000). *Prospects for Household Appliances*. Halifax Urban Mines. Retrieved from https://irep.ntu.ac.uk/id/eprint/6671/

Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE)

Environmental Audit Committee. (2020). *Electronic waste and the Circular Economy*. First Report of Session 2019–21, HC 220. Retrieved from https://committees.parliament.uk/work/170/electronic-waste-and-the-circular-economy/publications/

German Environment Agency. (2017). *Strategies against Obsolescence: Ensuring a minimum product lifetime and improving product service life as well as consumer information*. Retrieved from https://www.umweltbundesamt.de/en/publikationen/strategies-against-obsolescence-ensuring-a-minimum

OECD. (Organisation for Economic Co-operation and Development). (1982). *Product Durability and Product-Life Extension: Their contribution to solid waste management*. Paris: OECD.

Oguchi, M. & Daigo, I. (2017). Measuring the historical change in the actual lifetimes of consumer durables. *PLATE (Product Lifetimes and the Environment) conference. (*pp.319-323). Delft, Netherlands. DOI: 10.3233/978-1-61499-820-4-319

Oguchi, M., Murakami, S., Tasaki, T., Daigo, I. & Hashimoto, S. (2010). Lifespan of commodities, Part II: Methodologies for estimating lifespan distribution of commodities. *Journal of Industrial Ecology*, 14(4), 613–626. https://doi.org/10.1111/j.1530-9290.2010.00251.x

Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC

Extended Abstract
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Employing Pedagogy in the Experience Economy to Extend Product Lifetimes

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Keywords: Co-creation; Empowerment; Transformational Knowledge; Embodied learning; Environmental Responsibility

Introduction

Within the experience economy, personalisation & customisation are primarily seen as methods to increase the rate and quantity of consumption (Kuksa et al 2022). This research takes an alternative view; exploring opportunities to reduce the environmental impact of consumption and to extend product lifetimes by viewing the customisation space as a site of learning. Drawing upon pedagogic theory, in particular Meyer & Land (2003)'s idea of 'transformational knowledge', this research will explore how embodied customisation experiences can provide individuals with the skills and confidence to fix, repair and maintain objects they own. It will aim to analyse the collateral impacts of a co-created product, beyond a Product Life-Cycle Analysis and towards a more holistic view of shifts and changes that may occur in wider patterns of consumption, care and maintenance for an individual empowered by a learning experience.

Context: Pedagogy and co-creation

As a goldsmith and workshop facilitator with experience in education, this research draws upon my knowledge of practical education and the impact it has on students. Accomplishment of a skill brings with it a sense of empowerment and agency in the world – that what we are able to say and think and do matters. Engaging with products in relation to their materiality and how they are made can increase wellbeing (Yair 2011) and can foster an appreciation of the value of maintenance and repair (Madon 2021; Durrani 2018). This 'sustain-ability' (Fry 2008) leads to a change in the way the students approach the material world; with more respect for the material things around us, we cannot help but develop a more considered and ethical approach to our consumption.

Definition of Terms

Making and co-creation

'Make-your-own' workshops (e.g. for couples making their own wedding rings, or a day of throwing pots with a ceramicist for example) are a space where consumers are able to become a part of the production process, revealing the often hidden/unknown methods of manufacture (e.g. soldering precious metals). The phrase 'co-creation' is used here to highlight the collaborative nature of these spaces where the customer can impact the design of their object with support from a skilled workshop facilitator. Co-creation can happen both online (e.g where the customer selects design options for their product) or in person. In-person co-creation may provide more potential to impact product lifetimes due to the embodied nature of these experiences. Embodied learning involves participation by engaging the body, which has been shown to enhance learning (Varela, Thompson & Rosch 1991).

Threshold concepts and transformational knowledge

A threshold concept is knowledge which transforms the learners' perception of a subject or experience, allowing *things normally not perceived to come into view* (Meyer & Land 2003). This perspective may be helpful in understanding the potential broader impacts of co-creation experiences in terms of empowerment to fix, mend and repair. Many of the objects we own are manufactured at a distance from us and the processes used are seen as mysterious and out-of-reach (Perzanowski 2021). Yet through a co-creation

experience material knowledge is gained pertaining to the product we are purchasing. It allows space for consumers to play a design role, to understand how to fix/repair and to discuss the objects directly with the manufacturers. Co-creation therefore creates an experience which sees customers move from passive recipients of goods and services to *connected, informed, and powerfully active collaborators in the creation of value (*Prahalad & Ramaswamy 2004).

Research Context

Online co-creation experiences have been shown to increase feelings of self efficacy after customising products through an interface (Turner et al 2020) and effective design of this interface can support the customer to make ethical purchasing decisions (Grosso et al 2024). At an in-person co-creation experience the workshop facilitator becomes this interface. The success of the workshop therefore is in part reliant on the insight and empathy of the facilitator – and the subsequent endurance of the product becomes about pedagogy as much as consumer choice. This research will show how workshop providers in the experience economy can enhance both the lifecycle of the product and the environmental ethics of the consumer. A comparison between online co-design and in-person, embodied co-creation will identify the point at which a co-creation experience can become more deeply transformational in nature.

The questions being explored are:

- To what extent can involvement in the making process lead to a sense of agency/empowerment to repair and maintain other products beyond the initial workshop?
- How can co-creation experiences be best designed to support material empathy and increase product lifetimes?

Methodology

Initial data will be gathered through workshop participation & observation (field notes), interviews and case studies. Data collection will seek to explore participants' perspectives on the acquisition of skills and the transferability of these skills. It will also explore how the facilitating businesses adapt their processes to accommodate public access.
New co-making workshops will then be designed, developed and facilitated with collaborating businesses as a cycle of action research towards the end of the project. The aim will be to holistically assess impact from both sides of the workshop – for the participants and for the facilitating business.

This expands upon existing research which highlights the self-efficacy, agency and enjoyment which current online co-creation experiences offer (Turner et al 2020; Trentin et al 2014).

Next steps

Co-creation experiences provide a unique opportunity to both support environmentally ethical consumer behaviour and to highlight opportunities for producers to enhance their green credentials.

This research is in its early stages, and participation in the PLATE conference will be an opportunity to test ideas and to build strategic partnerships to support and enhance the project development. As the project develops, companies will be invited to experience a co-making workshop and to explore opportunities to offer a co-making experience to their customers. By doing so, other environmental benefits can be achieved: the making process will necessarily become more localised, material and energy consumption can be reduced (Steiner 2021 and 2024) and companies will be able to gain valuable customer input in the appropriate design and development of their products. The experience economy continues to grow, and if we can harness this to support environmentally ethical practices then everyone benefits.

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References:

Durrani, M. (2018). "People Gather for Stranger Things, So Why Not This?" Learning Sustainable Sensibilities through Communal Garment-Mending Practices. *Sustainability*, *10*(7), 2218. https://doi.org/10.3390/su10072218

Grosso, C; Monzi, C; Fraccascia, L; Nonino, F. (2024) *Empowering Consumer for the green transition while shopping for customized product. (Intervento presentato al convegno 11th International conference*

on customization and personalization tenutosi a Novi Sad). pp. 184-192.

Fry, T 2008: *The Gap in the Ability to Sustain* in *Design Philosophy Papers* 6:1, pgs 101-110

Kuksa, I.; Fisher, T. & Kent, A. (2022). *Understanding Personalisation: New Aspects of Design and Consumption*. Chandos Publishing

Meyer, J.H.F & Land, R (2003): *Threshold Concepts and Troublesome Knowledge: Linkages to ways of thinking and practising within the disciplines* in Rust, C (ed.): *Improving Student Learning: Theory and Practice* Oxford Centre for Staff and Learning Development

Madon, J. (2021). Free repair against the consumer society: How repair cafés socialize people to a new relationship to objects. Journal of Consumer Culture, 22(2), 534-550. https://doi.org/10.1177/14695405219908 71 (Original work published 2022)

Perzanowski, A (2021): *The Right to Repair: Reclaiming the Things We Own* Published online by Cambridge University Press 30 December 2021 [accessed 29/04/24]

Prahalad, C. K., & Ramaswamy, V. (2004). *The future of competition: Co-creating unique value with customers.* Boston: Harvard Business School Press.

Steiner, R 2021: *Future-Makers: Making a Living without Costing the Earth* in *Journal of Jewellery Research* Vol.4 pgs 77-91

Steiner, R 2024: *Head out of the cloud: Co-Creation as Grounding in a Digital Age* in 11th International Conference on Customisation and Personalisation, Conference proceedings pgs 225-232

Trentin, A, Perin, E & Forza, C (2014) Increasing the consumer-perceived benefits of a mass-customization experience through sales-configurator capabilities. *Computers in Industry*, Volume 65, Issue 4,pp 693-705 https://doi.org/10.1016/j.compind.2014.02.004

Turner, F, Merle, A & Gotteland, D (2020) Enhancing consumer value of the co-design experience in mass customization. *Journal of Business Research,* Volume 117, pp 473-483 https://doi.org/10.1016/j.jbusres.2020.05.052

Varela, F., Rosch, E. & Thompson, E. 1991: *The Embodied Mind: Cognitive Science and Human Experience* MIT Press

Yair, K (2011) *Craft and Wellbeing*. Crafts Council Report https://www.craftscouncil.org.uk/documents/865/Craft_and_wellbeing_2011.pdf [accessed 26/05/2024]

Extended Abstract
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Design Strategies to Strengthen Epistemic Value in Consumer Electronics and Prolong Product Lifetime

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Keywords: consumer electronics; epistemic value; novelty; product lifetime; product satiation

Introduction

The consumer electronics waste has become a serious environmental concern (World Health Organization, 2024). A significant factor driving this issue is “premature obsolescence,” which refers to the premature discontinuation of a product use or the premature replacement of a functioning product with a new one (Magnier & Mugge, 2022; Ylä-Mella et al., 2022). Current consumer replacement theory attributes this phenomenon to psychological value trade-offs, where consumers prematurely value new products over their current ones (Van den Berge et al., 2021). This shift is often driven by an attraction to novel features, updated designs, and the overall sense of novelty offered by new products on the market, while their owned devices increasingly lose appeal due to familiarity and boredom (Echegaray, 2016; Van den Berge et al., 2021). Although existing research highlights the importance of preserving the perceived value of owned products to combat premature obsolescence (Magnier & Mugge, 2022; Van Nes, 2016), effective design strategies are underexplored. This study aims to explore design strategies to preserve value of owned consumer electronics, focusing on strengthening their epistemic value to prolong product lifetime and reduce waste.

What is Epistemic Value?

The epistemic value of products is one of five key consumption values that shape consumer decisions (Sheth et al., 1991). Alongside other values (e.g., functional and emotional value), it plays an important role in influencing whether consumers retain or replace a currently owned product. Consumers perceive epistemic value in products through three dimensions: novelty, offering something unexpected or unknown; curiosity, sparking a desire to learn more; and a change of pace, providing variety that breaks daily routines and satisfies the human need for diversity (Magnier & Mugge, 2022; Sheth et al., 1991). However, the psychological trade-offs inherent in epistemic value present a challenge to long-term product use. While epistemic value initially attracts consumers by offering fresh experiences, these experiences can become repetitive and predictable over time, potentially resulting in boredom or satiation. To address this issue, design strategies should focus on sustaining the epistemic value of consumer electronics already in use, thereby reducing the likelihood of premature replacement.

Current Design Strategies

Existing research on enhancing the epistemic value of currently owned consumer electronics has predominantly focused on two approaches. The first is design newness, which leverages the visual novelty aspect of epistemic value by offering consumers visually distinctive design through modifications of aesthetic attributes such as color, shape, and overall form (Mugge & Dahl, 2013; Talke et al., 2017). However, this approach is primarily studied in the context of new product purchases and generally provides only short-lived novelty, as the initial excitement fades quickly. The second approach refers to upgradability, enabling consumers to replace individual components (e.g., processors or batteries) over the product’s lifetime (Jaeger-Erben et al., 2023; Khan et al., 2018; Proske & Jaeger-Erben, 2019). For instance, Fairphone employs modular design, enabling consumers to upgrade specific parts as needed. While upgradability can help sustain epistemic value by introducing new functionalities over time, it primarily addresses the technical aspect of design. Together, these two design approaches reflect a narrow portfolio of design strategies, leaving a wide range of other possibilities

unexplored. In this study, we aim to explore the possibility of developing design directions that prolong the lifetime of consumer electronics by strengthening their epistemic value throughout the ownership period.

Methods

To achieve the research objective, we first aim to generate a diverse range of product design concepts that enhance the long-term epistemic value of consumer electronics. To this end, we conducted four two-hour workshop sessions with 24 participants, all of whom held bachelor's degrees in product design. The workshops employed a structured brainstorming approach informed by principles of creative facilitation (Heijne & Van der Meer, 2019). This workshop format has previously been adopted to explore the potential for developing design directions (Ackermann et al., 2021; Casais et al., 2018). Each workshop comprised three brainstorming rounds, during which participants generated design ideas using quick sketches or Post-it notes and then shared their concepts within their groups. To encourage diverse exploration, each round focused on a distinct product category, with three product groups serving as ideation stimuli: (1) Technology Products (e.g., smartphones, laptops, TVs), characterized by regular technological updates; (2) Utilitarian Products (e.g., refrigerators, vacuum cleaners), emphasizing functionality; and (3) Expressive Products (e.g., coffee machines, headphones), associated with self-expression and symbolic meaning. To mitigate pattern bias, the order of product categories varied across workshops. The recorded design ideas (N = 350) and audio transcripts (collected with consent) were subsequently reviewed and analyzed using an inductive thematic analysis approach in Atlas.ti. The first author systematically coded and clustered the ideas to identify emerging design strategies, which were then iteratively reviewed in collaboration with co-authors to ensure conceptual clarity and methodological rigor.

Findings

The data analysis of the design workshops led to the identification of eight overarching design strategies and 19 sub-strategies focused on prolonging the epistemic value of consumer electronics throughout their ownership period. Four strategies address all three dimensions of epistemic value—novelty, curiosity, and change of pace. These strategies include: (1) Hardware Upgradability, which allows consumers to integrate future technical advancements into their device through hardware modifications, aligning with existing upgradability strategies in the literature; (2) Expanded Functionality via Software Upgrades, which enables continuous software updates to provide ongoing benefits beyond mere technical improvements; (3) Multi-Purpose Design, which enhances versatility by allowing products to serve multiple functions or be repurposed for different scenarios; and (4) Dynamic Engagement, which sustains long-term interest through interactive elements and gamification. Additionally, two other strategies specifically emphasize novelty and curiosity. These refers to 5) Anthropomorphism, which focuses on enhancing user engagement by attributing human-like behavior, personalities or characteristics to products; and 6) Adaptability, which enables products to dynamically learn, adjust, and respond to evolving user needs, behaviors, and contexts, thereby increasing their long-term relevance and usability. Finally, our findings highlight the need to expand the original conceptualization of epistemic value (Sheth et al., 1991) by introducing a fourth dimension: preventing the decline of epistemic value over time. This dimension encompasses two key strategies, which refer to 7) Timeless Design, which focuses on evergreen aesthetics and enduring functionality to ensure long-term relevance; and 8) Self-Care, which integrates self-cleaning and maintenance features to preserve a product's aesthetic and functional newness with minimal user effort.

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References

Ackermann, L., Tuimaka, M., Pohlmeyer, A. E., & Mugge, R. (2021). Design for Product Care - Development of Design Strategies and a Toolkit for Sustainable Consumer Behaviour. *Journal of Sustainability*

Research, 3(2), e210013. https://doi.org/10.20900/jsr20210013

Casais, M., Mugge, R., & Desmet, P. (2018). Objects with symbolic meaning: 16 directions to inspire design for well-being. *Journal of Design Research, 16*(3-4), 247-281. https://doi.org/10.1504/jdr.2018.099538

Echegaray, F. (2016). Consumers' reactions to product obsolescence in emerging markets: the case of Brazil. *Journal of Cleaner Production, 134*, 191-203. https://doi.org/10.1016/j.jclepro.2015.08.119

Heijne, K., & Van der Meer, H. (2019). *Road Map for Creative Problem Solving Techniques: Organizing and Facilitating Group Sessions*. Boom uitgevers Amsterdam.

Jaeger-Erben, M., Proske, M., & Hielscher, S. (2023). Scalability and durability, or: is modular the new durable? The case of smartphones. In M. Jaeger-Erben, H. Wieser, M. Marwede, & F. Hofmann (Eds.), *Durable Economies: Organizing the Material Foundations of Society* (pp. 201-230). DOI: 10.14361/9783839463963-009

Khan, M. A., Mittal, S., West, S., & Wuest, T. (2018). Review on upgradability – A product lifetime extension strategy in the context of product service systems. *Journal of Cleaner Production, 204*, 1154-1168. https://doi.org/10.1016/j.jclepro.2018.08.329

Magnier, L., & Mugge, R. (2022). Replaced too soon? An exploration of Western European consumers' replacement of electronic products. *Resources, Conservation and Recycling, 185*. https://doi.org/10.1016/j.resconrec.2022.106448

Mugge, R., & Dahl, D. W. (2013). Seeking the Ideal Level of Design Newness: Consumer Response to Radical and Incremental Product Design. *Journal of Product Innovation Management, 30*(S1), 34-47. https://doi.org/10.1111/jpim.12062

Proske, M., & Jaeger-Erben, M. (2019). Decreasing obsolescence with modular smartphones? – An interdisciplinary perspective on lifecycles. *Journal of Cleaner Production, 223*, 57-66. https://doi.org/10.1016/j.jclepro.2019.03.116

Sheth, J. N., Newman, B. I., & Gross, B. L. (1991). Why we buy what we buy: A theory of consumption values. *Journal of Business Research, 22*(2), 159-170. https://doi.org/10.1016/0148-2963(91)90050-8

Talke, K., Müller, S., & Wieringa, J. E. (2017). A matter of perspective: Design newness and its performance effects. *International Journal of Research in Marketing, 34*(2), 399-413. https://doi.org/10.1016/j.ijresmar.2017.01.001

Van den Berge, R., Magnier, L., & Mugge, R. (2021). Too good to go? Consumers' replacement behaviour and potential strategies for stimulating product retention. *Current Opinion in Psychology, 39*, 66-71. https://doi.org/10.1016/j.copsyc.2020.07.014

Van Nes, N. (2016). Understanding replacement behaviour and exploring design solutions. In T. Cooper (Ed.), *Longer lasting products: Alternatives To The Throwaway Society* (pp. 107-131). Routledge. https://doi.org/10.4324/9781315592930

World Health Organization. (2024). *Electronic waste (e-waste)*. https://www.who.int/news-room/fact-sheets/detail/electronic-waste-(e-waste)

Ylä-Mella, J., Keiski, R. L., & Pongrácz, E. (2022). End-of-Use vs. End-of-Life: When Do Consumer Electronics Become Waste? *Resources, 11*(2), 18. https://doi.org/10.3390/resources11020018

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Vulnerabilities of Design Strategies for Retaining Emotional Value in Consumer Electronics

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Keywords: Emotional Value; Prolonged Use; Early Replacement; Design Strategies; Consumer Electronics.

Introduction

Replacement decisions for consumer electronics involve trade-offs between product values, including emotional value (Van den Berge et al., 2021). Emotional value emerges when a product evokes positive emotions and affective states (Sheth et al., 1991). It can be acquired through diverse mechanisms, including sensory appeal and symbolic associations (Desmet et al., 2001; Orth et al., 2018). Design strategies support designers on how to translate these mechanisms into concrete product features that foster emotional value (Haines-Gadd et al., 2018; Wu et al., 2021). However, design strategies for emotional value are rarely implemented in consumer electronics. One reason may be that emotional value is shaped by individual consumer experiences (Kato, 2021). Thus, design strategies for emotional value may fail if they do not resonate with the user. This makes emotional value less predictable and harder to design for. Additionally, shifting emotions over time may undermine a product's relevance (Chapman, 2009). This may cause products that initially establish emotional value to lose this value gradually. We define these shortcomings that prevent design strategies from creating or retaining emotional value during ownership as *vulnerabilities*.

For example, The Globe is a conceptual clock that replaces time markers with city names tied to a user's experiences (Orth et al., 2018). By evoking nostalgia, it aligns with strategies for fostering emotional value (Haines-Gadd et al., 2018). However, one of the vulnerabilities of this strategy is that it may fail to create emotional value from the outset for this product if the city-based time display does not resonate with a user's expectations of a clock, potentially preventing product acquisition. Furthermore, even when it initially fosters emotional value, nostalgia may turn into frustration due to the product's impracticality for daily timekeeping.

This study contributes to the literature by examining how and why design strategies for emotional value become vulnerable despite their initial promise, making products designed with these strategies susceptible to early replacement. By understanding and tackling these vulnerabilities, we can help products retain emotional value over time.

Methodology

Ethical approval was obtained before data collection. Semi-structured interviews were conducted with ten professionals in the consumer electronics industry, with ten more planned. Each interview lasted about an hour and was preceded by a 15-minute sensitizing activity. The sample included product and user experience designers, design researchers, and design managers. This purposive sampling (Palinkas et al., 2015) ensured a comprehensive exploration of design strategies and their vulnerabilities.

The sensitizing activity introduced Emotional Durability Design Nine (Haines-Gadd et al., 2018), a tool for incorporating emotional value into new product development. This aligned the tool with the participants' expertise and laid the study's foundation. Participants explored nine product examples (Figure 1), including conceptual cases (e.g., Standard Lamp (Casais et al., 2018)) and market products (e.g., Phillips Hue). Non-electronics examples were included to provoke reflection on adapting these strategies for consumer electronics. Each card detailed how the product fostered emotional value, enabling participants to evaluate the design strategy's effectiveness over time.

During the activity, participants selected three cards, matched them with the relevant design strategy themes, and assessed the product's potential to retain emotional value over time. They then placed the cards on a product ownership timeline (Shi et al., 2022), from pre-acquisition to pre-disposal. This activity contextualized when emotional value might diminish and prompted reflections on the causes.

Interviews expanded on the activity. Participants reflected on why the emotional value of the selected products might diminish over time and suggested ways to retain it. They also shared professional insights on industry challenges, including why many design strategies struggle to transition to market-ready products. The responses were thematically analyzed using inductive coding (Braun & Clarke, 2006).

Preliminary Findings

Preliminary findings reveal five key vulnerabilities hindering emotional value retention in consumer electronics. These vulnerabilities highlight the multifaceted challenges design strategies face while prolonging product use.

User-specific Vulnerabilities

Consumers' insufficient pre-purchase awareness of products fostering emotional value limits their acquisition, while limited post-purchase engagement with features supporting emotional value reduces their long-term impact. Additionally, low self-efficacy and motivation in activities that build or later restore emotional value (e.g., personalization, aftercare) further hinder retention, prompting early replacement.

Product-Service System (PSS)-related Vulnerabilities

Poorly integrated digital and physical features and inadequate services (e.g., maintenance, customer support) create fragmented user experiences. These prevent users from fully utilizing features that foster emotional value (e.g., Phillips Hue's features embedded in the app that some users do not utilize), leading to frustration. Over time, this weakens emotional value retention, potentially shortening product use.

Organizational Vulnerabilities

Conflicting departmental goals, time constraints, and overemphasizing technical metrics can hinder the organizational adoption of design strategies for emotional value. Underinvestment in long-term support systems (e.g., software or hardware upgrades) undermines emotional value retention, risking its decline in later ownership stages and prompting early replacement.

Technical Vulnerabilities

Technical barriers can hinder the implementation of design strategies, often leading to poor execution. For example, one vulnerability of the evolvability strategy can be its dependence on modular technologies, which may restrict design flexibility. Consequently, products may fail to realize their full potential,

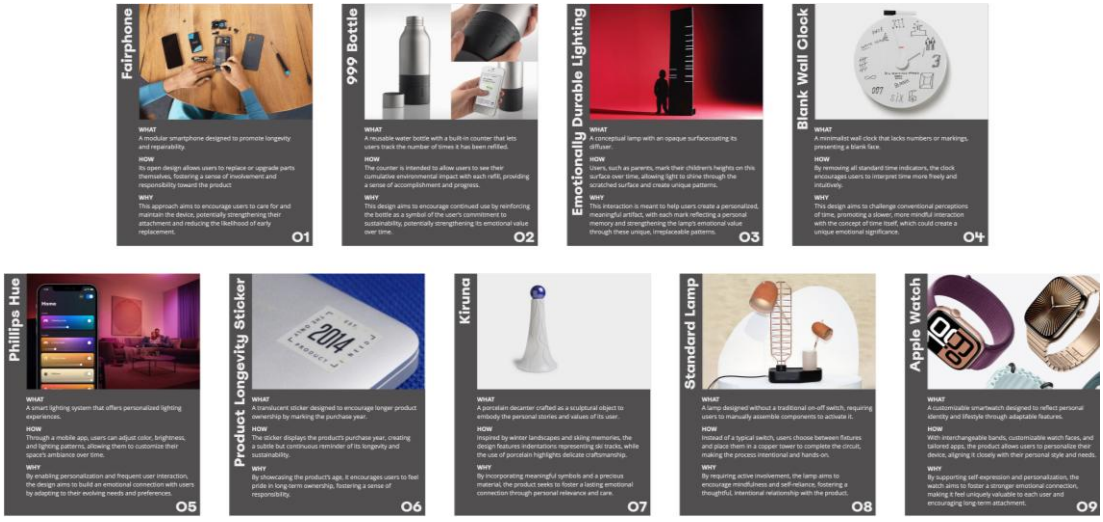


Figure 1. Design example cards used in the sensitizing activity.

reducing the strategy's likelihood of fostering emotional value and increasing the risk of early replacement.

Market-driven Vulnerabilities

Profit-driven business models misalign with design strategies for prolonged use, favoring market and technological trends that encourage early replacement. By overemphasizing new features, they overshadow the emotional value of owned products, making them feel outdated. This undermines design strategies' capacity to withstand external pressures and help products retain emotional value over time.

Conclusion

This study addresses a gap in design literature by examining the vulnerabilities of design strategies for retaining emotional value in consumer electronics. Identifying vulnerabilities advances the understanding of emotional durability in consumer electronics and how design can better accommodate shifting consumer emotions over time. The findings offer valuable insights for design practitioners and researchers to retain emotional value and counter early product replacement. Ongoing analysis will explore opportunities to address these vulnerabilities, supporting sustainable design practices that prolong product use and reduce e-waste.

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References

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101. DOI: 10.1191/1478088706qp063oa

Casais, M., Mugge, R., & Desmet, P. (2018). Objects with symbolic meaning: 16 directions to inspire design for well-being. *Journal of Design Research*, *16*(3-4), 247-281. http://dx.doi.org/10.1504/JDR.2018.099538

Chapman, J. (2009). Design for (emotional) durability. *Design Issues*, *25*(4), 29-35. http://dx.doi.org/10.1162/desi.2009.25.4.29

Desmet, P., Overbeeke, K., & Tax, S. (2001). Designing products with added emotional value: Development and appllcation of an approach for research through design. *The design journal*, *4*(1), 32-47. http://dx.doi.org/10.2752/146069201789378496

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). The global e-waste monitor 2020. *United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam*, *120*.

Haines-Gadd, M., Chapman, J., Lloyd, P., Mason, J., & Aliakseyeu, D. (2018). Emotional durability design nine—A tool for product longevity. *Sustainability*, *10*(6), 1948. http://dx.doi.org/10.3390/su10061948

Kato, T. (2021). Functional value vs emotional value: A comparative study of the values that contribute to a preference for a corporate brand. *International Journal of Information Management Data Insights*, *1*(2), 100024. https://doi.org/10.1016/j.jjimei.2021.100024

Orth, D., Thurgood, C., & Van Den Hoven, E. (2018). Designing objects with meaningful associations. *International Journal of Design*, *12*(2), 91-104.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and policy in mental health and mental health services research*, *42*, 533-544. https://doi.org/10.1007/s10488-013-0528-y

Sheth, J. N., Newman, B. I., & Gross, B. L. (1991). Why we buy what we buy: A theory of consumption values. *Journal of business research*, *22*(2), 159-170. https://doi.org/10.1016/0148-2963(91)90050-8

Shi, T., Huang, R., & Sarigöllü, E. (2022). Consumer product use behavior throughout the product lifespan: A literature review and research agenda. *Journal of environmental management*, *302*, 114114. https://doi.org/10.1016/j.jenvman.2021.114114

Van den Berge, R., Magnier, L., & Mugge, R. (2021). Too good to go? Consumers' replacement behaviour and potential strategies for stimulating product retention. *Current opinion in psychology*, *39*, 66-71. https://doi.org/10.1016/j.copsyc.2020.07.014

Wu, J., Jin, C., Zhang, L., Zhang, L., Li, M., & Dong, X. (2021). Emotionally sustainable design toolbox: A card-based design tool for designing products with an extended life based on the user's emotional needs. *Sustainability*, *13*(18), 10152. DOI: 10.3390/su131810152

Extended Abstract
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Understanding Mental Book Value: Exploring Replacement Decisions and Lifetime Expectations

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Keywords: Mental Book Value, Lifetime Expectations, Replacement decisions, Sustainable consumer behavior, Electric appliances.

Introduction

A substantial number of electric appliances that enter the waste stream are still functional at replacement (Magnier & Mugge, 2022; Woidasky & Cetinkaya, 2021). Although an electric appliance might still be capable of delivering utility, the owner can assess that sufficient value has been delivered (Echegaray, 2016). Coherently, "time for a new product" consistently emerges as one of the primary reasons for a replacement (Magnier & Mugge, 2022). Gaining a deeper understanding of how consumers decide it is time for a new product is essential for encouraging more resource-efficient and environmentally sustainable choices.

Replacement decisions involve two interrelated processes: acquiring a new appliance and retiring the old one (Roster & Richins, 2009). According to the theory of mental book value, retiring an appliance requires consumers to assess its remaining value (Guiltinan, 2010; Okada, 2001). This theory describes how consumers assign the purchase price of an appliance to its own mental account (Prelec & Loewenstein, 1998). Over time and use, the value in this mental account depreciates until the appliance has delivered its money's worth, a point known as the mental breakeven point (Okada, 2001, 2006). The more frequent and positive user experiences are, the greater the value that is obtained and the quicker an appliance reaches its mental breakeven point (Okada, 2001). Before reaching this point, consumers are typically reluctant to replace appliances, as doing so forces them to write off the remaining value, recognize unpaid costs, and incur a perceived loss (Gourville & Soman, 1998; Okada, 2006). Following the same reasoning, it is not "time for a new product" until the owned product has made its money's worth.

Some appliances typically become eligible for such premature replacement sooner than others, as the depreciation of the mental book value varies with how consumers assess these appliances' importance and functionality (Guiltinan, 2010). For instance, smartphones are often replaced to keep up with trends in technology and fashion, reflecting their importance for consumers' self- and social-identity, while washing machines are typically replaced in response to failure, as they are primarily valued for their service utility (Cox et al., 2013). Consumers' expectations of appliances' lifetimes have also been speculated to play a role in assessing when these have made their money's worth (Haase et al., 2024; Magnier & Mugge, 2022). However, this relationship remains largely unexplored.

Understanding how the mental book value influences replacement decisions and how this may vary across product categories is essential to encouraging longer lifetimes of electric appliances. This study addresses this by exploring how consumers estimate the use-time of their electric appliances (i.e., the period between purchase and replacement (Tröger et al., 2017)) and determine when these appliances have made their money's worth.

Method

In-depth, face-to-face interviews were conducted at participants' homes using a semi-structured format, allowing for new topics to emerge (Gioia et al., 2013).

Before the interviews, participants completed a 20-minute sensitizing booklet designed to familiarize themselves with lifetime and replacement concepts. addressing the purchase, ownership, and replacement phases

of the customer journey. The booklet was divided into three sections, each requiring the selection of two appliances: (1) those currently in the participant's possession, (2) those replaced while still functional, and (3) those considered for replacement despite remaining functional. To ensure diverse product categories and facilitate cross-participant comparisons, the smartphone, coffee machine, television, and vacuum cleaner were preselected in the first section. The smartphone was mandatory due to its high market penetration and short replacement cycles, making it a particularly relevant case study (Magnier & Mugge, 2022; Statista, 2024).

Interview questions ranged from concrete estimations of electric appliance lifetimes to questions aimed at challenging these estimations and uncovering underlying considerations. The concept of money's worth was newly introduced in the interviews and approached similarly as for the questions on lifetime estimations. All materials were pre-tested in pilot sessions.

Participants were recruited via a university-based consumer panel and the final sample consisted of 20 participants with a diversity in age (22-75; mean = 49) and gender (55% female). The interviews averaged 55 minutes and were fully transcribed. The transcriptions were coded inductively in Atlas.ti, using a reflexive approach to thematic analysis. This assured that potential nuances in the data were preserved, while also acknowledging the influence and importance of interpretation (Byrne, 2022).

Preliminary results & discussion

Initial familiarization with the data revealed preliminary codes and themes and the final results will be shared at the conference. As in previous research, it has been observed that the mental book value is influenced by how frequent and positive user experiences were (Okada, 2001). Participants' expectations of appliance lifetimes also influenced their decisions about when these had made their money's worth, corresponding with previous research (Haase et al., 2024; Magnier & Mugge, 2022). Additionally, the preliminary findings suggest that consumers approach lifetime expectations differently between categories. For instance, smartphone lifetimes were relatively more tied to how long participants anticipated using them, while vacuum cleaner lifetimes were tied to anticipated functional failure in the near future. Brands, purchase prices, and the perceived robustness and complexity of appliances also emerged as factors influencing these expectations. Moreover, some participants based these expectations on their own experiences, whereas others based these on their observations of others.

Participants also revealed a tendency to compare their self-perceptions regarding use-times with their perceptions of others. For instance, some participants expressed how they perceive themselves as less sensitive to replacement than most people. They also attributed their own premature replacements to unique circumstances, while characterizing the behavior of others as trend-driven or overly demanding. This misalignment suggests pluralistic ignorance, where individuals mistakenly perceive their attitudes and behaviors as different from those around them, despite underlying similarities (Moojen et al., 2022). Furthermore, participants have been observed to adjust their expectations of others' use-times upon realizing that these exceeded their own. This adjustment hints to the role of cognitive dissonance, where inconsistencies between self-perceptions and external observations are resolved by revisions in attitudes or beliefs (McGrath, 2017).

Conclusions

This research contributes to the gap in the literature on mental book value depreciation by uncovering the factors that influence when consumers decide that an appliance has made its money's worth. By doing so, this research aims to contribute to research on the mental book value and lifetime expectations. Leveraging these insights could help design strategies to raise lifetime expectations and discourage premature replacement, thereby promoting more sustainable consumer practices.

References

Byrne, D. (2022). A worked example of Braun and Clarke's approach to reflexive thematic analysis. Quality & Quantity, 56(3), 1391-1412. DOI: 10.1007/s11135-021-01182-y

Cox, J., Griffith, S., Giorgi, S., & King, G. (2013). Consumer understanding of product

lifetimes. Resources, Conservation and Recycling, 79, 21-29. https://doi.org/10.1016/j.resconrec.2013.05.003

Echegaray, F. (2016). Consumers' reactions to product obsolescence in emerging markets: the case of Brazil. Journal of Cleaner Production, 134, 191-203. DOI: 10.1016/j.jclepro.2015.08.119

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking Qualitative Rigor in Inductive Research. Organizational Research Methods, 16(1), 15-31. DOI: 10.1177/1094428112452151

Gourville, J. T., & Soman, D. (1998). Payment Depreciation: the Behavioral Effects of Temporally Separating Payments From Consumption. Journal of Consumer Research, 25(2), 160-174. https://psycnet.apa.org/doi/10.1086/209533

Guiltinan, J. (2010). Consumer durables replacement decision-making: An overview and research agenda. Marketing Letters, 21(2), 163-174. DOI: 10.1007/s11002-009-9085-2

Haase, L. M., Mugge, R., Mosgaard, M. A., Bocken, N., Jaeger-Erben, M., Pizzol, M., & Jørgensen, M. S. (2024). Who are the value transformers, value co-operators and value gatekeepers? New routes to value preservation in a sufficiency-based circular economy. Resources, Conservation and Recycling, 204, 107502. https://doi.org/10.1016/j.resconrec.2024.107502

Magnier, L., & Mugge, R. (2022). Replaced too soon? An exploration of Western European consumers' replacement of electronic products. Resources, Conservation and Recycling, 185. https://doi.org/10.1016/j.resconrec.2022.106448

McGrath, A. (2017). Dealing with dissonance: A review of cognitive dissonance reduction. Social and Personality Psychology Compass, 11(12), e12362. https://doi.org/10.1111/spc3.12362

Moojen, R., Gillebaart, M., & De Ridder, D. (2022). Misperceived eating norms: Assessing pluralistic ignorance in the food environment. Appetite, 179, 106284. https://doi.org/10.1016/j.appet.2022.106284

Okada, E. M. (2001). Trade-ins, Mental Accounting, and Product Replacement Decisions. Journal of Consumer Research, 27(4), 433-446. https://doi.org/10.1086/319619

Okada, E. M. (2006). Upgrades and New Purchases. Journal of Marketing, 70(4), 92-102. https://doi.org/10.1509/jmkg.70.4.092

Prelec, D., & Loewenstein, G. (1998). The Red and the Black: Mental Accounting of Savings and Debt. Marketing Science, 17(1), 4-28. http://dx.doi.org/10.1287/mksc.17.1.4

Roster, C. A., & Richins, M. L. (2009). Ambivalence and attitudes in consumer replacement decisions. Journal of Consumer Psychology, 19(1), 48-61. https://doi.org/10.1016/j.jcps.2008.12.008

Statista. (2024). Penetration rate of smartphones in Europe from 2014 to 2029. Statista. https://www.statista.com/forecasts/1147144/smartphone-penetration-forecast-in-europe

Tröger, N., Wieser, H., & Hübner, R. (2017). Smartphones are replaced more frequently than T-shirts. In Patterns of consumer use and reasons for replacing durable goods. Springer Gabler Wiesbaden.

Woidasky, J., & Cetinkaya, E. (2021). Use pattern relevance for laptop repair and product lifetime. Journal of Cleaner Production, 288, 125425. https://doi.org/10.1016/j.jclepro.2020.125425

Business Models for Longevity



Research paper
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Re-purposing Wind Turbine Blades: Matching Strategies and Innovation Governance Forms

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Keywords:
Innovation governance, re-purposing strategies, waste management, wind turbine blade materials

Abstract: The decommissioning of wind turbine blades poses an escalating environmental and waste management challenge, as the composite materials found in these blades are difficult to recycle and often end up in landfills. With the projected growth in retired wind turbine blades, the waste burden is expected to reach 40–60 million tons by 2050. Traditional disposal methods, like mechanical and thermochemical recycling, are costly and result in low-value materials. Repurposing presents a sustainable alternative; however, matching decommissioned blades with appropriate industrial applications requires an innovative governance approach. This study leverages insights from innovation governance research and proposes a conceptual model for reusing decommissioned blades, focusing on bridging the gap between potential suppliers and users in various industries. By examining applications in construction, agriculture, and renewable energy systems, the study illustrates feasible repurposing strategies and explores the regulatory mechanisms needed to facilitate effective matching. Through expert interviews and case studies, the paper identifies barriers, such as logistical constraints and material degradation, and advocates for intermediate and third-party governance forms to support this marketization process. The findings highlight the importance of systematic matching mechanisms and regulatory frameworks in addressing the wind turbine blade disposal issue, underscoring the need for collaborative efforts in shaping sustainable solutions for end-of-life turbine materials.

Introduction

In this conceptual paper, we suggest a novel way of matching potential users of waste materials with the providers of end-of-line wind turbine blades. In the wake of the renewable energy transition, the end-of-life disposal of blades from wind turbines presents a growing challenge. So far, the problem of decommissioning wind turbine blades (WTB) has been overshadowed by the urgency issues related to developing fossil-free energy sources. as a critical issue by industry actors. However, piles of turbine blades mount as increasingly larger wind power plants are being decommissioned (see Figure 1). The annual rate of decommissioned wind blade material is forecasted to reach 43.4 million tons by 2050 in Europe alone (Lichtenegger et al. 2020). Adding to the issue salience, waste management regulatory regimes tighten, creating new challenges for industry actors concerning handling this growing source of waste (Chioatto et al 2023). This is important not only from a commercial point of view since the disposal of blades represents a potential cost, but also from a sustainable image point of view, turbine producers find themselves increasingly criticized by salient stakeholders for not being a sufficiently green alternative (Fan & Zhang, 2024; Lichtenegger et al, 2020).



Figure 1: EOL wind turbine blade depot

WTBs are heavy and durable constructions, with a projected operational lifetime of 20-25 years and very little downtime. Blades primarily consist of glass fiber-reinforced polymer and in some constructions carbon fibers (Spini & Bettini, 2024). They are molded through a process known as resin infusion, creating a sturdy blade, which is also energy-consuming to break down into valuable primary components. Furthermore, the recycling economics is strained, since polymers become cross-linked in the curing process and their material quality and market value deter. Most often, they end up as a filler material, used in buildings, etc.

From a waste management hierarchy perspective, strategies for maintaining material value by keeping blades in their manufactured form are thus sought after (The European Waste Framework Directive, 2008/98/EC). Although there are examples of blade or blade segments being repurposed for instance as decorations in parks, they are few and far in between and do not address the volume and synchronicity issues related to managing waste stream operations (Drake & Spinier, 2013). At the same time, we suspect – given the recent salience of this problem – that the value-creating options related to matching the qualities of decommissioned blades with the potential material needs of manufacturers have not been adequately researched. Using insights from innovation governance research and recent research on reshaping industrial waste, we set out to conceptually explore how an alternative business model for matching possible users of decommissioned WTBs with potential users. The paper is structured as follows. First, we provide a background, outlining the magnitude of the problem related to decommissioning and the technique of blades and reviewing the existing literature. Next, we provide innovation governance as a theoretical lens, inspired by the literature on market shaping and the experiences from applying this perspective on a recent project on reshaping industrial waste (Laursen & Andersen, 2023). We provide a conceptual viable model for this initiative and corroborate it by using insights from expert interviews with industry actors. We end the paper by discussing possible avenues for new research and implementation roadblocks.

The magnitude and growth of the wind turbine blade disposal problem

As the global wind energy sector has expanded, a pressing environmental challenge has emerged concerning the disposal of WTBs at the end of their operational lifespan. Traditionally constructed from composite materials such as fiberglass and, in some cases, carbon fiber reinforced plastic, WTBs are built to withstand harsh weather conditions and deliver years of reliable energy production. However, these materials also make the blades difficult to recycle or repurpose, and thus they typically end up in landfills when retired. With the significant upscaling in wind energy deployment worldwide, particularly over the last two decades, the magnitude of blade disposal has reached concerning proportions, signaling an urgent need for sustainable waste management solutions.

The scale of the disposal problem is driven by several factors, with one of the most prominent being the rapid growth in wind turbine installations globally. According to recent industry reports, approximately 90 gigawatts (GW) of wind power capacity were installed annually from 2020 onward, translating into thousands of new turbines being erected each year (GWEC, 2021) Given that the typical operational lifespan of a turbine is about 20–25 years, the volume of blades entering the waste stream is set to grow significantly over the next decade, as early-generation turbines are gradually decommissioned. By 2050, it is estimated that between 40 and 60 million tons of composite material from blades will require disposal unless effective recycling or repurposing methods are implemented on a large scale.

A crucial aspect of the disposal problem is that current recycling methods for blade materials are either costly or technologically challenging, with only limited facilities worldwide capable of processing these materials. Present methods, such as mechanical shredding, thermal treatment, and chemical recycling, often struggle with the unique properties of blade composites. These materials are designed to resist breakdown, meaning that conventional recycling processes either yield low-value products or are

prohibitively expensive. As a result, most decommissioned blades end up in landfills, with studies indicating that as much as 85–90% of blade waste has historically been disposed of this way.

Another contributor to the problem is the recent trend toward the production of larger blades as a means of improving turbine efficiency and output. Larger blades not only contain more composite material but also require more complex disposal or recycling processes due to their size. This trend amplifies the scale of the disposal problem, as each new generation of turbines is likely to produce more waste than the last, further straining existing waste management infrastructure.

Repurposing strategies for sustainable development

As wind turbines reach the end of their operational lifespan, finding ways to repurpose their large, durable blades is essential. Innovative strategies to extend the life of these materials sustainably include repurposing as well as different degrees of disintegration for reuse:

Existing Repurposing strategies

1. Repurposing in Construction and Infrastructure
   - *Bridge and Pathway Construction:* Repurposed blades can be utilized as structural elements in pedestrian bridges, pathways, and other outdoor facilities. Their aerodynamic design, strength, and longevity make them suitable for such uses.
   - *Public Infrastructure*: Several cities have already adopted turbine blades in parks and public spaces as playground equipment, seating, and even bike shelters, turning these structures into functional, sustainable urban features.
   - *Emergency Housing and Modular Shelters*: Given the durability and lightweight nature of blades, they can serve as building components for emergency shelters or modular housing, providing a low-cost housing solution in remote or disaster-prone areas.
2. Agricultural and Industrial Applications
   - *Sound Barriers Along Highways*: Blades can be repurposed as sound barriers near highways and industrial zones. Their shape and material can help dampen noise pollution.
   - *Farm Infrastructure*: On farms, blades can be adapted for use as fencing, storage, and animal shelters, offering affordable and durable structures that withstand outdoor conditions.
3. Energy Systems and Renewable Integration
   - *Hybrid Energy Structures*: Repurposed blades could serve as support for hybrid renewable setups, such as solar canopies, allowing for the integration of solar panels to increase energy generation.
   - *Supports in Off-Grid Microgrid Systems*: Decommissioned blades can be reused in off-grid or microgrid systems, especially in remote or developing areas where additional materials may not be readily available.
   - *Battery Storage Facilities*: Repurposing blades as enclosures for battery energy storage systems (BESS) can add a sustainable touch to energy storage infrastructure.

Thermochemical recycling of turbine blades

When looking further than mechanical recycling of End-of-Life turbine blades, thermochemical methods are the next step in the recovery of components from the blades. Typically, these methods are divided into thermal and chemical methods, with several technologies under each category such as pyrolysis, fluidized beds, solvolysis, etc. (Ge 2024). Compared to mechanical recycling approaches none of the thermochemical processes are currently operational at industrial scale but are at lab and pilot scales.

When applying both thermal and chemical there is a loss of mechanical properties of the fiber reinforcement, be it glass or carbon fibers. This can be losses of more than 50% of the tensile strength of the fibers, but some methods have proven to provide high-strength fibers with retained tensile strength in the range of approx. 90% (Liu 2019, Sokoli 2017). To increase the value of the recovered products from the turbine blades it is important that the fiber component can be recovered with a high retained

strength, as this allows for a wider range of secondary applications of the fibers. The thermal methods cover pyrolytic methods (conventional and microwave-assisted) as well as fluidized bed recovery of composites. In pyrolysis, the composite is subjected to high temperatures in the range of 400-700oC in the absence of oxygen to produce oil from the resin as well as some non-condensable gas from the resin and a solid fraction including the fiber material (Gopalraj 2020). However, during pyrolysis, the fibers generally deteriorate and lose much of their tensile strength, normally ending in the range of 50% of the original strength in the case of conventional pyrolysis and 75% for microwave-assisted pyrolysis (Leon, 2023). This leads to the need for further treatment of the fibers using various surface treatments to minimize defects (Spini 2024). In fluidized beds, a high airflow at elevated temperatures (400+oC) allows for the recovery of fibers when treated, however, due to the heat the fibers are significantly decreased in mechanical properties (Spini 2024), as was seen with pyrolysis.
Solvolysis covers methods where solvents are used at moderate to high temperatures and pressures to degrade the resin of the composite and leave the exposed fibers. However, temperature also negatively affects the properties of the fibers, leading to a high degree of focus on low-temperature solvolysis approaches, which at the same time provide a more sustainable energy use.
Finally, a method for deconstructing epoxy composites into bisphenol-A and clean fibers using a ruthenium-catalyzed process has been demonstrated (Ahrens 2023). Although a promising step for recycling epoxies, this is reported as a slow process with the deconstruction of a 5g turbine blade taking 6 days to complete (Ahrens 2023).

Designing for recycling

As turbine blades will be needed in the future as well an approach of designing for recycling is also gaining traction. Several approaches are pursued in this regard, with examples such as alternative formulations compared to traditional epoxies and polyesters. In 2021 an alternative thermoset formulation was used by Siemens Gamesa to produce their Recyclable Blade which is tested under operational off-shore conditions (Spini 2024). This blade is reported to be recyclable using low-temperature solvolysis (Leon 2023). Likewise, LM Windpower is testing a thermoplastic resin (Elium® by Arkema) for producing recyclable blades (Spini 2024). The use of thermoplastics compared to thermosets can potentially highly influence the difficulties normally observed with the recycling of thermosets.

In summary, current strategies for re-purposing and various forms of recycling are less than optimal or under-used and only partly match the magnitude of the problem and the management of the growing WTB flows. Finding the right users of the waste material is a central challenge in waste management symbiosis (Angelis-Diakis et al, 2021). In the next section, we therefore seek ways to extend the existing use or dissemination of use strategies.

Re-use as an innovation-matching problem

The different re-uses (repurposing, recycling) of WTBs present technical opportunities, but current models for creating symbiosis effects are inadequate. Viewing the problem as one of innovation matching has so far been ignored. In the following, we apply an innovation-matching perspective, as we believe the application of market governance principle is a viable way forward in solving the waste problem. To become innovations, the WTB waste output needs to be marketized, which requires a viable and ongoing exchange between users and providers of material flows, rather than one-time solutions.

Innovation can broadly be understood as the process of creating and implementing new and valuable ideas that successfully meet market needs in new ways. New ideas can be manifest in products and services, but also new ways of organizing work, etc. (Nelson, 1991; Metcalfe et al, 2024). Innovation processes are however not randomly appearing and there are systematic differences concerning whether various levels of social systems are capable of being innovative (Porter, 1990; Chesborough, 2024). This has turned the focus to the processes governing innovation. Innovation governance is here defined as an institutional actor's attempt to establish frameworks, processes and practices that support innovation activities. Innovation governance is increasingly seen by policymakers and other stakeholders as a central means for solving the systemic problems related to the looming climate crisis.

A key issue in innovation governance is how to match resources— like physical items,

knowledge, and skills— with problem owners. This process involves setting up regulatory conditions that help businesses find ways to create value together. In environments where businesses interact, such as markets or industries, this matching process is crucial because there aren't established systems to connect resource providers with those who hold complementary resources.

From an innovation governance perspective, the challenge of matching potential users with providers of waste streams differs depending on the waste hierarchy level. Two different concerns are at stake: one concern pertains to the potential loss of value involved in the handover of waste from end-of-life WTBs to an alternative use and the other pertains to the cost of searching and matching waste with potential alternative beneficial uses. As the material moves up (or down) in the waste hierarchy parameters relating to these issues change. Breaking down the waste into its primary components is costly in terms of energy use and loss of potential features in the material. At the same time, the more generic the material is, the easier it is to find alternative users of that material. This allows for innovation governance regulatory mechanisms that are close to if not the same as regular market mechanisms, such as auctions. Maintaining the blade material in its present state for as long time as possible preserves the value and character of the material, but the matching costs related to searching for and possibly contracting with users are high and correspondingly require capable governance mechanisms. Below, we conceptually match the different states of blades in the waste hierarchy with adequate governance mechanisms.

The way resources are paired with potential users involves two main steps: potential suppliers search for relevant resources while buyers look for resources with potential usefulness. This exchange transforms random offerings into valuable matches. Information plays a vital role in this process, helping to connect different market players.

The interactions between suppliers are not random; they depend on relationships between them and the available resources. Suppliers influence one another indirectly, and their interactions with buyers and other market players also shape their decisions.

Matching providers of end-of-use turbine blades with potential users

The generic governance forms suggested in Figure 2 show a hierarchy matching the re-used forms of waste from WTBs. It includes (simple) market governance, intermediate governance forms and third-party governance forms. At the base of the waste hierarchy, we find market governance for reuse. In this form, potential us-

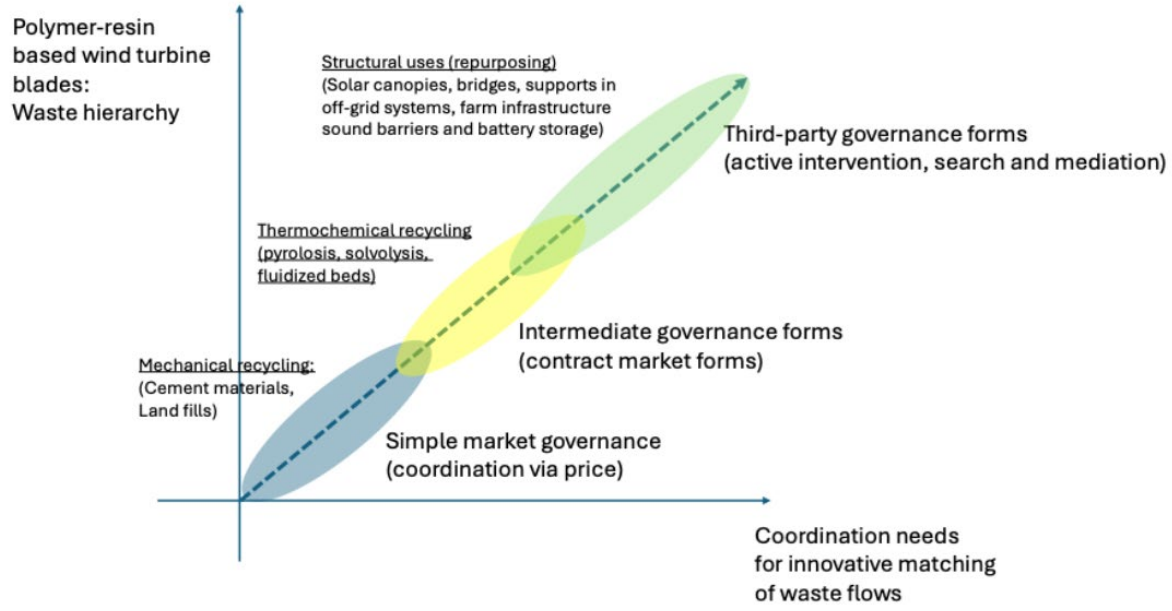


Figure 2. Matching waste hierarchies with waste management forms © own work.

ers are only limited by market size and coordination between users and providers is regulated by price signals. This form requires developing a reusable material out of end-of-life turbines, which can be valorised and used like other materials. For instance, US cement producers buy EOL blades on market terms and use them as filler materials (Jacoby, 2022). The corresponding market governance mechanism can ensure the absorption of waste flows to an almost unlimited extent, but it does little to levitate the environmental impact of the waste material. For instance, using turbine blade material in cement simply delays the problem related to releasing the material as epoxy is re-released when buildings are demolished.

Matching potential users with the advantages related to thermochemical recycling as a process for managing waste flows calls for exchanging much more information than in the case of material, corresponding to a governance form which can deal with more complex matching of users and producers. In the intermediate governance form, systematic scrutiny of existing industry uses and accessible descriptions of material characteristics and timing of production processes. This is needed for potential users can deploy cost-benefit perspectives and determine whether adaption to this waste material as a resource provides a reasonable business case. Also, this governance form opens for the formation of and commitment to buyer-supplier relationships where mutual negotiations can lead to the development of joint solutions. Problems with some innovation matching similarities to the one suggested here, are found in waste management treatment, where specification and scrutiny of available wastewater qualities are critical for matching potential users and providers (Duong & Saphores, 2015).

At the top of the waste hierarchy, we find strategies for matching users who benefit from maintaining most of the priorities of the material with providers of WTBs. This requires not only coordination of material properties but also of logistical flows and clock speed, given the physical properties of the blade that make them difficult to store and handle. The experiences from “Reshape Waste” - a recent project at Aalborg University, show that third-party innovation governance, where re-purposing of materials is used to develop new products and solutions valuable to markets, rather than replace existing materials would be a relevant option to explore further (Feast & Laursen, 2023).

Conclusions

In summary, innovative ways of solving how waste material can be reused require both technological and commercial solutions. So far, however, little focus has been given to the matching of innovation governance forms and the challenges of matching users and providers. Effective matching happens when suppliers understand their own goals and relationships, allowing them to collaboratively create valuable exchanges. Parallel to developing new ways of repurposing and recycling the material, we suggest a stronger focus on designing processes for systematically scrutinizing and developing new matches.

References

Ahrens, A., Bonde, A., Sun, H. et al. (2023) Catalytic disconnection of C–O bonds in epoxy resins and composites. Nature 617, 730–737. https://doi.org/10.1038/s41586-023-05944-6

Alderson, W. (1957): *Market behaviour and executive action*, Richard D. Irwin

Angelis-Dimakis, A., Arampatzis, G., Pieri, T., Solomou, K., Dedousis, P., & Apostolopoulos, G. (2021). SWAN platform: A web-based tool to support the development of industrial solid waste reuse business models. *Waste Management & Research*, *39*(3), 489-498. https://doi.org/10.1177/0734242X21989413.

Chesbrough, H. (2024). Twenty years of open innovation. *MIT Sloan Management Review*, *65*(2), 1-3.

Chioatto, E., & Sospiro, P. (2023). Transition from waste management to circular economy: the European Union roadmap. *Environment, Development and Sustainability*, *25*(1), 249-276 https://doi.org/10.1007/s10668-021-02050-3.

Cooperman, A., Eberle, A., & Lantz, E. (2021). WTB material in the United States: Quantities, costs, and end-of-life options. *Resources, Conservation and Recycling*, *168*, 105439. https://doi.org/10.1016/j.resconrec.2021.105439

Drake, D. F., & Spinler, S. (2013). OM forum—Sustainable operations management: An enduring stream or a passing fancy? *Manufacturing & Service Operations Management*, *15*(4), 689-700. https://doi.org/10.1287/msom.2013.0456

Duong, K., & Saphores, J. D. M. (2015). Obstacles to wastewater reuse: an overview. *Wiley Interdisciplinary Reviews: Water*, *2*(3), 199-214. https://doi.org/10.1002/wat2.1074.

Fan, W., & Zhang, C. (2024). Does Green Finance Affect Economic Performance? Growth and Crowding-Out Consequences. *Emerging Markets Finance and Trade*, 1-21. 10.1080/1540496X.2024.2345186

Feast, L., & Laursen, L. (2023). Design from Waste Materials: Situation, Problem, and Solution. *Learn X Design Conference Series*. https://dl.designresearchsociety.org/learnxdesign/learnxdesign2023/full-paper/16

Gharde, S., Kandasubramanian, B. (2019) Mechanothermal and chemical recycling methodologies for the Fibre Reinforced Plastic (FRP), Environmental Technology & Innovation, 14, 100311, https://doi.org/10.1016/j.eti.2019.01.005.

Ge, Z., Wu, Y., Zeng, M., Zhang, H. (2024) A Critical Review on the Structure and Recovery Technologies of End-of-Life Wind Turbine Blades. Energy & Fuels, 38 (20), 19393-19413. DOI: 10.1021/acs.energyfuels.4c03648

Global Wind Report 2021, available online: https://gwec.net/wp-content/uploads/2021/03/GWEC-Global-Wind-Report-2021.pdf (accessed on Nov 8, 2024)).

Laursen, L. N., & Andersen, P. H. (2023). Resource and supplier interaction in network innovation governance: the case of innovating at Unilever. *Journal of Business Research*, *156*, 113465. https://doi.org/10.1016/j.jbusres.2022.113465

Gopalraj, S.K., Kärki, T. (2020) A review on the recycling of waste carbon fibre/glass fibre-reinforced composites: fibre recovery, properties and life-cycle analysis. SN Appl. Sci. 2, 433. https://doi.org/10.1007/s42452-020-2195-4

Leon, M. J. (2023). Recycling of wind turbine blades: Recent developments. Current Opinion in Green and Sustainable Chemistry, 39, Article 100746. https://doi.org/10.1016/j.cogsc.2022.100746

Liu, P., Meng, F., Barlow, C.Y. (2019) Wind turbine blade end-of-life options: An eco-audit comparison, Journal of Cleaner Production 212, 1268-1281, https://doi.org/10.1016/j.jclepro.2018.12.043.

Nelson, R. R. (1991). Why do firms differ, and how does it matter? *Strategic Management Journal*, *12*(S2), 61-74. https://doi.org/10.1002/smj.4250121006

Metcalfe, S., Broström, A., & McKelvey, M. (2024). On knowledge and economic transformation: Joseph Schumpeter and Alfred Marshall on the theory of restless capitalism. *Industry and Innovation*, 1-14. https://doi.org/10.1080/13662716.2024.2376318

Sokoli, H.U., Beauson, J., Simonsen, M.E., Fraisse, A., Brøndsted, P., Søgaard, E.G. Søgaard (2017) Optimized process for recovery of glass- and carbon fibers with retained mechanical properties by means of near- and supercritical fluids, The Journal of Supercritical Fluids 124, 80-89, https://doi.org/10.1016/j.supflu.2017.01.013.

Spini, F., & Bettini, P. (2024). End-of-Life wind turbine blades: Review on recycling strategies. *Composites Part B: Engineering*, 111290. https://doi.org/10.1016/j.compositesb.2024.111290

Waste Framework Directive." Accessed: Nov. 7, 2024. [Online]. Available: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en.

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Exploring Consumer Behavior on Product Longevity as a Pathway to Product-Service System Adaptation.

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Keywords: Product longevity; Product-service systems; Consumer electronics; Circular economy; electronic waste

Abstract: The growing environmental challenge of consumer electronic waste has become increasingly urgent and is projected to reach 82 million tons by 2030. This paper examines product-service systems (PSS) as a potential approach to minimize e-waste and extend overall product longevity and circularity. The relationships with electronic devices and perceptions of product longevity and ownership versus leasing were explored among 20 participants aged 21 to 65, all from Denmark. Insights gained provided a basis for identifying key technological (e.g., software obsolescence) and psychological (e.g., endowment effect, mistrust of leasing) barriers to PSS adoption. A six-step user-centric PSS model is proposed, advocating product-oriented services where consumers maintain ownership but receive company maintenance and repair. The Ownership PSS model underlines consumer trust via transparent pricing, flexible solutions, and alignment with EU right-to-repair policies. This research highlights the need for further quantitative assessment (e.g., life cycle analysis) and broader cultural sampling to strengthen adoption pathways in the electronics sector.

Introduction

The rapid growth of consumer electronics has significantly intensified the global challenge of electronic waste (e-waste). In 2022, the world produced 62 million tons of e-waste, which is projected to rise to 82 million tons by 2030 (Baldé et al., 2024). Electronic devices also face digital obsolescence—even when hardware remains functional, software support can lapse, prompting consumers to upgrade prematurely. These trends highlight an unsustainable consumption of electronics and the urgent need for circular practices in the sector.

While various approaches could address this problem, Product-Service Systems (PSS) offer a promising solution. In recent years, academics and businesses have increasingly examined how subscription-based PSS can shift from traditional ownership to service-based models, delivering tangible products alongside intangible services (Mont et al., 2006; Tukker, 2004). Such models may extend product lifecycles, reduce waste, and help fulfil circular economy principles (European Parliament, 2023).

However, the adoption of PSS in consumer electronics remains limited, partly due to social and psychological barriers, including strong emotional attachments to ownership and scepticism toward leasing costs (Hobson et al., 2018). Behavioural economics concepts such as the Endowment Effect and loss aversion (Kahneman et al., 1991) suggest consumers value items they own more highly and fear losses (e.g., relinquishing ownership). On the technological side, digital obsolescence and modular hardware design also influence product longevity and repair feasibility (Fischer et al., 2017; Framework, n.d.).

Given these dynamics, this study addresses two key questions:

How do consumer perceptions of ownership and product longevity influence PSS adoption in consumer electronics?

What are the main barriers and opportunities for implementing PSS models to reduce e-waste, and how can we adapt them to overcome economic, psychological, and technological hurdles?

Literature review

In recent years, subscription-based PSS has emerged as a transformative approach in various industries, sparking interest in its potential to drive sustainability and circularity. As it has gained momentum in the last decade, academic research has increasingly centred on understanding the different types of PSS and establishing a valid conceptual framework. According to Tukker (2004), there are generally three distinct types, each with unique characteristics and economic and environmental benefits, as illustrated in Figure 1.

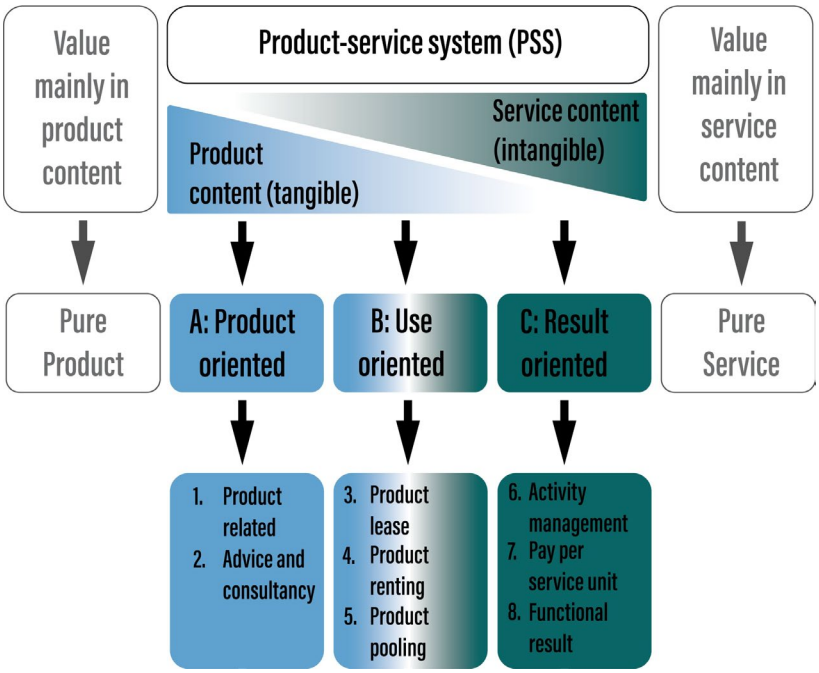


Figure 1. Tukkers three types of PSS

Product-Oriented:

The first type is Product-Oriented, which emphasizes delivering a product and offering additional services such as maintenance, repair, and upgrades. The consumer maintains full ownership of the product but benefits from the extended service and support from the company.

Use-oriented:

Use-oriented refers to when the product transitions from ownership to a leasing-based approach. The supplier retains ownership of the product and its life cycle, while the consumer pays a monthly fee for its usage. The supplier is responsible for maintenance and ensuring the product's functionality.

Result-oriented:

Result-oriented is when the consumer and supplier agree on a desired outcome rather than a specific product. While most PSS types lead to more minor environmental improvements, the Result-Oriented PSS has the highest sustainable impact (Tukker, 2004). This is due to the supplier being fully responsible for achieving the agreed-upon outcome, which often involves optimizing the service's efficiency, performance, lifespan, repairability, and sustainability of the product.

While research suggests that PSS can benefit the environment (Mont & Tukker, 2006), several challenges remain before it can be effectively implemented. A study by Hobson et al. (2018) highlights some of these challenges, presenting a hypothetical service system for mobile phones. The system allowed users to refurbish, repair, and upgrade phones, paying a monthly subscription fee. However, the limited awareness of the environmental impact of phone production and consumers' stronger emotional attachment to their devices than anticipated made it challenging to persuade them away from traditional ownership models (Hobson et al., 2018). This cognitive bias, known as the Endowment Effect, leads people to value something they own more than identical items they do not own (Kahneman et al., 1991).
A similar concept was presented by The European Circular Economy Stakeholder Platform alongside Fairphone, which produces modular phones. This PSS model focuses on extending product life cycles through modularity (Fischer et al., 2017). It highlights how modular product designs can be integrated into PSS models with companies like Fairphone to extend product lifetime. Another company could be Framework, which designs sustainable, modular laptops focusing on repairability and upgradability (Framework, n.d.). These PSS revealed similar patterns, with participants acknowledging potential benefits but remaining sceptical, particularly about the higher leasing costs compared to ownership.
A more positive response was observed for a PSS involving baby prams (Mont et al., 2006). Leasing baby prams was seen as a practical and cost-effective option for short-term use. It is also a valuable example of how a subscription-based service can extend the lifespan of products (Mont et al., 2006). Prams are made of durable components, such as the chassis, which can last through multiple users. Certain parts, such as the textile components, can be refurbished or replaced, including the interior lining, wind stopper, hood, and pockets. Looking at PSS from a larger perspective, companies such as Rolls-Royce also currently employ PSS as part of their business model, offering the "Power by the hour" program: the airlines lease engines and pay based on their specific usage (Liu et al., 2019). While significant research has been conducted on different PSS, a notable gap exists in applying these models within the consumer electronics sector.

This article seeks to fill the research gap by exploring consumers' relationship with their current electronic products and uncovering the underlying factors influencing this connection. This will be achieved through interviews and compiled thoroughly by thematic analysis. These insights will be used to investigate the opportunities and challenges of implementing PSS in consumer electronics.

Method

The study employed a qualitative approach, using thematic analysis to examine consumer attitudes toward product longevity and PSS adoption. This method was chosen for its ability to identify and interpret patterns in qualitative data (Braun & Clarke, 2006). The analysis followed Braun and Clarke's six-step framework, refining insights iteratively. The data were transcribed and analyzed using the steps in Figure 2, allowing the identification of recurring patterns in consumer behaviour. Initial codes, such as "ownership attachment" and "repair barriers," were organized into categories later to be condensed into themes for further analysis.

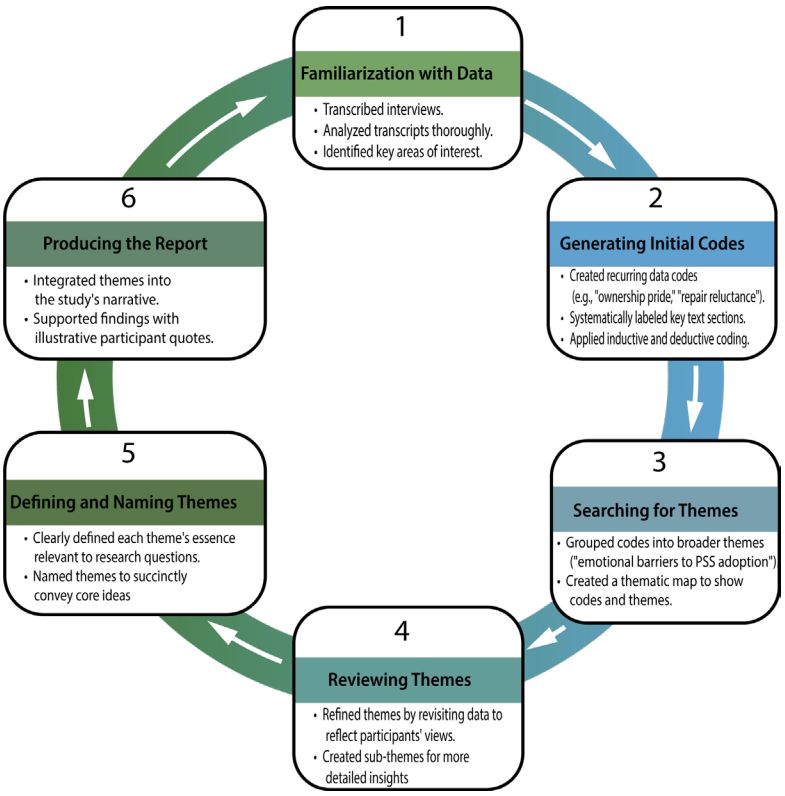


Figure 2. Tukker's three types of PSS (adapted from Tukker, 2004)

The data included 20 semi-structured interviews, a method Kallio et al. (2016) recommended for its flexibility and depth. The interviewees, aged between 21 and 65, were from Denmark and included both men and women. Each interview took around 30 minutes and was recorded and transcribed using AI tools, primarily Sonix and Microsoft Teams Speech-to-Text, to facilitate transcription. The transcripts were reviewed and cross-verified with recordings for accuracy. They were then analyzed to build familiarity with the data, laying the foundation for coding and theme development. Figure 3 shows an abbreviated example of the data-to-theme process. Initial codes were created from participant quotes, revealing common themes. As codes were identified, patterns emerged through clustering, resulting in six overarching themes.

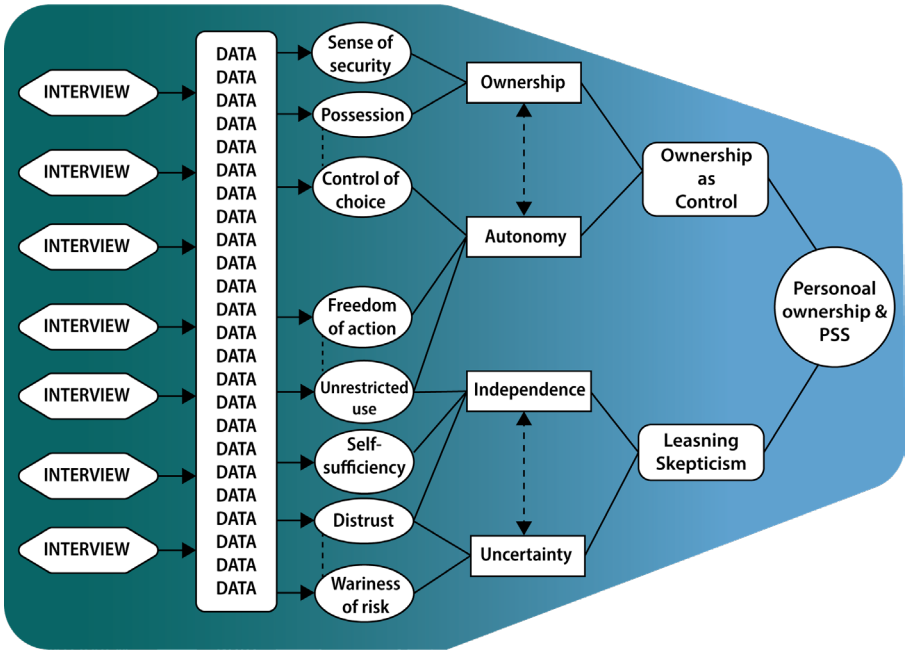


Figure 3. Coding, clustering and categorizing a theme

Analysis

This section presents the findings from research, interviews, and thematic analysis (see Table 1). These themes shed light on consumer attitudes toward product longevity and provided insights into potential barriers and opportunities for PSS adaptation.

Theme and Sub-Themes	Description	Illustrative Quotes
1. Personal ownership & PSS - Ownership as Control - Emotional Comfort	Ownership provides control and emotional security, while leasing raises concerns.	*"I prefer owning because I can control and repair my items."* *"Knowing it's mine gives me peace of mind."*
2. Cost, Quality & Economic Considerations - Cost vs. Quality - Economic Trade-Offs	Higher prices are associated with quality, but affordability can drive shorter product lifespans.	*"If I pay more, I expect the product to last longer."* *"Cheaper items don't last as long."*
3. Reparation & Knowledge Gaps - Lack of Resources - Repair Complexity	Costs, knowledge gaps, and complex designs hinder repairs.	*"There are no resources for repairing large appliances."* *"It's cheaper to buy a new one than repair it."*
4. Product Longevity & Consumer Expectations - Lifespan Expectations - Market Pressure	Product lifespans depend on the type, with trends and obsolescence forcing upgrades.	*"I expect washing machines to last longer than phones."* *"Products don't last like they used to in the 70s."*
5. Sustainability & Ethics in Consumption - Circular Economy - Consumer Responsibility	Sustainability is seen as critical, but manufacturers are perceived as disinterested.	*"Framework promotes reuse."* *"I think I should recycle more, but my items are often worn out."*
6. Product Functionality - Practical Use - Simplistic Products	Practicality and durability are prioritized over aesthetics or trends.	*"I choose products for functionality rather than appearance."*

Table 1. Themes, sub-themes and illustrative quotes

1. Personal Ownership and Its Role in Product-Service Systems

The first theme identified from the interviews was Personal Ownership and Its Role in PSS. The qualitative analysis and data gathering revealed a strong preference among participants for ownership over leasing products. Nearly all participants interviewed preferred to manage their products independently, and leasing was perceived as a loss of control. As one participant shared, *"Knowing it's mine gives me peace of mind."* and another *"I prefer owning because I can control and repair my items."* This sentiment reflects the emotional comfort and security derived from ownership. The cost was another significant concern, with them expressing difficulty estimating the long-term leasing expenses. This indicates a psychological barrier to adopting leasing models: for these consumers, possession itself carries significant value. A few participants did acknowledge that leasing might be acceptable in very specific situations – for example, to fulfil a short-term need (like borrowing a speciality gadget for a project) – but none saw it as a desirable long-term arrangement for everyday electronics.

2. Cost, quality, and financial factors

The second theme is consumers' general attitudes toward electronic devices' price, quality, and economic factors. The interviews revealed a complex relationship between product lifespan, cost, and quality expectations. A common expectation was that higher prices correlate with longer product lifespans. One participant noted, "*If I pay more, I expect the product to last longer.*" However, not all participants agreed; some mentioned that they did not always see a clear correlation between price and longevity. However, most participants agree that expensive products last longer than cheap electronics. Several participants indicated a willingness to pay more for products designed to endure, and one participant remarked, "*I don't mind paying more for a product that lasts longer.*" Participants would only consider leasing: "If leasing were cheaper than buying and included repairs, I could consider it".

3. Repairability and Knowledge Gaps

Most participants expressed frustration with the lack of resources and accessibility for repair. Professional repair services were often described as inconvenient, time-consuming, or expensive, discouraging interviewees from choosing repair over replacement. One participant noted, "*Professional repairs take too long and are often difficult to access.*" Cost was a key factor in repair decisions, with participants choosing replacement if repairs neared the price of a new unit. For example: "*I don't repair things if the price is close to that of a new device.*" Another participant added, "The biggest factor is probably the price; if it's cheaper to repair, I will do it." Environmental considerations played a secondary role in this decision, with participants acknowledging that repairs are often more sustainable. As one participant explained: "*I should think more about the environment, but the availability of repairs often makes it hard.*" Some participants extended product lifespans, such as those who repaired their washing machines, replacing parts to make it last 17 years instead of the expected 10.

4. Product Longevity and Consumer Expectations

Interviewees generally expected expensive products to be more durable. For instance, one individual shared, "*If I pay 1,350 € for a laptop, I expect at least 4-5 years of lifespan*." Similarly, expectations for product longevity varied by category, with phones and computers anticipated to last 3-4 years and larger appliances expected to last 8-12 years. Many noted that phones and computers were often changed not because of physical degradation but due to a lack of software updates or an inability to support modern features. This is also known as digital obsolescence, which refers to situations where the hardware technically functions as intended, but the software does not due to technological advancements. Some also expressed frustration with the lifespan of electronics, observing that devices with more integrated electronics tend to have shorter lifespans.

5. *Sustainability and ethics in consumption*

Some interviewees expressed enthusiasm for initiatives like Fairphone and Framework, prioritizing product modularity, recyclability, and longevity. One participant noted that "*Framework and Fairphone support the idea of reuse and extended product lifetimes*." Some favourably viewed refurbished products, with participants reporting positive experiences regarding durability: *"I often buy refurbished products, and they hold up well."* Many participants felt companies prioritize marketing over genuine sustainability, with one stating, "*Manufacturers don't seem genuinely interested in sustainable products*." The importance of design for disassembly was another recurring theme. Several participants noted that making products easy to disassemble would improve the recycling of valuable materials. Others acknowledged that environmental factors rarely influenced their decisions "*I don't think about the environment when deciding to repair or replace something*."

6. *Product functionality*

Many interviewees value functionality over trends or social status regarding product use and replacement. Several participants emphasized their preference for holding on to older products as long as they still meet their needs, with one participant noting, "*I keep products that still work, even if they are old.*" Similarly, others highlighted that they prioritize function over aesthetics or social status when making purchasing decisions: "*I buy products for their function, not social status.*"
Participants also noted that they only replace products when they become inoperable. For example, one participant shared, "*My phone is customized to my needs, so I will only replace it when it breaks.*" However, the desire for improved features was also acknowledged, with some expressing excitement: "*It's exciting when new products can do more.*"

Discussion

Our findings illuminate why typical consumers have been reluctant to give up product ownership, even when a service model could offer sustainability benefits. Participants in this study were generally unwilling to relinquish ownership of their electronics, a phenomenon explained by the Endowment Effect, which states that people place a higher value on items they own than on equivalent items they do not own (Kahneman et al., 1991). The idea of not owning an item, especially a personal device like a smartphone that holds one's data and daily utility, evoked clear discomfort. These products are seen as integral to one's identity, reflecting a deep emotional attachment. Losing ownership was repeatedly described as the most difficult challenge when considering a subscription-based PSS for electronics. This resistance is underpinned by loss aversion: the perceived "loss" of giving up one's device (or the right to call it one's own) looms larger than the potential gains of a service model. A general mistrust of leasing models also exacerbates the issue – several participants voiced concerns that service providers might impose hidden costs or leave them without a working device at a critical moment.

Another major theme was frustration over the limited options for repairs, highlighting structural and technological obstacles. Consumers desire more chances to fix their electronics, and this wish aligns with recent policy efforts like the European Union's Right-to-Repair legislation. These new regulations aim to simplify repairs and make them more attractive by improving access to spare parts and mandating that products be designed for repairability (Yakimova, 2024). Such policies reinforce the notion that future devices – particularly under PSS models – should be modular and more serviceable.
Indeed, companies like Fairphone and Framework (mentioned by several interviewees) already enable customers to replace or upgrade components easily (Fischer et al., 2017; Framework, n.d.). These examples highlight the importance of modular product architecture in extending product lifespans. However, our study found that even when repairability is built into the model, it does not fully change consumer perceptions. Many participants admitted that if a repair (whether within a PSS or outside it) became too expensive or cumbersome, they would still rather buy a new product than deal with the hassle. This aligns with Hobson et al.'s (2018) observation that consumers often have limited knowledge of their products' actual environmental impact, making it hard to convince them to opt for a service-based solution purely for sustainability reasons.

Economic considerations also strongly influenced attitudes. Most interviewees indicated they would only shift to a PSS if the financial benefits were obvious. This finding resonates with Zeithaml's (1988) notion of perceived value as a trade-off between benefits and cost. In practice, our participants prioritized immediate *tangible benefits* (like cost savings or superior service) over *abstract benefits* such as sustainability. This explains why, despite Tukker's (2004) vision that result-oriented PSS could yield the most significant sustainability outcomes (by having consumers lease products or buy performance outcomes), such models face headwinds: people are simply reluctant to relinquish ownership unless they see a clear personal advantage.

Our qualitative data strongly suggest that a pure use-oriented or result-oriented model where the company owns the product and the consumer merely accesses it is currently not the most appealing approach for mainstream electronics consumers. The psychological and trust barriers are too high. Instead, a product-oriented PSS (where the consumer retains ownership and the company provides supplemental services) appears to be a more pragmatic path forward. This approach aligns with participants' comfort zone by not forcing them to give up their devices, thereby easing the behavioural transition while still introducing service elements to extend longevity. It acts as a transitional strategy toward more sustainable consumption patterns. In a product-oriented service, a company could sell a device but then offer a service package for maintenance, repairs, upgrades, and eventual take-back or recycling. The consumer enjoys the security of ownership alongside the convenience of professional support, and the company gains opportunities for recurring revenue and deeper customer engagement. Such a model can gradually build consumer confidence in service-based solutions without breaching the psychological attachment to ownership.

Based on the study results, we developed a six-step Ownership PSS Model to address the identified barriers and guide businesses in implementing this kind of hybrid approach. The model focuses on key areas that need to be addressed to make PSS attractive and viable for consumer electronics. In essence, it outlines a *hybrid ownership-service strategy*: rather than requiring customers to rent or lease devices outright, it encourages companies to leverage ownership (which consumers prefer) as a foundation and layer on services that enhance product longevity and value. By doing so, it seeks to gradually build trust and comfort with PSS. Below, we present the six steps of the model, each targeting a specific barrier or opportunity highlighted by our research.

Ownership PSS Model

To synthesize the gathered data and insights, a proposed model is a hybrid ownership-service approach that retains what consumers value about owning products while introducing service elements to prolong product life. It provides actionable guidance for companies transitioning from a pure sales model to a more circular, service-enhanced model. Each step of the model corresponds to a critical design consideration identified in our findings. The model is shown in Figure 4.

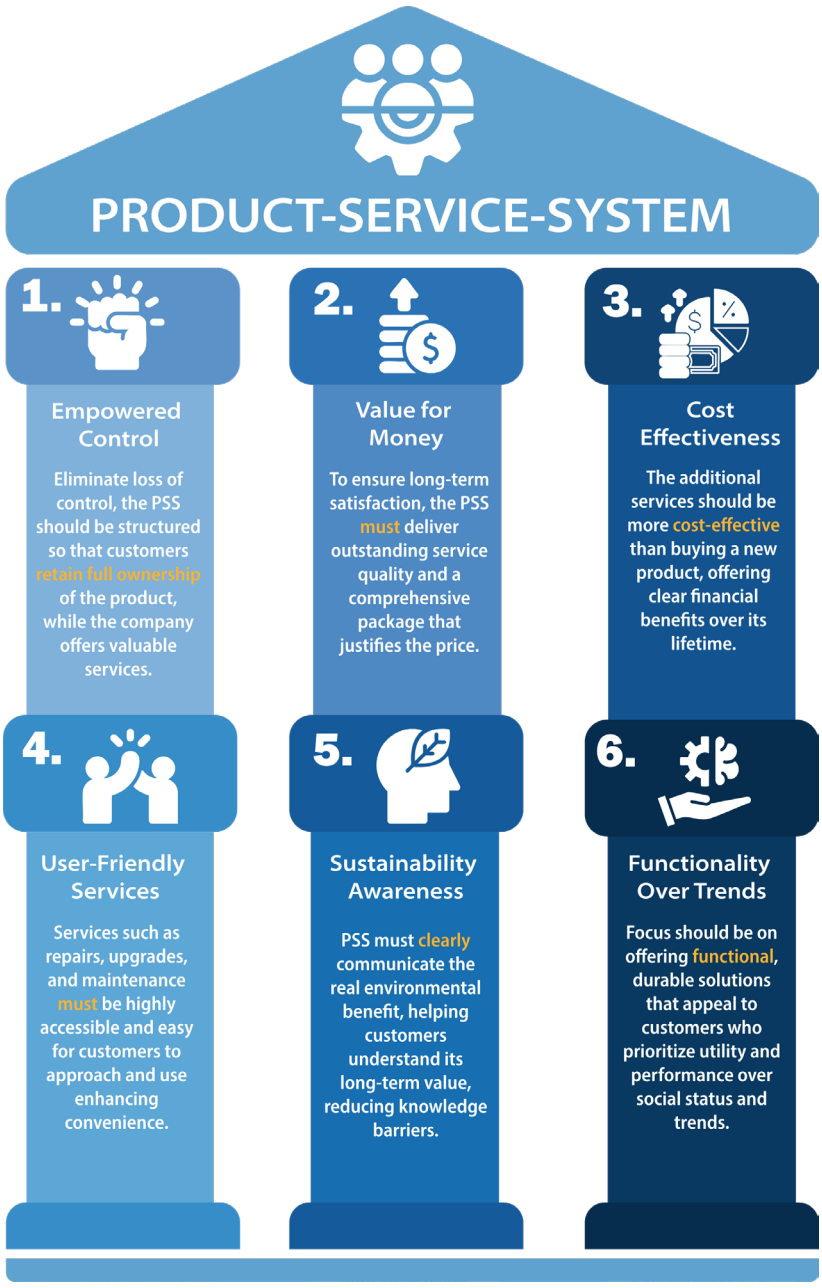


Figure 4. Ownership PSS Model

Example of Ownership PSS Model

The model was applied to a washing machine as a real-world example, supporting Europe's right-to-repair initiative, See Figure 5. Starting July 31, 2026, manufacturers must offer affordable repairs for household appliances like washing machines, dishwashers, fridges, and ovens (Repair.eu, 2024).

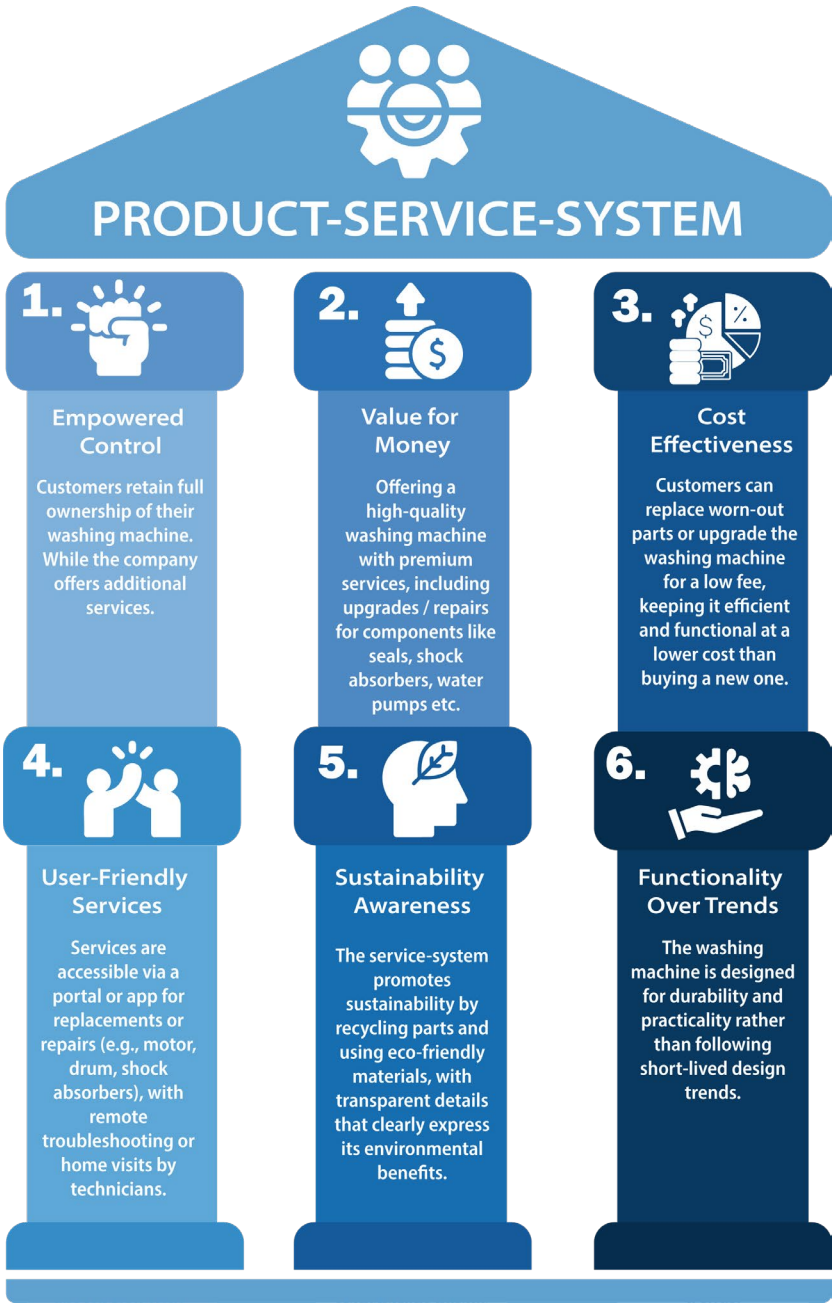


Figure 5. Washing machine example of the Ownership PSS Model

Limitations and Future Work

Like any exploratory study, this research has certain limitations that must be acknowledged, and it opens several avenues for future investigation:

Limited Sample & Cultural Context: Our interview sample was limited to 20 participants, all located in Denmark. This homogenous context (high-income, European, with a strong consumer-rights culture) may not represent the full spectrum of consumer attitudes globally. The findings and the proposed model should be tested with broader and more diverse samples. Future research should include participants from multiple geographic and cultural backgrounds to see if attitudes toward ownership and PSS differ in other contexts (e.g., countries with different levels of trust in service providers or varying cultural attitudes toward ownership). Expanding participant diversity will improve the generalizability of the results.

Qualitative Data & Generalizability: This study relied on qualitative insights and self-reported attitudes without quantitative measures of how widespread these attitudes are. While the themes identified are illuminating, we lack statistical evidence of their prevalence. Future work could employ surveys or experiments to quantify consumer willingness-to-adopt PSS under various conditions. For example, a survey could measure what percentage of consumers in different markets would prefer a hybrid ownership service model over leasing. Such data would complement our qualitative findings and help validate (or refine) the six-step model's assumptions. Additionally, longitudinal studies could track whether attitudes change after consumers gain experience with PSS offerings (e.g., through field trials).

Scope of Analysis – Environmental Impact: Our study did not include a detailed Life Cycle Assessment (LCA) or any quantitative analysis of the environmental benefits of the proposed PSS model versus traditional ownership. This was beyond our scope, but it is an important next step. Future research should incorporate LCA to objectively quantify how much e-waste reduction or carbon savings a product-oriented PSS could achieve. For instance, applying an LCA to our washing machine example could compare the environmental footprint of the service model (with longer use and recycling) against the footprint of the typical buy-and-dispose cycle. Such an analysis would provide hard evidence of the sustainability gains (or potential trade-offs) and could identify any rebound effects (e.g. if lower usage costs lead to more frequent machine use). Demonstrating clear environmental benefits will also be crucial for justifying PSS business models to policymakers and consumers alike.

Cross-Sector Comparison: This research focused on consumer electronics; however, many of the identified barriers (emotional attachment, trust, repair issues) could play out differently in other product domains. Future studies could conduct cross-sector analyses comparing consumer behaviour across product categories – for example, how do attitudes toward a PSS for electronics compare with attitudes toward PSS in clothing, furniture, or automobiles? Some sectors might find consumers more amenable to service models (for instance, car leasing is already common, whereas phone leasing is not). Understanding these differences could help refine the user-centric model for different industries or identify sectors where fully use-oriented PSS might be feasible sooner.

In summary, while our study provides initial evidence and a conceptual model, further work is needed to test, quantify, and expand these ideas. Researchers and practitioners can build on this foundation by addressing the above points – broadening samples, adding quantitative analyses (including LCA), comparing across sectors, and piloting new service concepts. Such efforts will help ensure that PSS implementations are well-intentioned, empirically effective in different contexts, and truly beneficial from an environmental standpoint.

Conclusion

This research aimed to understand consumer's perceptions of product longevity and ownership to identify pathways for adopting Product-Service Systems (PSS) in consumer electronics. By analyzing interactions with electronic devices among 20 Danish participants of various ages, it was found that none were willing to lease their products due to strong psychological attachments, lack of awareness about PSS benefits, and perceived inconveniences of subscription services.

The study identified key barriers and opportunities and proposed a six-step model to enhance PSS accessibility. This model aims to ease the transition to a system where consumers retain ownership while companies provide services like maintenance and upgrades. While it offers a conceptual framework, its implementation is complex and requires further exploration of areas like product architecture, modularity, and integration of EU's right-to-repair policies.

Encouraging more companies to adopt product-oriented services can increase revenue and improve customer relationships and environmental benefits. To succeed, companies must build consumer trust, communicate environmental advantages clearly, and offer user-friendly service options that are not bound to a subscription model.

References

Baldé, C. P., Kuehr, R., Yamamoto, T., McDonald, R., D'Angelo, E., Althaf, S., Bel, G., Deubzer, O., Fernandez-Cubillo, E., Forti, V., Gray, V., Herat, S., Honda, S., Iattoni, G., Khetriwal, D. S., Luda di Cortemiglia, V., Lobuntsova, Y., Nnorom, I., Pralat, N., & Wagner, M. (2024). *The Global E-Waste Monitor 2024* (No. 2). International Telecommunication Union (ITU) and United Nations Institute for Training and Research (UNITAR).

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

European Parliament. (2023, May 24). *Circular economy: Definition, importance and benefits*. European Parliament. https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits

Fischer, A., Achterberg, E., & Ballester, M. (2017). *The Circular Phone: Legal, Operational and Financial solutions to unlock the potential of the 'Fairphone-as-a-service' model* (p. 40). Circle Economy and Fairphone.

Framework. (n.d.). *About Framework*. Framework. Retrieved 9 April 2025, from https://frame.work/dk/en/about

Hobson, K., Lynch, N., Lilley, D., & Smalley, G. (2018). Systems of practice and the Circular Economy: Transforming mobile phone product service systems. *Environmental Innovation and Societal Transitions*, *26*, 147–157. https://doi.org/10.1016/j.eist.2017.04.002

Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1991). Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias. *Journal of Economic Perspectives*, *5*(1), 193–206. https://doi.org/10.1257/jep.5.1.193

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Liu, J., Wan, M., Jiang, W., & Zhang, J. (2019). How Does Leasing Affect Green Product Design? *Mathematical Problems in Engineering*, *2019*(1), 5780342. https://doi.org/10.1155/2019/5780342

Mont, O., Dalhammar, C., & Jacobsson, N. (2006). A new business model for baby prams based on leasing and product remanufacturing. *Journal of Cleaner Production*, *14*(17), 1509–1518. https://doi.org/10.1016/j.jclepro.2006.01.024

Mont, O., & Tukker, A. (2006). Product-Service Systems: Reviewing achievements and refining the research agenda. *Journal of Cleaner Production*, *14*(17), 1451–1454. https://doi.org/10.1016/j.jclepro.2006.01.017

Tukker, A. (2004). Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment*, *13*(4), 246–260. https://doi.org/10.1002/bse.414

Yakimova, Y. (2024, April 23). *Right to repair: Making repair easier and more appealing to consumers*.

https://www.europarl.europa.eu/news/en/press-room/20240419IPR20590/right-to-repair-making-repair-easier-and-more-appealing-to-consumers

Zeithaml, V. A. (1988). Consumer Perceptions of Price, Quality, and Value: A Means-End Model and Synthesis of Evidence. *Journal of Marketing*, *52*(3), 2–22. https://doi.org/10.1177/002224298805200302

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Enhancing Critical Raw Material Usage through Battery Cell Extraction and Reuse

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Keywords: Reuse; Remanufacturing; Critical raw materials; Product-as-a-Service; Li-ion Battery.

Abstract: This paper proposes a circular economy business model for recycling and remanufacturing Bosch Gen 3 batteries to enhance sustainability and economic viability. The model integrates collection, robotic disassembly, and state-of-health-based categorisation to extract the most valuable, reusable cells and then tests a battery remanufacturing option to maximize profit and critical raw material recovery. Two collection methods are analysed: incentivized returns (Option 1) and battery waste sorting at recycling centres (Option 2). A Monte Carlo simulation evaluates profitability with several uncertainties, including logistics and deposit refunds. Option 1 is more likely to obtain higher-quality cells, but is less likely to be profitable due to the high costs associated with the incentive, while Option 2 is more cost-effective, but yields lower-quality cells. This study highlights opportunities to optimize incentives and recycling value, providing a scalable framework for sustainable battery end-of-life management.

Introduction

The demand for lithium-ion batteries (LIBs) is growing over 30% annually, projected to reach 4.7 TWh and $400 billion by 2030, driven by electrification and energy transitions(J. Fleischmann & Schaufus, 2023). This growth depends on critical raw materials (CRMs) like lithium, cobalt, and nickel, which face supply chain risks and environmental concerns. In the power tool industry, LIBs are valued for their energy density and lifespan, but challenges include securing material supplies, ensuring tool compatibility, and recycling to recover valuable resources. Tackling these issues is essential for sustainable growth and reduced environmental impact (Zeng et al., 2014).

Although consumer drop-off programs are expanding, current recycling practices remain fragmented and inadequate. Batteries are often treated as mixed e-waste, limiting the recovery of valuable materials (Zeng et al., 2014). Recent regulatory changes, such as the European Union's Batteries Regulation, emphasize circular economy principles by setting strict standards for lifecycle sustainability. Effective from August 2023, these regulations mandate reductions in hazardous substances, higher recycling targets, and designs that allow easy battery removal and replacement by 2027. Such measures provide a favourable policy framework for improving battery management systems (Directorate-General for Environment, 2023).

CRM recovery could possibly be facilitated by selective disassembly from LIBs, However, analysis of real-life case studies has concluded that the economic feasibility of product disassembly is strongly linked to the recovery and reuse of functional components from the processed products. Fuji Film's single-use camera remanufacturing model incorporates modular design, automation, and efficient logistics, processing up to 33 million units annually. This system achieved a 62% reduction in CO_2 emissions and demonstrated the economic viability of scalable, sustainable end-of-life management (Duflou et al., 2008).

This paper builds on these principles to propose a circular economy model for Bosch Gen 3 tool batteries (*Power for All Alliance*, 2024), which would fall under category 6, based on the EU waste electrical and electronic equipment (WEEE) category classification (Magalini et al., 2014). The model combines reverse logistics, automated disassembly, state-of-health (SoH) testing, and customer incentives to address inefficiencies in current systems. By focusing

on residual value extraction and profitable remanufacturing, the study highlights the potential to optimize CRM recovery and reduce e-waste through a potentially profit business model.

Methodology

Case Study: Bosch PFA Gen 3 Battery

This study focuses on the Bosch Generation 3 (gen 3) 4Ah battery (*Power for All Alliance*, 2024). The gen 3 4Ah battery was selected for its high potential volume and standardized design, ensuring compatibility with 164 tools from 12 different manufacturers' tools under the Power for All Alliance. As the latest generation (gen 3), it offers a single capacity option (4Ah) in one physical size, unlike the gen 2, which had seven capacities across two physical sizes. This streamlined design enhances its suitability for robotic disassembly. While not the highest-volume model at the time of writing, the transition from gen 2 to gen 3 batteries was already underway.

According to Eurostat, 244,048 tonnes of portable batteries were sold in 2022 (Eurostat, 2024)However, this data encompasses all battery types and is reported by weight rather than individual units. To estimate Bosch lithium-ion power tool battery sales, Bosch's European power tool revenue, which totalled €5.6 billion in 2023 (Bosch Power Tools, 2024), can be used as a reference. Assuming an average sales price of €100 per unit, this equates to approximately 56 million power tools sold in 2023. Bosch power tools also report that 10% of its power tool sales occur in Germany, suggesting around 5.6 million units were sold there in 2023. Additionally, market data from the United Kingdom indicates that 81.1% of power tools sold in 2022 were cordless (Protrade, 2023) Applying this proportion to Bosch's estimated German sales suggests that approximately 4.5 million cordless power tools, most of which would contain a LIB.

Figure 2: Flow chart of proposed EOL treatment

While this is a rough estimation and limited to Germany, it highlights the substantial number of Bosch batteries sold annually, supporting the economic feasibility of a circular economy model presented in this paper.

Figure 1 provides an exploded view of the gen 2 battery, highlighting individual components such as the plastic housing, cells, nickel strip and Battery Management System (BMS). A sample battery was manually disassembled, and its components were weighed to estimate their recycling value, which is detailed in the *results* section.

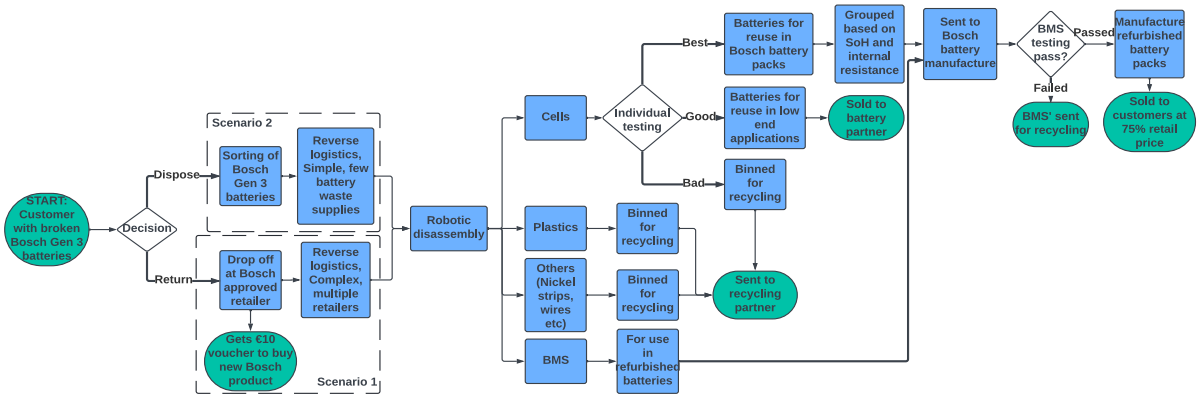


Figure 1: Flow chart of proposed EOL treatment



Figure 3: Bosch gen 2 battery exploded view (Power for All Alliance, 2024)

This battery employs 21700 lithium-ion cells (the number refers to the width (21mm) and length (70mm) of the cell), which are optimal for remanufacturing and recycling efforts due to their higher energy density than more traditional 18650 cells used in gen 2 batteries. The proposed battery remanufacturing model (shown in *Figure 2* below) developed for this paper, covers the battery from failure at the customer, through collection/incentivised return, to robotic disassembly and eventual remanufacturing into a new battery.

Battery collection/deposit refund

End-of-life management for these batteries typically follows three pathways: landfill disposal, incineration, or recycling, often accompanied by a hoarding tendency, where users store broken batteries at home for extended periods (Mudgal et al., 2011). When choosing recycling customers typically dispose of their broken tool battery at either an e-waste collection centre or in a dedicated battery disposal container, from where it is collected and sent to a specialised battery recycling centre (Bebat, 2024).

While specific recycling data on tool LIBs is unavailable, estimates from battery and accumulator recycling data (Eurostat, 2025) indicate that approximately 46% of batteries sold in the EU were collected for recycling in 2022. However, this calculation is flawed, as it relies on a three-year reference period—significantly shorter than the typical lifespan of LIBs, as highlighted by BeBat, the Belgian battery collection agency.

"*…there has been strong growth in recent years in the market for lithium rechargeable batteries...It is clear that the current method of calculating the collection rate is no longer adequate…"* (Bebat, 2023)

Additionally, the data does not distinguish between individual cells and battery packs, such as the Bosch gen 3 tool batteries, which are generally more likely to be recycled due to their larger size and structured disposal pathways (Mudgal et al., 2011). To increase this conservative 46% collection rate and capture the battery before it is shredded, this model introduces one novel approach, namely providing a financial incentive for the customer to return the battery to a retailer hereby referred to as option 1. A second approach is also explored where the batteries are separated at the battery treatment facility referred to as option 2. These two methods of collection are compared in the *results* section.

1. Option 1: Incentivised return

To encourage the return of Gen 3 batteries, the model would offer customers a Bosch voucher upon returning their battery to an approved dealer. A voucher value of €10 was determined as an appropriate amount, based on the recommended retail price of the Gen 3 battery of €126 at the time of writing (Bosch, 2024).

The voucher program costs are discounted in the model to an effective cost of (€2 – €4). The cost of a €10 voucher to a company is less than its face value and depends on factors like the cost of goods sold (COGS), redemption rate, administrative expenses, and potential additional sales. For example, if COGS is €5 and only 60% of vouchers are redeemed, the cost per voucher is €3. This option also requires robust logistics to collect and consolidate batteries nationwide for processing, since batteries could be returned at any Bosch dealer, and would have to make its way to a central point. These reverse logistics costs, due to dispersed retailers, are estimated to range from (€0.50 – €2) per battery pack, with a mode of €1. This wide range reflects uncertainties in transportation and handling expenses.

2. Option 2: Battery waste sorting

This approach utilizes the existing battery collection system, where batteries are deposited into collection boxes and transported to centralized recycling centres. At these centres, a new sorting process would be added where only gen 3 batteries are sorted from other

types before being sent to a robotic disassembly plant via reverse logistics. The amount paid per battery pack to the battery recycling centre is €1, this value was estimated, based on the costs incurred by the battery recycler to collect the batteries together with an additional fee for the sorting. The reverse logistics costs are lower than Option 1 (€0.30–€0.80) due to simpler processes in the logistics chain, being a point-to-point flow.

Both option 1 and option 2 facilitate battery collection and transportation but differ in cost and battery quality. Incentivized returns would incur higher costs due to customer rewards and complex logistics, but would likely yield higher-quality batteries with remaining usable life. In contrast, battery waste sorting is cheaper and simpler, however, would likely result in lower-quality batteries, as these are often used until failure before being discarded. This is reflected in the model, with a change in the number of "Best" and "Bad" cells in *Table 1*.

Battery Robotic Disassembly

The battery disassembly process would be outsourced to a partner organization such as Circuli-ion (Circu Li-ion, 2024) a company that specialises in battery disassembly. The proposed model would leverage purpose-built robotic systems specifically optimized for only gen 3 battery packs. Robotic disassembly allows for the efficient separation of components, including cells, plastic casings, BMS, nickel strips, and screws. This automated approach minimizes manual labour and is both cost-effective and scalable. The calculation of this cost includes fixed and operational costs to support the disassembly process. The number of operators is based on the quantity of batteries being processed, the shift duration is 8 hours, with a total working day in Belgium of 250 per year and a disassembly time of 1 minute, this is the maximum throughput of such a robotic disassembly process. If more throughput is required, then an additional robotic disassembly set-up would be required.

$$N_{bats/yr} = \frac{Time_{shift} * 60}{Time_{dissassemble}} * Working\ days$$

$$N_{bats/yr} = \frac{8 * 60}{1} * 250$$
$$= 120{,}000\ bats\ per\ year\ per\ operator$$

Each operator could manage approximately 120,000 battery packs annually. Operating two shifts per day allows the robotic disassembly station to process up to 240,000 packs per year, requiring two full-time operators. With an annual salary of €50,000 per operator, the total salary cost would be €100,000. The robotic equipment, with an initial investment estimated at €500,000, would depreciate over 10 years, resulting in an annual depreciation cost of €50,000. Consequently, the total maximum annual cost for the disassembly station would amount to €150,000.

$$C_{pack} = \frac{Annual\ cost}{Batteries} = €/bat$$

$$C_{per\ pack(min)} = \frac{150{,}000}{240{,}000} = €0{,}625/bat$$

$$C_{per\ pack(max)} = \frac{100{,}000}{120{,}000} = €0{,}833/bat$$

In the model, the disassembly time per battery is not 1 minute as in these simple calculations but rather modelled as a distribution ranging from (0,5 – 2) minutes. This range accounts for variations in battery condition and incorporates uncertainty in the disassembly process.

Cell Testing and Sorting

Each cell would undergo automated testing to measure its internal resistance and estimate its State of Health (SoH), a key metric that indicates the cell's remaining capacity and performance relative to its original specifications, with a SoH of 100% representing a new or like-new cell (Ufinebattery, 2024; Zatta et al., 2024). The cost of testing is assumed to be €0,1 per cell, based on a rapid electrical parameter testing technique. This assessment determines the value of each cell and enables sorting into three categories.

1. Recycling "bad cells": Cells with an SoH below 50% are designated for recycling.
2. Low-End Reuse "good cells": Cells with an SoH between 50% and 70% are suitable for low-demand applications.
3. High-End Reuse "best cells": Cells with an SoH above 70% qualify for high-demand applications, such as remanufactured Bosch gen 3 batteries, where they would be reassembled into packs sold at a reduced price.

Recycling

Cells with an SOH lower than 50% would be deemed “bad” and be binned for recycling. Due to their separation from the battery pack, these cells would yield a high CRM recovery rate as opposed to the current method of shredding battery packs as a complete unit and then separating the materials. All other components of the batteries such as the plastics, nickel strips etc are also recycled, due to their lower value and difficulty in reuse. The revenues generated from selling these components are listed in *Figure 3* and *Table 2.*

Low-end reuse

This study assumes cells with a SoH between 50% and 70% are classified as “good.” While these cells retain sufficient serviceable life, their performance is inadequate for use in remanufactured Bosch gen 3 batteries, which are expected to exhibit a capacity and lifespan comparable to new batteries. Instead, these cells would be sold to companies producing low-end household energy storage systems, where energy density is less critical. Consequently, the resale value of these cells is lower than their potential value in remanufactured packs but higher than their recycling value. For this model, the estimated value of a "good" cell is €1, derived from a comparison of the recycling value (€0.47) and the price of a new cell (€2.10). This valuation reflects the intermediate market potential of these cells in secondary applications.

High-End Reuse: Remanufacturing Battery Packs

Cells deemed “best” (SoH > 70%) undergo further processing to ensure compatibility and longevity. They are balanced to the same float voltage and grouped by SoH. They are then sent to the battery manufacturing plant together with the BMS’ in the next process.

Logistics to Remanufacturing plant

The "best" cells, along with all extracted BMS units, would be transported to the battery assembly plant for further processing. This transportation would follow a point-to-point logistics model, similar to the logistics from the battery sorter to the robotic disassembly facility. Accordingly, the same cost uncertainty values are applied, reflecting the variability in transportation expenses.

Test BMS

At the battery production facility, the BMS units would undergo testing using a custom-designed test jig. This process, likely manual, would involve a worker inserting the PCBs into a test jig where basic functionality checks are performed and subsequent reconfiguration of "good" BMS units for use in remanufactured battery packs. The cost of testing each BMS is estimated at €0,5 based on high-volume standardised PCB testing (PCB online Team, 2021).

Remanufactured battery reassembly

The "best" cells and "good" BMS units would then be reassembled into remanufactured battery packs using new plastic housings, nickel strips, and screws at Bosch's automated manufacturing plant. These remanufactured gen 3 batteries would be sold at 70% of the price of a new battery, representing the primary source of revenue and a key innovation of this model.

Monte Carlo simulation

To identify the optimal battery collection option and simulate the overall cost, revenue, and profit of the model, while accounting for uncertainties in variables such as logistics and testing, a Monte Carlo simulation was developed. This model was implemented in Excel using the ModelRisk Monte Carlo software add-in (Vose software, n.d.). The input variables for the model, detailed in *Table 1*, are characterized by minimum, mode, and maximum values, assuming a normal distribution as previously discussed in the paper.

Table 1: Model inputs

Variable name (per pack)	Min	Mode	Max
Option 1: Incentivised return			
Reverse logistics	€0,5	€1	€2
Deposit refund cost	€2	€3	€4
Best cells %	20%	30%	40%
Option 2: Battery waste sorting			
Sorting		€1	
Reverse logistics	€0,3	€0,5	€0,8
Best cells %	10%	20%	30%
Applies to option 1 and option 2			

Robotic disassembly time	0,5min	1min	2min
Testing cells (per cell)		€0,1	
Logistics to Bosch	€0,3	€0,5	€0,8
Test BMS		€0,5	

The Monte Carlo model runs two simulations (Option 1 and Option 2), each with 5000 samples, and a manual seed of 1 (for reproducibility of results). The results of this model will be discussed below.

To simulate a realistic business model, a quantity of batteries is needed. This quantity would represent the number of batteries that could be processed in one year. This number is an uncertainty and therefore a distribution, with a range from (120 000 – 240 000). These come from the minimum and maximum number of batteries that can be processed by 1 or 2 operators and one robotic disassembly line, as discussed previously.

Results

Recycling values

The first step involves calculating the value of the recycled component materials extracted from the battery. A key advantage of this proposed process is that the separation of individual components significantly increases their recycling value compared to shredding, where materials are mixed, reducing their purity and therefore value. Additionally, the extraction efficiency of CRMs is higher in this method, as material loss during processing is minimized due to precise separation. The disassembled gen 2 battery is provided below in *Figure 3* to show its components. The gen 2 battery was easily accessible at the time of this study, hence the use of the gen 2 bill of materials (BOM). The weights and components (with identification numbers matching *Figure 3*) in *Table 2* have been adjusted for gen 3 specifications. For instance, cell weights reflect the use of Type 21700 lithium cells in gen 3, replacing Type 18650 cells in gen 2.

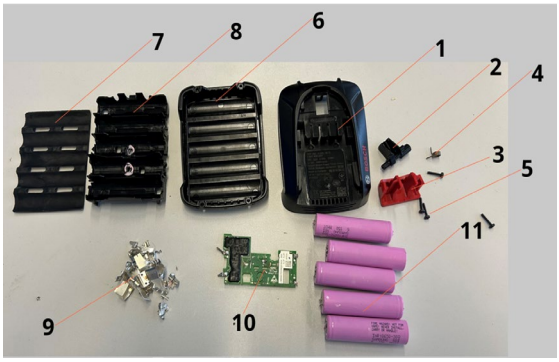


Figure 4: Bosch power for all (PFA) gen 2 battery disassembled (labels in Table 2)

Recycling values are sourced as indicated, except for the housing, made of PC/ABS FR40, where the general plastic waste value of €454/ton (Eurostat, 2024) was used due to a lack of specific pricing for plastic with FR40. The flame-retardant additive complicates recycling, reducing demand or increasing costs; thus, the analysis applies a 50% reduction in its value. As with the previously mentioned Fuji Film example, it is possible that these plastics could be repurposed to manufacture new housings. However, the viability of this option remains uncertain due to the unknown condition of the housing. Additionally, since the value of these housings is significantly lower than the cells, this possibility was excluded from this study.

Table 2: Recycling value of Gen 2 battery

Part (*Figure* 3 number)	Material	N	Weight	Value (€/ton)	Source	Value (€)
Housing (1,6)	PCABS FR40	2	91,2	€227*	(Eurostat, 2024)	€0,02
Housing (cells) (8)	PCABS FR40	1	24,6	€227*	(Eurostat, 2024)	€0,006
Push button (3)	ABS	1	4,6	€454	(Eurostat, 2024)	€0,002
Rubber plate (7)	Elastomer	1	4,9	€454	(Eurostat, 2024)	€0,002
Nickle (9)	Nickle		10,3	€8510	(Rockawaywrecycling, 2024)	€0,087
Screws (5)	Steel	4	1,8	€220	(Metaloop, 2024)	€0,004
Spring (4)	Steel	1	0,4	€220	(Metaloop, 2024)	€0,001
Cells (Bad) (11)	21700 LiPo	X	360	€1381	(Scrapmonster, 2024)	Variable

BMS (Bad) (10)	PCB Grade 1	0,5	7,9	€4500	(Repairprice.co.uk, 2024)	€0,04
Total recycling value (excl cells)					€ 0,154	

The recycling value per pack is €0.154, a low figure due to unknown material compositions, such as screw steel grades or elastomer types, leading to conservative estimates. A detailed analysis of gen 3's BOM and material composition analysis would be necessary for more accurate pricing, which wasn't possible for this study. This would likely increase the estimated recycling value.

Monte Carlo simulation

The first outcome of the Monte Carlo simulation is the total profit, illustrated in *Figure 4*. This profit is calculated by multiplying the annual number of battery packs processed by the total revenue (from best and good cells, functional BMS units, and recycling value), minus all associated costs (including logistics, robotic disassembly, deposit refunds for Option 1, and sorting fees for Option 2). The simulation is repeated 5,000 times, with each iteration sampling different values from the distributions of the variables, resulting in a distribution of potential profit outcomes for both options.
The resulting distributions represent the best, worst, and most likely scenarios for each option. The analysis reveals that Option 2 is more likely to be profitable, with a mean profit of €278,192, compared to Option 1, which shows a mean loss of €175,814. However, it is noteworthy that Option 1 can still achieve profitability in some scenarios, as indicated by instances with positive profit, while Option 2 may occasionally result in a net loss, as shown by some instances with negative profit. These variations arise from the high degree of uncertainty in the input variables. Further research and data collection could reduce this uncertainty and narrow the distributions, though the general conclusion of the study is unlikely to change unless the variables are significantly shifted.

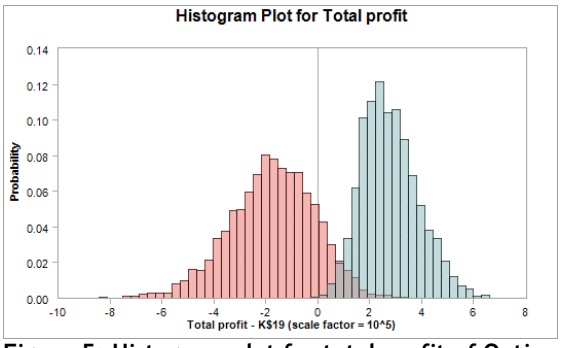


Figure 5: Histogram plot for total profit of Option 1(red) and Option 2(blue)

The tornado plot presented in *Figure 5* illustrates the sensitivity of total profit to the uncertainty of the input variables for Option 1. The most significant source of uncertainty is the deposit refund, which ranges between €2 and €4, as detailed in *Table 1*. This variability substantially impacts expenses, as the refund is applied to every battery pack returned. Reserve logistics follows closely as another major source of uncertainty, given its similar impact on costs. Reducing the uncertainty of these inputs could significantly enhance the reliability of the model's predictions. A pilot study could be conducted to establish a narrower distribution for the deposit refund, while an analysis of logistics routes could provide more accurate estimates of transportation costs between the retailers and the disassembly plant. Such refinements would help minimise uncertainty and improve the robustness of Option 1's financial projections.

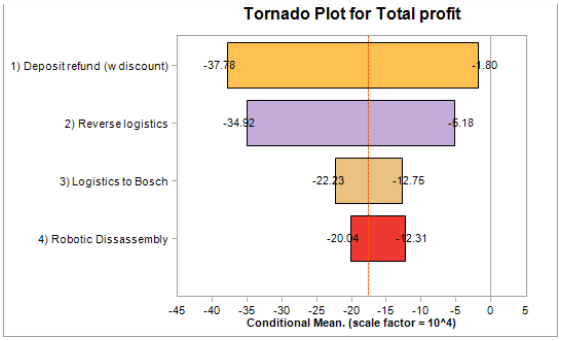


Figure 6: Tornado plot for total profit of Option 1

The tornado plot for Option 2, shown in *Figure 6,* highlights reverse logistics as the largest contributor to variability, similar to Option 1. Other expenses, such as robotic disassembly and logistics to Bosch, also exhibit the same uncertainties as those identified in Option 1.

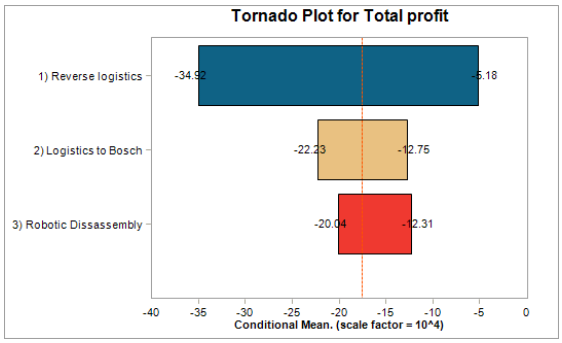


Figure 7: Tornado plot for total profit of Option 2

Figures 7 and *8* present the box plots of all revenues and expenses contributing to the profit calculation, expressed on a per-battery basis. A key difference between Option 1 and Option 2 is the revenue generated. As discussed, Option 1 is expected to yield a higher percentage of "best" cells, as the financial incentive encourages customers to return battery packs before they are fully depleted. However, this benefit comes at a significant cost due to the deposit refund. The simulation aimed to determine whether the improved cell quality in Option 1 would offset this additional expense. As shown in *Figure 4*, the results indicate that it does not, making Option 2 the more cost-effective choice.

To mitigate these costs, market research could be conducted to identify the optimal battery return voucher value. While this study used a €10 voucher, discounted to (€2 – €4), a lower nominal voucher value might achieve similar battery return rates, significantly reducing costs while maintaining benefits. Additionally, profitability could be improved by enhancing the recycling value of components not reused. Given that these parts are sorted and separated without impurities, negotiating higher prices based on their purity could represent another pathway to improve revenue.

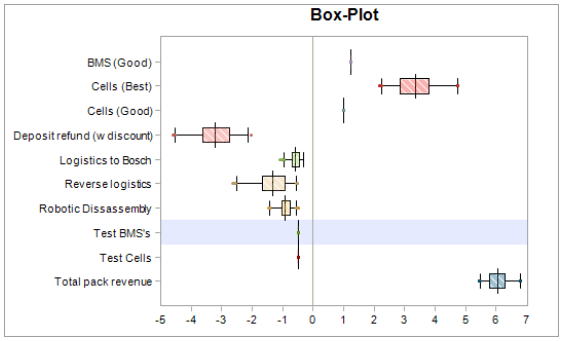


Figure 8: Box plot of factors for Option 1

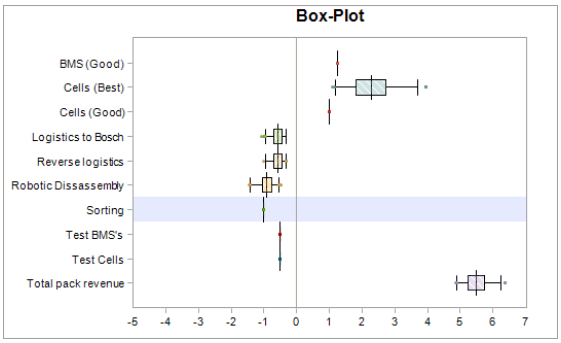


Figure 9: Box plot of factors for Option 2

Conclusions

This study presents an innovative circular economy model for Bosch gen 3 batteries, integrating reverse logistics, robotic disassembly, SoH-based categorization, and incentivized returns. The model demonstrates how combining these elements can potentially maximize the reuse of CRMs, reduce electronic waste, and provide a scalable approach to battery remanufacturing and recycling.

The Monte Carlo simulation revealed key insights into the viability of two collection options. Option 1, which involves incentivized customer returns, is assumed to yield higher-quality "best" cells; however, this benefit comes with significant costs, making it less likely to be profitable under current assumptions. Conversely, Option 2, based on battery waste sorting at recycling facilities, is more cost-effective and more likely to yield a positive profit, albeit with likely lower-quality cells.

The Monte Carlo method effectively simulates uncertainties but has limitations. Its accuracy depends on input distributions, which may not fully reflect real-world variability. The model assumes independence between variables like logistics costs and battery return rates, oversimplifying potential correlations. It also provides a static analysis, excluding long-term market shifts and regulatory changes. Additionally, reliance on estimated data for key variables introduces potential inaccuracies. Recognising these limitations highlights the need for empirical validation, pilot studies, and real-world data to improve model accuracy.

To improve the profitability and scalability of both collection models, further research is needed to refine key uncertainties, such as deposit refund values and logistics costs. Enhancing the recycling value of non-reusable

components (such as the FR40 plastic casings) through better pricing strategies and exploring automated cell identification at recycling centres could further optimise efficiency. A key sustainability trade-off lies between remanufacturing and direct recycling. While remanufacturing retains embedded energy and reduces reliance on mined materials, prolonged cell use may lower recoverable material value and increase waste from failures. Future research should assess whether extending battery life or prioritising early remanufacturing offers greater economic and environmental benefits. Integrating life cycle assessments (LCAs) into profitability models would provide a more comprehensive view, guiding policy and industry adoption.

Overall, the model underscores the potential of circular business practices to address global resource challenges and sets a benchmark for improving end-of-life battery management.

Acknowledgements

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References

Bosch Power Tools. (2024). *About us | Bosch Power Tools*. https://www.bosch-pt.com/ww/en/company/about-us/

Bosch. (2024). *Battery pack PBA 18V 4.0Ah PowerPlus | Bosch DIY Shop*. https://shop.bosch-diy.com/be/nl/18v-power-for-all/391/accupack-pba-18v-4.0ah-powerplus

Bebat. (2023). *Bebat Annual Report 2023*. https://2023.bebat.be/#numbers

Circu Li-ion. (2024). *Circu Li-ion | battery upcycling*. https://www.circuli-ion.com/

Ufinebattery. (2024, June 27). *Comprehensive Guide to Battery SoC and SoH Metrics*. https://www.ufinebattery.com/blog/battery-state-of-charge-and-battery-state-of-health/

Duflou, J. R., Seliger, G., Kara, S., Umeda, Y., Ometto, A., & Willems, B. (2008). Efficiency and feasibility of product disassembly: A case-based study. *CIRP Annals - Manufacturing Technology*, *57*(2), 583–600. https://doi.org/10.1016/J.CIRP.2008.09.009

Protrade. (2023, July). *Electric Corded Tools Versus Cordless Power Tools - Protrade*. https://www.protrade.co.uk/blog/electric-corded-tools-versus-cordless-power-tools/?srsltid=AfmBOoqo6rVJUNFcDuFj2xrReBX7FhuKXti3Zo1EnrQvc48LiM5i4AiN

Eurostat. (2024). *Recycling - secondary material price indicator - Statistics Explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Recycling_%E2%80%93_secondary_material_price_indicator

PCB online Team. (2021, April 9). *Functional Testing of PCB Assembly and PCBA FCT Costs*. https://www.pcbonline.com/blog/functional-testing-of-pcb-assembly.html

Fleischmann, J., & Schaufus, P. (2023, January 23). *Lithium-ion battery demand forecast for 2030 | McKinsey*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular

Scrap monster. (2024). *Lithium-Ion Battery Scrap Price USD/LB in USA and Canada Scrap Yards Today - Electronics Scrap*. https://www.scrapmonster.com/scrap-yard/price/lithium-ion-battery-scrap/122

Vose software. (n.d.). *ModelRisk | Risk Analysis Add-In for Excel*. Retrieved December 6, 2024, from https://www.vosesoftware.com/Risk-In-Excel/

Mudgal, S., Guern, Y. Le, Tinetti, B., Chanoine, A., Pahal, S., & Witte, F. (2011). *Comparative Life-Cycle Assessment of nickel-cadmium (NiCd) batteries used in Cordless Power Tools (CPTs) vs. their alternatives nickel-metal hydride (NiMH) and lithium-ion (Li-ion) batteries*. https://circabc.europa.eu/ui/group/636f928d-2669-41d3-83db-093e90ca93a2/library/8d7a2e3f-4ec7-4c47-915c-4389f3fa52e8/details?download=true

Directorate-General for Environment. (2023, July 17). *New law on more sustainable, circular and safe batteries enters into force - European Commission*. https://environment.ec.europa.eu/news/new-law-more-sustainable-circular-and-safe-batteries-enters-force-2023-08-17_en

Rockawayrecycling. (2024). *Nickel Scrap Prices*. https://rockawayrecycling.com/metal/nickel/

Power for all alliance. (2024). https://www.powerforall-alliance.com/en/

Bebat. (2024). *Recycling process | Bebat*. https://www.bebat.be/nl/recyclageproces

Metaloop. (2024). *Scrap Metal Price Index - Belgium - Metaloop*. https://www.metaloop.com/scrap-metal-price/belgium/

Repairprice.co.uk. (2024). *Scrap Printed Circuit Boards Recycling Prices | RepairPrice.co.uk*. https://www.repairprice.co.uk/scrap-printed-circuited-boards-recycling-prices

Eurostat. (2024). *Sales and collection of portable batteries and accumulators*. https://ec.europa.eu/eurostat/databrowser/view/env_waspb/default/table?lang=en

Magalini, F., Wang, F., Huisman, J., Kuehr, R., Balde, K., van Straalen, V., Hestin, M., Lecerf, L., Sayman, U., & Akpulat, O. (2014). *Study on collection rates of WEEE*. https://ec.europa.eu/environment/pdf/waste/weee/Final_Report_Art7_publication.pdf

Eurostat. (2025). *Waste statistics - recycling of batteries and accumulators - Statistics Explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_recycling_of_batteries_and_accumulators#Data_sources

Zatta, N., De Cesaro, B., Dal Cin, E., Carraro, G., Cristofoli, G., Trovò, A., Lazzaretto, A., & Guarnieri, M. (2024). Holistic Testing and Characterization of Commercial 18650 Lithium-Ion Cells. *Batteries 2024, Vol. 10, Page 248*, *10*(7), 248. https://doi.org/10.3390/BATTERIES10070248

Zeng, X., Li, J., & Singh, N. (2014). Recycling of Spent Lithium-Ion Battery: A Critical Review. *Critical Reviews in Environmental Science and Technology*, *44*(10), 1129–1165. https://doi.org/10.1080/10643389.2013.763578

Research paper
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Exploring take-back recovery strategies in the Circular Economy: A Multiple Case Study Analysis

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Keywords: Take back, Recovery, Return, Responsible disposal, Circular Economy, Design for X.

Abstract: The take-back of end-of-use products has gained increasing importance with the growing focus on the circular economy. However, not all take-back strategies have been thoroughly explored and understood in relation to consumer engagement. This study examines the role of take-back recovery approaches and strategies in the circular economy, integrating a product design and service lens to address consumer return practices. The research identifies four distinct opportunities under the take-back umbrella: Direct Reuse, Ease of Disassembly, Final Recovery, and Safe Disposal. For each opportunity, potential sub-opportunities are identified and expanded upon. Through a multiple case study analysis, these sub-opportunities are further developed using a "Design for X" approach to form nine distinct take-back strategies. This research emphasizes that the appropriateness of a take-back strategy depends on various factors, such as consumer behavior and context, industry specifics, and material flows. The study highlights the critical role of take-back systems and returns behavior in promoting circular product development and consumption.

Introduction

The shift from a predominantly linear economy to a Circular Economy (CE) is increasingly critical due to the environmental challenges associated with resource depletion and waste generation resulting from shorter product life cycles (Bhatia et al., 2020; Gupt & Sahay, 2015). Despite global efforts, only 30% of collected waste materials are recovered and recycled (Singh & Ordoñez, 2016), underscoring the need for more robust closed-loop systems, including effective take-back strategies. Take-back systems, which involve transferring end-of-use products from consumers back to recovery sites for reuse, recycling, or safe disposal (Chouinard et al., 2011; Ghoreishi et al., 2011), are central to the success of the CE.

Companies often face significant challenges in designing and implementing these systems (Abdessalem et al., 2012; Singh & Ordoñez, 2016). These challenges stem from a shortage of skilled professionals experienced in take-back practices (Waqas et al., 2018) and limited consumer awareness and participation (Jena & Sarmah, 2015). Historically, resource collection and reuse were common, supported by local charity shops or small businesses; however, industrialization has largely displaced these sustainable practices, leading to a reliance on virgin material extraction (Cooper, 1994). Furthermore, take-back behaviors are sometimes associated with socioeconomic status, impacting broader adoption (Iyer & Kashyap, 2007). In recent years, the growing environmental challenges have renewed interest in take-back systems as essential components of the CE (Bockholt et al., 2020; Ghoreishi et al., 2011; Paut Kusturica et al., 2020; Vegter et al., 2020). These systems are now recognized as viable solutions to modern consumption patterns, encouraging resource recovery and responsible disposal.

This research seeks to expand the understanding of take-back systems from a design perspective, focusing on strategies that maximize value recovery while minimizing harm to humans and the environment. Adapting the Reuse framework by Franconi et al. (2023), we employed a "Design for X" approach to analyze four critical take-back strategies—Direct Reuse, Ease of Disassembly, Final Recovery, and Safe Disposal —to identify the core components and factors that contribute to successful initiatives. Additionally, this research explores the role of consumer return behavior and awareness in shaping the take-back system. By examining multiple case studies, we provide insights into future developments and

best practices for designers and stakeholders interested in implementing effective take-back strategies.

Approach and methodology

This study employs a qualitative exploratory approach with multiple-case study approach to examine take-back strategies and their implications within a CE framework. The research aims to identify and classify different recovery strategies by integrating a Design for X (DfX) approach. The methodology follows four key stages: (1) data collection through literature review (2) development of criteria for analysis, (3) case study investigation (4) synthesis of findings into distinct take-back strategies.

Phase 1: Exploring and Classifying Take-Back Strategies

We began by establishing a comprehensive understanding of take-back systems and recovery strategies through literature analysis. This exploration focused on product value, design objectives, consumer behavior, and reprocessing methods for returned products. Our review identified that existing literature predominantly addresses take-back through terms like "reverse logistics," "closed-loop supply chain," and "reverse supply chain."

Based on these initial findings, we developed a focused search string: ("take-back" OR "reverse logistics" OR "reverse supply chain" OR "clos* loop supply chain") AND (step* OR stage* OR method* OR process* OR activity OR aim* OR type* OR intention* OR market value* OR consumer behavior*) AND (waste OR "end of life" OR "end of use"). We targeted English-language journal articles published between 2009 and September 2024, excluding content focused on reuse with ownership, perception of refurbished products, or collection center statistics.

Phase 2: Development of Analysis Framework

From our literature analysis, we identified recurring themes and characteristics of take-back systems. This allowed us to develop a structured analytical framework consisting of six key criteria (presented in Table 1) that capture the essential dimensions of take-back strategies: quality considerations, market value implications, type and origin of value, strategic aims, reprocessing methods, and consumer engagement patterns.

Criteria	Description
Quality	The condition and performance of products made from returned materials or components and compares them to products made from virgin materials.
Change in market value	Whether the value of the product increases, decreases, or remains the same compared to its previous life cycle.
Type (product, component, material), origin of value	The type of item being returned and its associated value created.
Aim of the take-back design strategy	The specific objectives driving the design strategy.
Reprocessing methods	The techniques used to enable the recovery of the item, and the entities responsible for carrying out these processes.
Consumer behavior and engagement	The behaviors required to support take-back processes.

Table 1. Key criteria for analyzing take-back strategies. These criteria were derived from recurring themes in the literature and provide a structured framework for evaluating different approaches. An enlarged version of the image is provided in Appendix 1.

Phase 3: Case Study Investigation

To complement the literature review, a multiple case study approach was adopted following Yin's (2009) case study methodology. We identified and examined diverse cases of take-back systems across various industries and product categories using resources like Google Scholar and ScienceDirect. Each case was systematically analyzed using our established criteria. A pattern-matching technique was applied, comparing observed take-back strategies. Once case studies were identified, each was analyzed using the pre-defined criteria (Table 1). The analysis involved Comparing case studies against the key characteristics of take-back strategies (Table 2), identifying similarities and deviations. Assessing the effectiveness of each strategy in terms of product recovery, material flow, and consumer engagement.

Phase 4: Application of Design for X

We then employed the Design for X (DfX) approach to translate our findings into practical design strategies. DfX is a systematic methodology that optimizes both design and process by accounting for various factors (Arnette et al., 2014) ensuring specific characteristics and quality criteria are integrated into final designs (Kuo et al., 2001).

This allowed us to articulate distinct take-back strategies with clear design implications. For each case study, we analyzed how products and systems were designed to facilitate specific recovery pathways, identifying common patterns and unique approaches that could be generalized into design strategies.

Characteristics	Quality	Product market value	Aim	Reprocessing	Consumer behaviour and engagement
Reuse	As is	High	Reuse/ Recycling	Cleaning	Return to retailer or processing facilities
Repair	Almost new	Mid-low	Reuse	Disassembly / Replace or Fix	Return to retailer or manufacture
Re-furbishment	Almost new	High-mid	Reuse/ Restoration	Cleaning / Disassembly repaired / Replace / Restored	Return with or without incentive
Re-manufacture	Like new	High-mid	Renovation	Disassembly / Clean / Inspection / Rebuilt	Return to recycle bin collection
Cannibalization	Almost new	High-mid	Reuse	Disassembly / Salvaging intact component	Return to manufacturer
Recycle	Usually lower than original	Low	Maximum material reuse/ Reproduce	Sort/ Clean/ Reprocessing	Recycle bin
Energy	Transformed	Low	Recover as an energy source	Sort/ Process	Return to manufacturer / Recycle
Safe disposal	N/A	N/A	Safely dispose hazardous material	N/A	Return

Table 2. Main recovery strategies comparison for take-back. Note that the table is based on a broad context and may vary according to the specific case and context. An enlarged version of the image is provided in Appendix 1.

Results

Classification of Take-Back Recovery Strategies

Our analysis of sixty-eight studies revealed that existing literature typically approaches take-back from one of two perspectives: a manufacturer-focused perspective and a consumer-focused perspective. The manufacturer-focused perspective follows the definition of take-back by Esenduran et al. (2016) as "an initiative organized by a manufacturer or retailer to collect used products or materials from consumers and reintroduce them into the original processing and manufacturing cycle." In contrast, the consumer-focused perspective emphasizes return behaviors, defining take-back as "all the activities involved in transferring the used product from the customers' possession to the recovery site" (Ghoreishi et al., 2011). This approach focuses on understanding behavioral patterns and consumer engagement (Elzinga et al., 2020). Additionally, Blomsma et al. (2019) present a circular strategies scanner, outlining 32 CE strategies that involve consumer behavior. However, a lack of clarity regarding recovery strategies in relation to both consumers and manufacturers may hinder progress toward a Circular Economy, as both play essential roles in the take-back system.

Categories of take-back based on value changes	**Resources Recovery**	**Product types**	**Reference (papers)**
Direct Reuse (Value remains)	Reuse as it is (product)	Packaging	Muranko et al. 2021; Ellen Macarthur Foundation. 2023; Nakajima and Vanderberg et al. 2006
		Fashion and textile	Tripa and Indrie et al. 2021
Ease of Disassembly (Value retain or increase)	Repair (product)	Fashion and textile	Zhang and Hale et al. 2022
		Consumer electronic	Svensson-Hoglund et al. 2021
	Refurbishment (product)	Furniture	Öhgren et al. 2019
		Fashion and textile	Dang et al. 2023
		Consumer electronic	Fleischmann et al. 2003; Curvelo Santana et al. 2021
	Remanufacture (product)	Transportation	Zhang et al. 2017
		Consumer electronic	Webster and Mitra et al. 2007
	Cannibalization (components or material)	Consumer electronic	Ripanti et al. 2016
Final recovery (Value transform)	Material recycling (components or material)	Fashion and textile	Sandvik and Stubbs et al. 2019
		Consumer electronic	Gu et al. 2021; Sun et al. 2022
		Packaging	Sazdovski et al. 2021
	Energy recovery	Food waste	Kadel et al. 2014
		electronic	Chandrasekaran et al. 2018
		Medicine	De Filippis et al. 2012
Responsible disposal (Value lost)	Safe disposal	Medicine/ pharmacy	Yanovitzky et al. 2016; Lystlund et al. 2014
		Paint packaging	Dursun and Sengul et al. 2006
		Batteries	Wagner et al. 2013

Table 3. Comparison of specific sub-strategies. An enlarged version of the image is provided in Appendix 1.

Thierry et al. (1995) focused on the practical dimensions of take-back, recognizing that consumer awareness and return behaviors are increasingly shaped by Product Recovery Management (PRM) as customers and regulatory bodies press manufacturers to manage product waste. They introduced the concept of "cannibalization" as a way to recover material value during reprocessing. Their work enabled us to categorize take-back into four distinct types based on value retention: Direct reuse (product value retention), ease of disassembly (product or material value retention), final recovery (component or material value decrease), and responsible disposal (no value). Our research expands this framework by categorizing take-back approaches according to distinct value and return pathways. Each pathway comprises specific sub-strategies tailored to different product types and recovery objectives, as summarized in Table 3. This categorization

acknowledges the diversity in recovery routes and the varied conditions under which products are returned, providing a more comprehensive framework than previously available in the literature.

Design strategies articulation under take-back

We employed the DfX approach to articulate a range of strategies encompassed within the take-back model. DfX is a systematic design methodology that seeks to optimize both design and process by accounting for various factors (Arnette et al., 2014), ensuring that specific characteristics, functions, or quality criteria are integrated into the final design (Kuo et al., 2001). To achieve this, we created a generic description of the case studies, organized according to different categorization criteria. Then, we employed DfX to generalize and articulate distinct take-back strategies derived from our case studies and definitions. This process involved analyzing each strategy to determine how it could be optimized for different X factors, considering recovery processes and consumer behavior. Additionally, we applied seven specific criteria, as outlined in our methodology, to comprehensively describe each take-back strategy.

Design for Direct Reuse (DfDR)

This strategy focuses on designing products that can be reused and resold “as is” once they are returned. There are two strategies that can be used within DfDR that are:

Design for Return Store (DfRS)

DfRS focuses on enabling efficient product recovery by providing consumers with a convenient method to return used products directly to retail locations for cleaning, reuse, or refilling. This approach facilitates resource recovery by allowing valuable products to be reclaimed and re-entered into the lifecycle. To make the in-store or e-commerce return process seamless, designers should consider clear instructions and providing prepaid labels, ensuring a straightforward and secure experience for consumers and enhancing accessibility and participation. Figures 2 and 3 illustrate a few applications of this strategy.



Figure 2. In-store return system at Loop. © Loop.

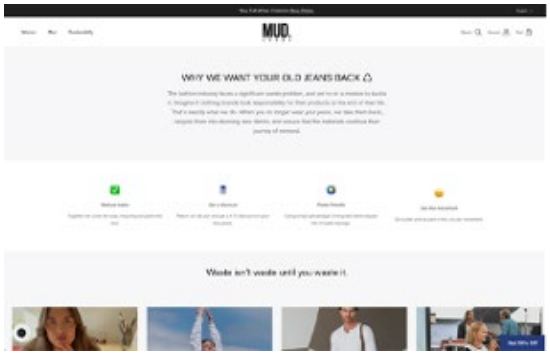


Figure 3. Mail return system at MUD Jeans. © MUD Jeans.

Design for Door-to-door Collection (DfDC)

DfDC aims to enable multiple uses of products through a collection and pick-up system, where products and/or packaging are returned and delivered after being refilled by the company. This strategy focuses on the use of durable materials, such as glass, metal, or heavy-duty plastics, along with refillable designs that support repeated use. The design must support efficient collection logistics, incorporating sustainable transportation practices. Direct collection from consumers allows products to be gathered in bulk and transported directly to processing facilities, minimizing handling and maximizing efficiency in recovery processes. To encourage regular engagement, companies often provide incentives such as discounts or rewards for consumers who consistently return items, fostering long-term participation. Examples are mainly packaging, as shown in Fig. 4.



Figure 4. Product collection and return system at Milk & More. ©Milk & More

Design for Ease of Disassembly (DfED)

DfED is the practice of designing products that are able to retain or increase the value of the end-state of the product and/or material after the collection. DfED strategies include:

Design for Repair (DfR)

DfE aims to design products that can be efficiently broken down into individual components for repair, fixing specific faults or malfunctions, and restoring basic functionality. This approach often involves part replacement and the recycling of components that cannot be fixed. DfR employs non-permanent connections, such as screws or snap fits, instead of adhesives or welds, allowing parts to be separated without damage. Modular designs, which facilitate easy disassembly, are frequently adopted to streamline repairs. Additionally, many companies provide postal or drop-off services for collecting broken products, promoting consumer loyalty through accessible repair options. Examples include brands that accept damaged items or clothing for repair (Figure 5).



Figure 5. Fairphone repair take-back system. ©Fairphone.

Design for Refurbishment (DfRf)

DfRf focuses on restoring a product to a "like-new" or improved condition, making it suitable for resale. Refurbishment typically involves thorough cleaning, inspection, and replacement of worn-out parts. Products designed are often modular, with replaceable parts and durable materials that can endure multiple refurbishment cycles, extending product life. Non-replaceable components may also be recycled as part of this approach. Consumers are encouraged to return items to retail locations, drop-off hubs, or use mail-in services. Patagonia's wear program (Figure 6) and IKEA Local Recovery Hub (Figure 7) accept worn-out products for refurbishment in exchange for store credit or reward. In some cases, refurbishment involves creative methods to give new life to old products.

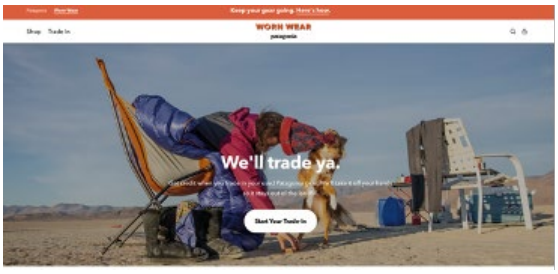


Figure 6. Patagonia's Wear Program aims to refurbish old products. ©Patagonia



Figure 7. IKEA Local Recovery Hub refurbishing old products ©IKEA

Design for Remanufacturing (DfRm)

DfRm is focused on enabling products to be efficiently disassembled, inspected, restored, and reassembled to a like-new condition. This approach emphasizes the use of durable materials and modular parts designed to endure multiple remanufacturing cycles. For instance, engine blocks are often designed for straightforward disassembly and reassembly, with standardized parts across models to allow component interchangeability, thereby simplifying the process and reducing time and labor costs (Figure 8). Non-reusable components may be recycled. Many companies

offer incentives for consumers to return used products or parts, which are then remanufactured to meet original performance standards.

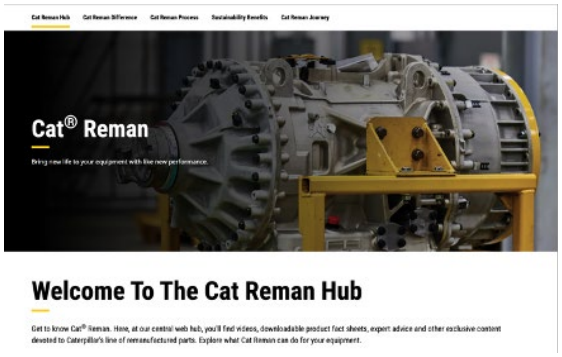


Figure 8. Caterpillar's Cat Reman program where it collects the products for remanufacturers. ©Caterpillar

Design for Cannibalization (DfC)

DfC aims to maximize the recovery and reuse of valuable components from products that are no longer functional or suitable for complete refurbishment or remanufacturing. This approach enables companies to salvage parts from returned, end-of-life products for use in repair, refurbishment, or new production, thereby minimizing waste and reducing the need for new resources. DfC focuses on designing products with modular, easily removable parts -such as processors - that can be salvaged even if the overall product is no longer operational. Many components are designed to be compatible across different models, enabling parts from one model to be used in the assembly of another, thus extending the lifecycle of these components without reprocessing them into raw materials. Companies provide drop-off locations or partner with charity stores, offering incentives to encourage consumers to return used products. Examples include ink and toner recycling programs that recover parts for reuse (Figure 9).

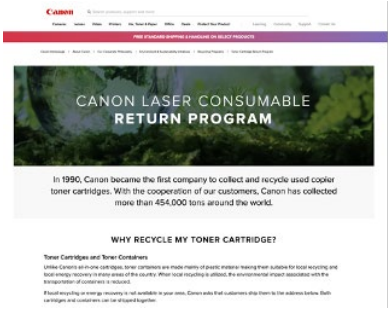


Figure 9. Canon toner recycle program. ©Canon

Design for a Final Recovery (DfFR)

DfFR is the practice of designing products that are able to transform value into new products after collection. DfFR strategies include:

Design for Material Recycling (DfMR)

DfMR focuses on enabling the efficient breakdown of products into raw materials that can be reused to create new products. This approach includes two sub-strategies: Design for “same purpose” and “design for different Purpose”. The "same purpose" strategy emphasizes recycling materials like metals and glass, aiming to reuse them in the production of the same or similar products. The "different purpose" strategy involves recycling materials that undergo a change in value during processing and repurposing them for different applications or products. To support these strategies, clear material labeling and the use of standardized, recyclable material facilitate sorting and processing at recycling facilities. Consumers are encouraged to deposit products in designated collection boxes or mail them back to the company. Some companies provide a QR code along with a prepaid envelope for easy returns, incentivizing customers to participate in the recycling process (Figure 10).



Figure 10. Everywhereapparel.com takes back clothing for recycling. ©Everywhere Apparel

Design for Energy Recovery (DfSR)

DfER aims to safely collect and process waste materials to recover energy, typically through specialized waste-to-energy facilities that prevent toxic emissions. In these facilities, the heat generated from incineration is converted into electricity or thermal energy for industrial applications. This approach also provides a safe disposal option for products, such as pharmaceuticals or food waste, which might otherwise pose an environmental impact (Figures 11 and 12), while simultaneously recovering energy from the waste. Designers should prioritize materials with high calorific values that provide substantial energy during

incineration while avoiding toxic materials that could release harmful emissions. Additionally, products should be designed for easy disassembly, allowing parts to be separated from those intended for incineration. Clear material labeling or QR codes further assist waste processors in identifying and managing each component.



Figure 11. Medication collection kiosk at CVS.



Figure 12. Food waste collection kiosk. © Wikimedia

Design for a Safe Disposal (DfSD)

DfSD focuses on ensuring that hazardous products are safely collected and disposed of, reducing risks to human health, soil, and water systems. This approach provides consumers with a secure and environmentally responsible method for disposing of potentially dangerous items, such as batteries, medications, and paint. Key design elements include tamper-resistant, spill-proof packaging that prevents hazardous materials from leaking or causing harm during collection, transportation, and disposal. Specialized facilities with strict emission controls are required to safely incinerate these products. Clear labeling and disposal instructions guide consumers on where and how to return items, whether through drop-off locations or mail-in services. To encourage responsible disposal, many take-back programs provide incentives, such as discounts on new purchases when customers return used products (e.g., batteries, Figure 13).

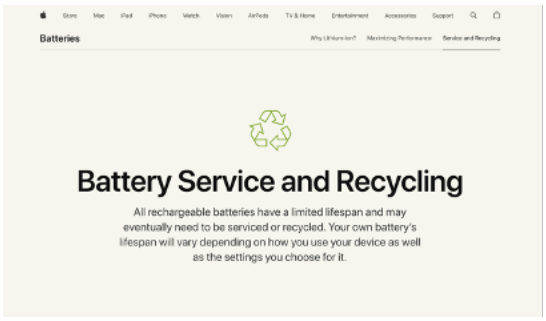


Figure 13. Apple's collection program for lithium-ion batteries. ©Apple Inc

Discussion and future work

This paper explores the essential role of take-back systems in advancing the CE by facilitating the recovery, reuse, and responsible disposal of products. This research contributes to the growing body of knowledge on take-back systems by establishing how a DfX approach can guide the development of take-back strategies that align with CE goals. The successful application of take-back strategies depends on various factors, including contextual conditions, consumer behavior, industry-specific challenges, geographical location, and material flow dynamics. By categorizing take-back strategies into Direct Reuse, Ease of Disassembly, Final Recovery, and Safe Disposal, with nine specific sub-strategies, we identified multiple pathways through which products can be reintegrated into the economy, each with distinct design requirements and operational challenges.

The Direct Reuse strategy focuses on designing products with durable materials to extend their lifespan and promote sustainable consumption behaviors. Ease of Disassembly (DfED) highlights the importance of designing products with modularity and non-permanent connections, enabling repair, refurbishment, remanufacturing, and cannibalization by maximizing the reuse of existing components. Implementing DfED requires close collaboration with manufacturing and logistics partners to ensure that disassembly and

reassembly processes are efficient and scalable. The Final Recovery and Safe Disposal strategy centers around designing products to be responsibly processed and minimizing environmental and health risks associated with their end-of-life disposal. Although these strategies serve as last-resort options for non-recyclable or hazardous products, they underscore the need for infrastructure investment and strict regulatory compliance to prevent potential contamination (Svensson-Hoglund et al., 2021). Additionally, the consumer plays a key role in facilitating take back for returning products at the end of their useful life (Sabbaghi et al., 2016). Successful implementation requires efficient logistics and strong consumer engagement practices.

Future research should focus on understanding consumer motivations and barriers to returning products in take-back programs. While incentives, such as discounts or rewards, have been shown to increase participation, further research is needed to understand the psychological and social factors that drive or hinder consumer engagement including how cultural norms, convenience perceptions, and environmental values interact to shape return behaviors. Additionally, exploring how technological advancements, such as digital tracking and product passports, could enhance the efficiency and effectiveness of take-back systems would be beneficial. Furthermore, emerging technologies like blockchain and AI have significant potential to optimize reverse logistics by improving traceability throughout product lifecycles, enabling predictive maintenance to extend product lifespan and creating personalized incentive systems that enhance consumer participation in take-back programs. Future research should also investigate how take-back strategies can be adapted to diverse industries or geographic regions with different infrastructural. The transferability of successful take-back models across varying contexts requires careful consideration of local waste management capabilities, cultural attitudes toward reuse and recycling, and region-specific policy frameworks that may either facilitate or hinder the implementation of circular initiatives

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References

Abdessalem, M., Alouane, A. B. H., & Riopel, D. (2012). Decision modelling of reverse logistics systems: Selection of recovery operations for end-of-life products. *International Journal of Logistics Systems and Management*, *13*(2), 139. https://doi.org/10.1504/IJLSM.2012.048933

Arnette, A. N., Brewer, B. L., & Choal, T. (2014). Design for sustainability (DFS): The intersection of supply chain and environment. *Journal of Cleaner Production*, *83*, 374–390. https://doi.org/10.1016/j.jclepro.2014.07.021

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D. C. A., Hildenbrand, J., Kristinsdottir, A. R., Kristoffersen, E., Shahbazi, S., Nielsen, K. D., Jönbrink, A.-K., Li, J., Wiik, C., & McAloone, T. C. (2019). Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation. *Journal of Cleaner Production*, *241*, 118271. https://doi.org/10.1016/j.jclepro.2019.118271

Bockholt, M. T., Hemdrup Kristensen, J., Colli, M., Meulengracht Jensen, P., & Vejrum Wæhrens, B. (2020). Exploring factors affecting the financial performance of end-of-life take-back program in a discrete manufacturing context. *Journal of Cleaner Production*, *258*, 120916. https://doi.org/10.1016/j.jclepro.2020.120916

Chouinard, Y., Ellison, J., & Ridgeway, R. (2011). The sustainable economy. *Harvard Business Review*, *89*(10), 52–62.

Cooper, M. L. (1994). Motivations for alcohol use among adolescents: Development and validation of a four-factor model. *Psychological Assessment*, *6*(2), 117. https://doi.org/10.1037/1040-3590.6.2.117.

Elzinga, R., Reike, D., Negro, S. O., & Boon, W. P. C. (2020). Consumer acceptance of circular business models. *Journal of Cleaner Production*, *254*, 119988. https://doi.org/10.1016/j.jclepro.2020.119988

Esenduran, G., Kemahlıoğlu-Ziya, E., & Swaminathan, J. M. (2016). Take-Back Legislation: Consequences for Remanufacturing and Environment.

Decision Sciences, *47*(2), 219–256. https://doi.org/10.1111/deci.12174

Franconi, A., Ceschin, F., Terzioglu, N., Corsini, L., & Ghoreishi, M. (2023). Defining alternative recovery strategies for reuse: An analysis of multiple case studies under the reuse umbrella. *Proceedings 5th PLATE Conference (PLATE 2023)*, 324–331. http://bura.brunel.ac.uk/handle/2438/27057

Ghoreishi, N., Jakiela, M. J., & Nekouzadeh, A. (2011). A cost model for optimizing the take back phase of used product recovery. *Journal of Remanufacturing*, *1*(1), 1. https://doi.org/10.1186/2210-4690-1-1

Iyer, E. S., & Kashyap, R. K. (2007). Consumer recycling: Role of incentives, information, and social class. *Journal of Consumer Behaviour*, *6*(1), 32–47. https://doi.org/10.1002/cb.206

Jena, S. K., & Sarmah, S. P. (2015). Measurement of consumers' return intention index towards returning the used products. *Journal of Cleaner Production*, *108*, 818–829. https://doi.org/10.1016/j.jclepro.2015.05.115

Kuo, T.-C., Huang, S. H., & Zhang, H.-C. (2001). Design for manufacture and design for 'X': Concepts, applications, and perspectives. *Computers & Industrial Engineering*, *41*(3), 241–260. https://doi.org/10.1016/S0360-8352(01)00045-6

Paut Kusturica, M., Golocorbin-Kon, S., Ostojic, T., Kresoja, M., Milovic, M., Horvat, O., Dugandzija, T., Davidovac, N., Vasic, A., & Tomas, A. (2020). Consumer willingness to pay for a pharmaceutical disposal program in Serbia: A double hurdle modeling approach. *Waste Management*, *104*, 246–253. https://doi.org/10.1016/j.wasman.2020.01.029

Sabbaghi, M., Behdad, S., & Zhuang, J. (2016). Managing consumer behavior toward on-time return of the waste electrical and electronic equipment: A game theoretic approach. *International Journal of Production Economics*, *182*, 545–563. https://doi.org/10.1016/j.ijpe.2016.10.009

Singh, J., & Ordoñez, I. (2016). Resource recovery from post-consumer waste: Important lessons for the upcoming circular economy. *Journal of Cleaner Production*, *134*, 342–353. https://doi.org/10.1016/j.jclepro.2015.12.020

Svensson-Hoglund, S., Richter, J. L., Maitre-Ekern, E., Russell, J. D., Pihlajarinne, T., & Dalhammar, C. (2021). Barriers, enablers and market governance: A review of the policy landscape for repair of consumer electronics in the EU and the U.S. *Journal of Cleaner Production*, *288*, 125488. https://doi.org/10.1016/j.jclepro.2020.125488

Thierry, M., Salomon, M., Van Nunen, J., & Van Wassenhove, L. (1995). Strategic Issues in Product Recovery Management. *California Management Review*, *37*(2), 114–136. https://doi.org/10.2307/41165792

Vegter, D., Van Hillegersberg, J., & Olthaar, M. (2020). Supply chains in circular business models: Processes and performance objectives. *Resources, Conservation and Recycling*, *162*, 105046. https://doi.org/10.1016/j.resconrec.2020.105046

Waqas, M., Dong, Q., Ahmad, N., Zhu, Y., & Nadeem, M. (2018). Critical Barriers to Implementation of Reverse Logistics in the Manufacturing Industry: A Case Study of a Developing Country. *Sustainability*, *10*(11), 4202. https://doi.org/10.3390/su10114202

Yin, R. K. (2009). *Case study research: Design and methods.* (Vol. 5). sage.

Appendix 1

Table 1. Different characteristics present in take-back strategy.

Criteria	Description
Quality	The condition and performance of products made from returned materials or components and compares them to products made from virgin materials.
Change in market value	Whether the value of the product increases, decreases, or remains the same compared to its previous life cycle.
Type (product, component, material), origin of value	The type of item being returned and its associated value created.
Aim of the take-back design strategy	The specific objectives driving the design strategy.
Reprocessing methods	The techniques used to enable the recovery of the item, and the entities responsible for carrying out these processes.
Consumer behavior and engagement	The behaviors required to support take-back processes.

Table 2. Main recovery strategies comparison for take-back. Note that the table is based on a broad context, and characteristics may vary according to the specific case and context.

	Characteristics				
Main Recovery Strategies	**Quality**	**Product market value**	**Aim**	**Reprocessing**	**Consumer behaviour and engagement**
Reuse	As is	High	Reuse/ Recycling	Cleaning	Return to retailer or processing facilities
Repair	Almost new	Mid-low	Reuse	Disassembly/ Replace or Fix	Return to retailer or manufacture
Re-furbishment	Almost new	High-mid	Reuse/ Restoration	Cleaning/ Disassembly repaired/ Replace/ Restored	Return with or without incentive
Re-manufacture	Like new	High-mid	Renovation	Disassembly/ Clean/ inspection/ rebuilt	Return to recycle bin collection
Cannibalization	Almost new	High-mid	Reuse	Disassembly/ salvaging intact component	Return to manufacturer
Recycle	Usually lower than the original	Low	Maximum material reuse/ Reproduce	Sort/ Clean/ reprocessing	Recycle bin
Energy	Transformed	Low	Recover as an energy source	Sort/ Process	Return to manufacturer / Recycle
Safe disposal	N/A	N/A	Safely dispose of hazardous material	N/A	Return

Table 3. Clustering terms based on literature analysis.

Categories of take-back based on value changes	**Resources Recovery**	**Product types**	**Reference (papers)**
Direct Reuse (Value remains)	Reuse as it is (product)	Packaging	Muranko et al. 2021 Ellen Macarthur Foundation. 2023 Nakajima and Vanderberg et al. 2006
		Fashion and textile	Tripa and Indrie et al. 2021
Ease of Disassembly (Value retain or increase)	Repair (product)	Fashion and textile	Zhang and Hale et al. 2022
		Consumer electronic	Svensson-Hoglund et al. 2021
	Refurbishment (product)	Furniture	Öhgren et al. 2019
		Fashion and textile	Dang et al. 2023
		Consumer electronic	Fleischmann et al. 2003 Curvelo Santana et al. 2021
	Remanufacture (product)	Transportation	Zhang et al. 2017
		Consumer electronic	Webster and Mitra et al. 2007
	Cannibalization (components or material)	Consumer electronic	Ripanti et al. 2016
Final recovery (Value transform)	Material recycling (components or material)	Fashion and textile	Sandvik and Stubbs et al. 2019
		Consumer electronic	Gu et al. 2021 Sun et al. 2022
		Packaging	Sazdovski et al. 2021
Responsible disposal (Value lost)	Energy recovery	Food waste	Kadel et al. 2014
		electronic	Chandrasekaran et al. 2018
		Medicine	De Filippis et al. 2012
	Safe disposal	Medicine/ pharmacy	Yanovitzky et al. 2016 Lystlund et al. 2014
		Paint packaging	Dursun and Sengul et al. 2006
		Batteries	Wagner et al. 2013

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Collaboration towards the design of sustainable and circular value chains: reviewing the state-of-the-art in literature and practice

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Keywords: Sustainability, circular economy, collaboration, circular value chains, circular ecosystems

Abstract: The transition to a circular economy (CE) is essential for extending product lifespans and maximizing resource use, contributing to resource efficiency and sustainability. Circular solutions demand extensive collaboration across the value chain, encompassing suppliers, distributors, and consumers. Based on a review of literature and existing frameworks for the design of circular value propositions, this study investigates key factors enabling collaboration within circular value chains and evaluates the extent to which existing frameworks address value chain collaboration. Nine key factors for collaborative circular value chains were identified: sustainability leadership, value mapping, shared vision building, trust-building, collaborative governance, collaborative processes, ecosystem perspectives and orchestration, and monitoring and evaluation. The analysis of 38 frameworks showed strong focus on value chain collaboration, but the ecosystem perspective and links to digitalisation and data sharing were underrepresented. The research highlights the role of collaborative governance and ecosystem orchestration in addressing challenges such as stakeholder engagement, data management, and balancing competitive and collaborative interests. Future research should focus on developing tools and frameworks that emphasize the intersection of sustainability, circularity, value chain collaboration, and digitalisation and data management. Comprehensive approaches are needed to help manufacturers develop capabilities for sustainable circular ecosystems, aligning roles and incentives between partners, facilitating collaboration and co-creation, and enhancing data sharing and management. The findings contribute to a deeper understanding of the factors necessary for sustainable collaborative circular value chains, providing a foundation for further research and practical guidance for industry.

Introduction

The transition towards a circular economy (CE) is vital for prolonging product lifetimes and ensuring that materials are kept at their highest utility and value for as long as possible. In turn, this can contribute to more efficient use of resources and potentially a more sustainable society. With increasing pressure from policies and consumers, product manufacturers in the EU are increasingly exploring how to (re)design their products and business models in line with a CE. One of the main challenges of extending product lifetimes and closing resource loops is the collaboration required throughout the value chain (Geissdoerfer et al., 2018). Wider value chain collaboration is needed to facilitate the extended use and circulation of resources, but also to enable the sharing of product-related information between actors. Product manufacturers cannot meet circularity requirements and identify the most effective measures for product lifetime extension, if they lack access to reliable and accurate information about the composition of their components and materials. In the automotive sector for example, gathering reliable information can be challenging due to the sheer number of parts, number of suppliers extending across multiple tiers, and lack of transparency. Supplier information is crucial to meet the EU's upcoming requirements regarding the design and end-of-life management of vehicles (e.g., including dismantling instructions, circularity passports, and 25% of recycled plastics in new vehicles) (European Commission, 2023). Recent research has highlighted the necessity of innovating towards *circular ecosystems,* with the purpose of changing how a set of actors interact to achieve circularity as a collective outcome (Konietzko et al., 2020). Digital product passports (DPP) are proving instrumental in these efforts, and recent advancements in collaborative data ecosystems and product traceability platforms (e.g., *Catena X*, n.d.; *Circularise*, n.d.)

demonstrate the potential of novel digital technologies to enable decentralised information exchange, overcome issues related to data sharing and trust, and enhance traceability. Yet another question that remains is how to – during the product development process – create and foster conditions for collaborative circular value chains, and what are factors that should be considered? While the importance of collaboration for a CE is apparent, there is still a lack of knowledge regarding the conditions and capabilities, despite efforts made (see e.g., Brown et al., 2021; Köhler et al., 2022), which foster successful value chain collaboration. Moreover, there is a need to understand whether available prescriptive frameworks for the design of circular value propositions aid companies in facilitating collaboration and overcome challenges towards sustainable and circular value chains. Therefore, this paper aims to (1) identify enabling factors for collaboration in circular value chains, and (2) evaluate to what extent value chain collaboration is integrated in existing frameworks targeted towards the development of circular value propositions. This research was conducted in multiple steps. First, we deploy a literature review to identify enabling factors for collaborative circular value chains. Second, we reviewed existing frameworks that support the development of circular value propositions, to investigate to what extent these address value chain collaboration. We conclude this paper by discussing our findings from the literature and the tool review, followed by recommendations for the development of design support to facilitate collaboration towards sustainable and circular value chains.

Methods

Literature review

A scoping review (Arksey & O'Malley, 2005) was performed to summarize relevant literature related to collaboration for circular value chains and extract enabling factors, as well as clarify research gaps and working definitions. The review focused on journal articles published from 2015 and onwards. Subsequently, the CE concept gained significant traction in research in policy . Three sources were utilised (Scopus, Web of Science, and Google Scholar) to identify relevant articles through a combination of search strings including: Circular, Sustainability, Value chain, Supply chain, Collaboration, co-design, and co-creation. First, 133 articles were identified and assessed on relevance by examining titles, keywords, and abstracts. Next, 45 articles were excluded due to lack of relevance, and 88 articles were reviewed, summarised, classified according to type, and assessed on relevance. Finally, articles of high relevance were read in detail (47 articles) and relevant factors for the development of collaborative circular value chains were extracted.

Practice review

An online search was conducted to identify prescriptive frameworks that focus on the design of sustainable and circular value propositions. The frameworks were identified ad-hoc and were gathered over a period spanning from September 2021 to March 2024. A total of 38 prescriptive frameworks were identified originating from manufacturers, consultancies, and NGOs. Recurrent themes in the literature review informed the development of a classification framework for the practice review. The frameworks were classified according to focus, type of intervention, and ecosystem elements. The classification framework ensured a systematic approach in evaluating the focus and scope of the frameworks and examine to what extent aspects related to sustainable and circular ecosystems, and value chain collaboration were integrated. The results were collaboratively reviewed and discussed among the authors to extract and refine key insights.

Findings and discussion

In the following section, we report and discuss our findings from the literature review and tool review, respectively. Furthermore, we outline some directions and recommendations for further research.

Factors for collaborative sustainable and circular value chains

Based on the literature review, enabling factors and corresponding actions for the development of collaborative sustainable and circular value chains were identified and clustered into themes. The themes identified related to

sustainability leadership, value mapping, shared vision building, building trust, collaborative governance, collaborative processes, ecosystem perspectives and orchestration, and monitoring and evaluation. Figure 1 provides a summarized overview of the enabling factors for collaborative sustainable and circular value chains (see Table 1 in appendix for explanations of each theme and corresponding references). A recurrent theme in the review was the notion of circular ecosystems, illustrated by the fact that 'ecosystem' appeared in 18 of the 88 reviewed abstracts. How circular ecosystems contribute to the three dimensions of sustainability remains somewhat unclear as the concept is not clearly defined and multiple interpretations exist (Trevisan et al., 2022). We align with (Konietzko et al., 2024), who notes that *"newly emerging innovation ecosystems for circularity should aim for positive value and impact across the social, environmental and economic dimensions."* Challenges for such ecosystems are involving relevant stakeholders, identifying shared benefits of a circular proposition, establishing a shared data platform (a necessity to measure progress towards circularity), and the management and orchestration of involved stakeholders (Konietzko et al., 2024). While innovation ecosystems address radical innovation and new markets through primarily temporary project-based efforts (Adner, 2006), circular ecosystems require continuous long-term partnerships focused on sustainable and closed resource loops through shared responsibility and collective resource management, necessitating greater transparency, integration, and information sharing across the entire value chain. In the absence of formal approaches and established standards to guide circular ecosystems, there are significant challenges and trade-offs between knowledge and information sharing, and intellectual property and competitive advantage (Köhler et al., 2022). In turn, this further emphasizes the importance of collaborative governance (i.e., formal agreements and rules for collaboration, accountability, and decision-making). Overall, the review indicated several gaps in the research focused on collaborative sustainable and circular value chains. First, while the role of novel digital technologies and technology providers in fostering circular value chains has been studied, there is currently limited research examining how these technologies and



Figure 1. Overview of factors extracted from the literature review. The diagram provides an overview and does not intend to suggest a specific order in which activities should be undertaken.

providers facilitate value chain collaboration aside from (Gebhardt et al., 2022a; Schöggl et al., 2023), and how they foster the conditions and capabilities for successful collaboration over time. Second, while there are some prescriptive frameworks for the co-development of circular value chains (Blomsma, Pigosso, et al., 2019; Santa-Maria et al., 2022), few provide practical guidance or iterative approaches on how to go about the involvement of external stakeholders in the development of a sustainable and circular value proposition, and how to guide stakeholder co-creation and the aforementioned challenges related to sustainable and circular ecosystems. Third, though some studies have examined the role of circular ecosystem orchestrators (Hansen & Schmitt, 2021; Marques-McEwan et al., 2023; Trevisan et al., 2022) there is still a limited understanding of what type of actors are best suited to take this role and how these orchestrators influence the effectiveness of

value chain collaboration and co-creation. Marques-McEwan et al. (2023) notes that technology companies (e.g. companies that facilitate resource recovery or a data ecosystem) can initially take the role of ecosystem orchestrator, and that the role likely changes over time from the technology provider to the product owner. Moreover, factors such as collaborative efficacy, distribution of agency and power, reciprocity, and setting (on-site, online) could also play a role in collaborative circular value chains (Berardi & Brito, 2021; Marquina et al., 2024).

Frameworks supporting collaborative circular value chains

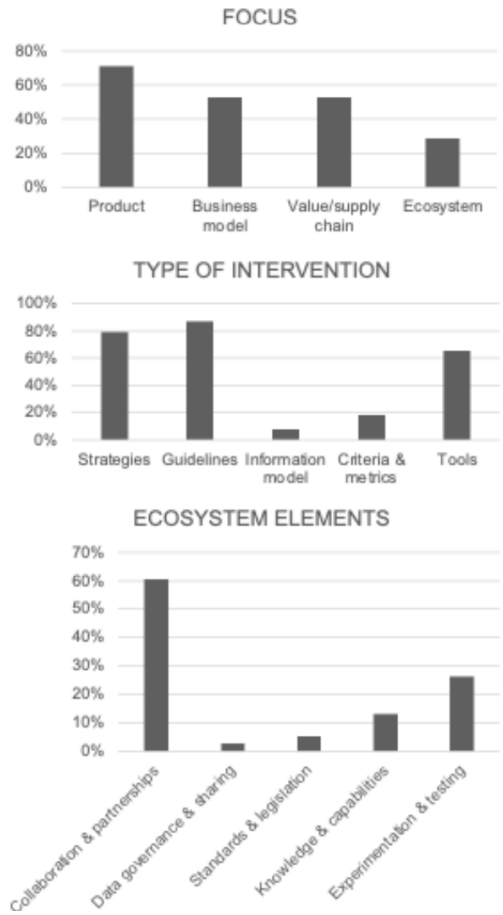


Figure 2. Exploration of frameworks for developing circular value propositions classified by focus, type of intervention, and ecosystem elements.

Figure 2 provides an overview of the reviewed 38 existing frameworks for the design of circular value propositions. The findings indicated that

most frameworks focus on individual ecosystem elements (i.e. products, business model, or value chain) and fewer take an ecosystem approach (i.e., the combination of product, business model, and value chain) to the development of sustainable and circular value propositions. While many frameworks focused on elements of value chain collaboration and partnerships (58%), few also included considerations regarding digitalization and data sharing and governance (3%). Around 80% of the reviewed interventions entailed proposed strategies and guidelines, while fewer focused on criteria and metrics (19%) and information models (8%).

Comparing findings and future research

Much of the examined literature advocates a holistic or ecosystem approach to the development of a circular product, business model, and value chain. The reviewed frameworks primarily focus on individual elements (product, business model, or value chain) and do not comprehensively address the combination of these elements. It should be noted that the notion of circular ecosystems has advanced substantially in recent years (Trevisan et al., 2022) and many of the gathered tools were conceptualized before 2020. The findings also indicated that a majority (60%) of the reviewed frameworks incorporated elements related to value chain collaborations and partnerships. Yet, the connection between collaboration and digitalisation in value chains remains underexplored in both the literature and frameworks, particularly in terms of clarifying roles and incentives in sustainability-related data sharing and management. As already pointed out by (Baumgartner et al., 2024), issues related to data sharing and transparency can potentially be overcome through novel digital technologies that can enable confidentiality-preserving and trustworthy environments. Furthermore, (Schöggl et al., 2023) provided evidence that digital technologies positively affect interorganizational collaboration in CE efforts. Overall, few frameworks provide a comprehensive approach or formal process that guide organizations through the steps of

developing a circular product and business model, including key considerations for the involvement of external stakeholders and successful value chain collaboration. Some examples are the circular design guide (Ellen MacArthur Foundation & IDEO, 2017) and the CIRCit workbooks (Kravchenko et al., 2020) that provide tools and practical guidance to address different challenges towards sustainable and circular ecosystems where different steps may be conducted with diverse actors. Extending product lifetimes and promoting practices such as repair, refurbishing, and remanufacturing require collaborative ecosystems of stakeholders – including manufacturers, material suppliers, service providers, and technology providers, who are aligned through shared responsibility, clear incentives, and long-term partnerships. Novel collaborative value chain partnerships are vital in managing product lifetimes, for example in enhancing material recovery and disassembly processes (Nußholz, 2018). To support product lifetime extension and circularity – there is a need to provide practical and clear guidance on how to foster and structure long-term value creating partnerships with value chain actors, through clarifying roles and incentives, trust-building mechanisms, collaborative structures, and data sharing frameworks. Therefore, future research will focus on comprehensive approaches toward mapping (existing and needed) stakeholders, resource flows, data and information flows, and capabilities for a sustainable and circular ecosystem. The readiness of diverse ecosystem actors regarding maturity in collaboration, sustainability and circularity, and data management is of key importance here, as this may steer the approach and collaborative process. Based on such an ecosystem mapping, guidance can be provided in understanding what capabilities and corresponding new partnerships and collaborations are needed, which guide what relevant stakeholders to strategically involve.

Conclusions

Based on a literature review and a review of existing frameworks, this study provides insights into factors that enable collaboration for sustainable and circular value chains and explores to what extent value chain collaboration is addressed in existing frameworks targeting the design of circular value propositions. The present research identified 9 factors for collaborative sustainable and circular value chains. These include sustainability leadership, value mapping, shared vision building, building trust, collaborative governance, collaborative processes, ecosystem perspectives and orchestration, and monitoring and evaluation. The analysis of 38 frameworks revealed significant attention to value chain collaboration and partnerships, yet considerations regarding the connection between collaboration, digitalisation, and data sharing remain underrepresented. The concept of circular ecosystems has emerged as a pivotal framework, highlighting the interdependence of diverse actors and the need for orchestration across industrial boundaries. However, significant challenges remain, particularly in stakeholder engagement, data management, and balancing collaboration with competitive interests. The lack of formal approaches and standards that address these difficulties, underscores the crucial role of collaborative governance and ecosystem orchestrators. The findings suggest that future research, and tool development, should prioritize the interface of sustainability and circularity, value chain collaboration, and digitalization. Particularly the role and influence of ecosystem orchestrators in enabling successful value chain collaboration and co-creation needs to be further examined. Furthermore, comprehensive approaches are needed to guide product manufacturers in developing the conditions and capabilities for collaborative sustainable and circular ecosystems to overcome the inherent challenges. These should clarify and align roles and incentives in a circular ecosystem, and foster data sharing and data management capabilities. The identified themes provide a foundation for further research and may be insightful for companies in the realization of sustainable and circular ecosystems. Future research will focus on incorporating the themes in a prescriptive framework that targets the development of collaborative sustainable and circular value chains, while also examining how these themes contribute (or do not contribute) to product manufacturers achieving sustainable and circular ecosystems. There are two main limitations of the study that should be noted. First, the review of tools was not systematic and exhaustive, there may be additional tools

focusing on circular value propositions that were not part of this study (e.g., some of these are identified in a recent and more systematic review by Rexfelt & Selvefors (2024)). Second, the literature review in this study was limited to collaboration in sustainable and circular value chains, while relevant insights may also be extracted from broader literature before 2015 at the interface of sustainability and value chains.

References

Adner, R. (2006). Match your innovation strategy to your innovation ecosystem. *Harvard Business Review*, *84*(4), 98–107; 148.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Arnold, M. (2017). Fostering sustainability by linking co-creation and relationship management concepts. *Journal of Cleaner Production*, *140*, 179–188. https://doi.org/10.1016/j.jclepro.2015.03.059

Baumgartner, R. J., Berger, K., & Schöggl, J.-P. (2024). Digital Technologies for Sustainable Product Management in the Circular Economy. In T. Lynn, P. Rosati, D. Kreps, & K. Conboy (Eds.), *Digital Sustainability: Leveraging Digital Technology to Combat Climate Change* (pp. 121–143). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-61749-2_7

Berardi, P. C., & Brito, R. P. (2021). Supply chain collaboration for a circular economy—From transition to continuous improvement. *Journal of Cleaner Production*, *328*, 129511. https://doi.org/10.1016/j.jclepro.2021.129511

Berlin, D., Feldmann, A., & Nuur, C. (2022). Supply network collaborations in a circular economy: A case study of Swedish steel recycling. *Resources, Conservation and Recycling*, *179*(March 2021), 106112. https://doi.org/10.1016/j.resconrec.2021.106112

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D. C. A., Hildenbrand, J., Kristinsdottir, A. R., Kristoffersen, E., Shabazi, S., Nielsen, K. D., Jönbrink, A. K., Li, J., Wiik, C., & McAloone, T. C. (2019). Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation. *Journal of Cleaner Production*, *241*. https://doi.org/10.1016/j.jclepro.2019.118271

Blomsma, F., Pigosso, D. C., & McAloone, T. C. (2019). A theoretical foundation for developing a prescriptive method for the co-design of circular economy value chains. *Proceedings of the International Conference on Engineering Design, ICED*, *2019-Augus*(August), 3141–3150. https://doi.org/10.1017/dsi.2019.321

Bocken, N. M. P., Rana, P., & Short, S. W. (2015). Value mapping for sustainable business thinking. *Journal of Industrial and Production Engineering*, *32*(1), 67–81. https://doi.org/10.1080/21681015.2014.1000399

Boldrini, J. C., & Antheaume, N. (2021). Designing and testing a new sustainable business model tool for multi-actor, multi-level, circular, and collaborative contexts. *Journal of Cleaner Production*, *309*(July 2020), 127209. https://doi.org/10.1016/j.jclepro.2021.127209

Brown, P., Bocken, N., & Balkenende, R. (2018). Towards Understanding Collaboration Within Circular Business Models. In L. Moratis, F. Melissen, & S. O. Idowu (Eds.), *Sustainable Business Models: Principles, Promise, and Practice* (pp. 169–201). Springer International Publishing. https://doi.org/10.1007/978-3-319-73503-0_9

Brown, P., Bocken, N., & Balkenende, R. (2019). Why do companies pursue collaborative circular oriented innovation? *Sustainability (Switzerland)*, *11*(3), 1–23. https://doi.org/10.3390/su11030635

Brown, P., Bocken, N., & Balkenende, R. (2020). How do companies collaborate for circular oriented innovation? *Sustainability (Switzerland)*, *12*(4), 1–21. https://doi.org/10.3390/su12041648

Brown, P., Von Daniels, C., Bocken, N., & Balkenende, R. (2021). A process model for collaboration in circular oriented innovation. *Journal of Cleaner Production*, *286*, 125499. https://doi.org/10.1016/j.jclepro.2020.125499

Catena X. (n.d.). Catena X - Your Automotive Network. Retrieved 5 December 2024, from https://catena-x.net/en/1

Chari, A., Niedenzu, D., Despeisse, M., Machado, C. G., Azevedo, J. D., Boavida-Dias, R., & Johansson, B. (2022). Dynamic capabilities for circular manufacturing supply chains—Exploring the role of Industry 4.0 and resilience. *Business Strategy and the Environment*, *31*(5), 2500–2517. https://doi.org/10.1002/bse.3040

Chirumalla, K., Reyes, L. G., & Toorajipour, R. (2022). Mapping a circular business

opportunity in electric vehicle battery value chain: A multi-stakeholder framework to create a win–win–win situation. *Journal of Business Research*, *145*, 569–582. https://doi.org/10.1016/j.jbusres.2022.02.070

Circularise. (n.d.). Product Traceability Platform for Supply Chain Compliance. Retrieved 5 December 2024, from https://www.circularise.com/

Danvers, S., Robertson, J., & Zutshi, A. (2023). Conceptualizing How Collaboration Advances Circularity. *Sustainability*, *15*(6), 5553. https://doi.org/10.3390/su15065553

de Pádua Pieroni, M., Pigosso, D. C. A., & McAloone, T. C. (2018). Sustainable Qualifying Criteria for Designing Circular Business Models. *Procedia CIRP*, *69*, 799–804. https://doi.org/10.1016/j.procir.2017.11.014

Eikelenboom, M., & de Jong, G. (2022). The Impact of Managers and Network Interactions on the Integration of Circularity in Business Strategy. *Organization & Environment*, *35*(3), 365–393. https://doi.org/10.1177/1086026621994635

Elia, V., Gnoni, M. G., & Tornese, F. (2017). Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production*, *142*, 2741–2751. https://doi.org/10.1016/j.jclepro.2016.10.196

Ellen MacArthur Foundation & IDEO. (2017). *The Circular Design Guide*. https://www.circulardesignguide.com/

European Commission. (2023). *Directive on end-of-life vehicles*. https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles_en

Fernandes, S. da C., Pigosso, D. C. A., McAloone, T. C., & Rozenfeld, H. (2020). Towards product-service system oriented to circular economy: A systematic review of value proposition design approaches. *Journal of Cleaner Production*, *257*. https://doi.org/10.1016/j.jclepro.2020.120507

Franco, M. A. (2017). Circular economy at the micro level: A dynamic view of incumbents' struggles and challenges in the textile industry. *Journal of Cleaner Production*, *168*, 833–845. https://doi.org/10.1016/j.jclepro.2017.09.056

Gebhardt, M., Kopyto, M., Birkel, H., & Hartmann, E. (2022a). Industry 4.0 technologies as enablers of collaboration in circular supply chains: A systematic literature review. *International Journal of Production Research*, *60*(23), 6967–6995. https://doi.org/10.1080/00207543.2021.1999521

Gebhardt, M., Kopyto, M., Birkel, H., & Hartmann, E. (2022b). Industry 4.0 technologies as enablers of collaboration in circular supply chains: A systematic literature review. *International Journal of Production Research*, *60*(23), 6967–6995. https://doi.org/10.1080/00207543.2021.1999521

Geissdoerfer, M., Bocken, N. M. P., & Hultink, E. J. (2016). Design thinking to enhance the sustainable business modelling process – A workshop based on a value mapping process. *Journal of Cleaner Production*, *135*(April 2018), 1218–1232. https://doi.org/10.1016/j.jclepro.2016.07.020

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production*, *190*, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Guldmann, E., & Huulgaard, R. D. (2020). Barriers to circular business model innovation: A multiple-case study. *Journal of Cleaner Production*, *243*, 118160. https://doi.org/10.1016/j.jclepro.2019.118160

Hallstedt, S. I., Isaksson, O., & Rönnbäck, A. A. Ö. (2020). The need for new product development capabilities from digitalization, sustainability, and servitization trends. *Sustainability (Switzerland)*, *12*(23), 1–26. https://doi.org/10.3390/su122310222

Hansen, E. G., & Revellio, F. (2020). Circular value creation architectures: Make, ally, buy, or laissez-faire. *Journal of Industrial Ecology*, *24*(6), 1250–1273. https://doi.org/10.1111/jiec.13016

Hansen, E. G., & Schmitt, J. C. (2021). Orchestrating cradle-to-cradle innovation across the value chain: Overcoming barriers through innovation communities, collaboration mechanisms, and intermediation. *Journal of Industrial Ecology*, *25*(3), 627–647. https://doi.org/10.1111/jiec.13081

Köhler, J., Sönnichsen, S. D., & Beske-Jansen, P. (2022). Towards a collaboration framework for circular economy: The role of dynamic capabilities and open innovation. *Business*

Strategy and the Environment, *31*(6), 2700–2713. https://doi.org/10.1002/bse.3000

Konietzko, J., Baldassarre, B., Bocken, N., & Ritala, P. (2024). Initiating a Minimum Viable Ecosystem for Circularity. In A. R. Ometto, J. Sarkis, & S. Evans (Eds.), *A Systemic Transition to Circular Economy: Business and Technology Perspectives* (pp. 65–83). Springer International Publishing. https://doi.org/10.1007/978-3-031-55036-2_4

Konietzko, J., Bocken, N., & Hultink, E. J. (2020). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, *253*, 119942. https://doi.org/10.1016/j.jclepro.2019.119942

Kravchenko, M., Hjort Jensen, T., Pigosso, D.C.A., & McAloone, T.C. (2020). *CIRCit workbooks: Guidance towards a circular transition*. CIRCit Nord. https://circitnord.com/workbooks/

Leising, E., Quist, J., & Bocken, N. (2018). Circular Economy in the building sector: Three cases and a collaboration tool. *Journal of Cleaner Production*, *176*, 976–989. https://doi.org/10.1016/j.jclepro.2017.12.010

Marques-McEwan, M., Xu, B., Bititci, U. S., & Jiang, M. (2023). Unveiling the rules for creating circular business ecosystems: A case study in the chemical industry. *Journal of Cleaner Production*, *427*, 139185. https://doi.org/10.1016/j.jclepro.2023.139185

Marquina, M. V. H., Le Dain, M.-A., Joly, I., & Zwolinski, P. (2024). Exploring determinants of collaboration in circular supply chains: A social exchange theory perspective. *Sustainable Production and Consumption*, *50*, 1–19. https://doi.org/10.1016/j.spc.2024.07.017

Nußholz, J. L. K. (2018). A circular business model mapping tool for creating value from prolonged product lifetime and closed material loops. *Journal of Cleaner Production*, *197*, 185–194. https://doi.org/10.1016/j.jclepro.2018.06.112

Oskam, I., Bossink, B., & de Man, A.-P. (2021). Valuing Value in Innovation Ecosystems: How Cross-Sector Actors Overcome Tensions in Collaborative Sustainable Business Model Development. *Business & Society*, *60*(5), 1059–1091. https://doi.org/10.1177/0007650320907145

Parida, V., Burström, T., Visnjic, I., & Wincent, J. (2019). Orchestrating industrial ecosystem in circular economy: A two-stage transformation model for large manufacturing companies. *Journal of Business Research*, *101*, 715–725. https://doi.org/10.1016/j.jbusres.2019.01.006

Pedersen, S., & Clausen, C. (2019). Staging Co-Design for a Circular Economy. *Proceedings of the Design Society: International Conference on Engineering Design*, *1*, 3371–3380. https://doi.org/10.1017/dsi.2019.344

Pedersen, S., Clausen, C., & Jørgensen, M. S. (2023). Navigating value networks to co-create sustainable business models: An actionable staging approach. *Business Strategy and the Environment*, *32*(1), 240–258. https://doi.org/10.1002/bse.3127

Pieroni, M. P. P., McAloone, T. C., & Pigosso, D. C. A. (2020). Circular Economy business model innovation: Sectorial patterns within manufacturing companies. *Journal of Cleaner Production (under Review).*, *286*(xxxx), 124921. https://doi.org/10.1016/j.jclepro.2020.124921

Rexfelt, O., & Selvefors, A. (2024). Mapping the landscape of circular design tools. *Resources, Conservation and Recycling*, *209*, 107783. https://doi.org/10.1016/j.resconrec.2024.107783

Rijswijk, K., de Vries, J. R., Klerkx, L., & Turner, J. A. (2023). The enabling and constraining connections between trust and digitalisation in incumbent value chains. *Technological Forecasting and Social Change*, *186*, 122175. https://doi.org/10.1016/j.techfore.2022.122175

Roos Lindgreen, E., Opferkuch, K., Walker, A. M., Salomone, R., Reyes, T., Raggi, A., Simboli, A., Vermeulen, W. J. V., & Caeiro, S. (2022). Exploring assessment practices of companies actively engaged with circular economy. *Business Strategy and the Environment*, *31*(4), 1414–1438. https://doi.org/10.1002/bse.2962

Santa-Maria, T., Vermeulen, W. J. V., & Baumgartner, R. J. (2022). The Circular Sprint: Circular business model innovation through design thinking. *Journal of Cleaner Production*, *362*, 132323. https://doi.org/10.1016/j.jclepro.2022.132323

Schöggl, J.-P., Stumpf, L., & Baumgartner, R. J. (2023). The role of interorganizational collaboration and digital technologies in the implementation of circular economy practices—Empirical evidence from manufacturing firms. *Business Strategy and the Environment*, *n/a*(n/a). https://doi.org/10.1002/bse.3593

Sudusinghe, J. I., & Seuring, S. (2022). Supply chain collaboration and sustainability performance in circular economy: A systematic literature review. *International Journal of Production Economics*, *245*, 108402. https://doi.org/10.1016/j.ijpe.2021.108402

Trevisan, A. H., Castro, C. G., Gomes, L. A. V., & Mascarenhas, J. (2022). Unlocking the circular ecosystem concept: Evolution, current research, and future directions. *Sustainable Production and Consumption*, *29*, 286–298. https://doi.org/10.1016/j.spc.2021.10.020

Appendix 1: Results from literature review and practice review

Table 1. Overview of key factors for the development of collaborative circular value chains extracted from the literature review.

Theme	Description	Examples of relevant references
Building trust	Building trust is crucial for collaboration and transparency in circular business model (CBM) innovation but challenging due to undeveloped standards and potential power imbalances. While formal agreements offer structure, trust through relational mechanisms is key. Strategies to overcome barriers include developing collaboration competencies, using intermediaries for data sharing, and leveraging technologies like blockchain for secure, transparent information exchange.	(Berardi & Brito, 2021; Chari et al., 2022; Danvers et al., 2023; Gebhardt et al., 2022b; Guldmann & Huulgaard, 2020; Konietzko et al., 2020; Leising et al., 2018; Marquina et al., 2024; Rijswijk et al., 2023)
Collaborative governance	Circular value chains require partnerships beyond traditional roles to enable resource recirculation and shared value. Governance, in the form of explicit rules, decision-making structures, and mechanisms such as penalties and incentives are critical for guiding collaboration and promoting sustainable behaviours. Balancing knowledge sharing with competitive advantage through IP agreements is key. Policy-driven financing and data solutions like digital product passports (DPPs) enable transparency, standardization, and trust, fostering collaboration within circular value chains.	(Brown et al., 2020, 2021; Gebhardt et al., 2022b; Hallstedt et al., 2020; Hansen & Revellio, 2020; Köhler et al., 2022; Konietzko et al., 2020; Pieroni et al., 2020; Sudusinghe & Seuring, 2022)
Collaborative processes	Pro-active collaboration, design thinking methodologies, co-design processes, and stakeholder workshops have been associated with fostering more inclusive and participatory approaches in the development of circular value propositions. Collaborative innovations depend on power dynamics and power symmetries in value chains, where power asymmetries can diminish willingness to collaborate and joint problem solving, and reciprocity can enable collaborative relationships, wellbeing, and inclusion.	(Berardi & Brito, 2021; Berlin et al., 2022; Blomsma, Pieroni, et al., 2019; Blomsma, Pigosso, et al., 2019; Franco, 2017; Geissdoerfer et al., 2016; Leising et al., 2018; Marquina et al., 2024; Pedersen & Clausen, 2019)
Ecosystem perspective	To enable the development of collaborative circular value chains it is essential that actions are taken to enable firms to adopt an ecosystem perspective. An ecosystem perspective adopts a wider and intra-organizational perspective that captures circularity as a systemic property and examines how multiple actors can direct collective efforts towards a circular value proposition to provide shared opportunities and outcomes for environmental and economic sustainability.	(Arnold, 2017; Boldrini & Antheaume, 2021; Chari et al., 2022; de Pádua Pieroni et al., 2018; Konietzko et al., 2020; Marques-McEwan et al., 2023; Sudusinghe & Seuring, 2022; Trevisan et al., 2022)
Ecosystem orchestration	Ecosystem orchestration involves an intermediary facilitating collaboration, interactions, and transactions among actors in a circular ecosystem. Orchestrators assess roles, readiness, and bridge barriers like cultural, technological, and institutional gaps. The role of orchestrator is not fixed but likely changes over time,	(Danvers et al., 2023; Hansen & Schmitt, 2021; Marques-McEwan et al., 2023; Oskam et al., 2021;

	for example from technology or service providers to the product/solution owners.	Parida et al., 2019; Trevisan et al., 2022)
Monitoring and evaluation	Monitoring and evaluation are critical for collaborative circular value chains as it provides a framework to assess current and necessary capabilities for a circular ecosystem, identify opportunities and weaknesses, and ensure alignment between stakeholders towards shared sustainability goals. Effective monitoring of readiness towards a circular value chain can create a sense of urgency amongst stakeholders, inform strategic decisions and policies, and foster transparency and accountability within a network which enhances cooperation.	(Chari et al., 2022; Elia et al., 2017; Marquina et al., 2024; Roos Lindgreen et al., 2022)
Shared vision	A shared vision (of a circular product, business model, and value chain) is crucial for collaborative circular value chains. Vision development can be enabled through joint activities with relevant stakeholders involved, to align perspectives and negotiate a shared vision. Establishing a vision is important for collaborative intent, system transformation, and long-term cooperation. Visions should be explicit statements of desired futures enabled through interactive elements such text, images, drawings, and storytelling.	(Brown et al., 2018; Hallstedt et al., 2020; Konietzko et al., 2024; Leising et al., 2018; Marquina et al., 2024)
Value mapping	It is vital to understand the perceived value of a circular solution for customers and other stakeholders, and identify shared value, ownership, and risks. Value mapping maps impacts on external stakeholders, finding positive economic interlinks between actors, and aligning solutions. Value mapping requires the identification of relevant stakeholders and flows of resources, information, and finances. The effectiveness of value mapping can depend on the tool used, and the facilitator and users.	(Arnold, 2017; Blomsma, Pieroni, et al., 2019; Bocken et al., 2015; Brown et al., 2019; Chirumalla et al., 2022; Eikelenboom & de Jong, 2022; Fernandes et al., 2020; Marques-McEwan et al., 2023; Pedersen et al., 2023)
Sustainability leadership	Sustainability leadership is crucial for collaborative circular value chains to clarify the relationship between stakeholders' efforts on circularity and sustainability goals as well as promoting structural and cultural transformation through dedicated leaders. Sustainability leaders can drive collaboration and help overcome implementation barriers on individual, organizational, value chain, and institutional levels.	(Arnold, 2017; Blomsma, Pieroni, et al., 2019; Chari et al., 2022; Hansen & Schmitt, 2021)

Table 2. Overview of analysed prescriptive frameworks for circular value propositions.

#	Name of framework	Source	Link
1	10 principles of circular design	Nike	https://www.nikecirculardesign.com/guides/MiniGuide.pdf
2	10 steps to create a circular business model	Fischer and Achterberg (2016)	https://v.fastcdn.co/u/bcd99f8d/48799320-0-finance-white-paper-.pdf
3	A quick design guide for the circular economy	Indeed (2023)	https://www.indeed-innovation.com/wp-content/uploads/2023/02/A-quick-design-guide-to-the-circular-economy.pdf
4	Beyond net zero: a systemic design approach	Design council	https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/beyond-net-zero-a-systemic-design-approach/
5	BM3C2 framework	University Nantes	http://www.bm3c2.fr/index.php/telecharger-trames/
6	Circulab toolbox	Circulab	https://circulab.com/toolbox-circular-economy/

7	Circular built environment playbook	World Green Building Council	https://worldgbc.org/article/circular-built-environment-playbook/
8	Circular design guide	Ellen MacArthur Foundation and IDEO (2017)	https://www.circulardesignguide.com/
9	Circular design guidelines	Stora Enso	https://www.storaenso.com/-/media/documents/download-center/documents/sustainability/stora-enso_circular_design_guidelines.pdf
10	Circular design map	Switchrs	https://switchrs.com/wp-content/uploads/2021/03/Circular-Design-Map-V4.0-A4.pdf
11	Circular Design Metrics	DS Smith	https://www.dssmith.com/media/our-stories/2021/5/launch-circular-design-metrics
12	Circular Economy Business Modelling guide	CIRCit	https://www.nordicinnovation.org/sites/default/files/documents/2020/WB2_CIRCit.pdf
13	Circular product design and development	CIRCit	https://www.nordicinnovation.org/sites/default/files/documents/2020/WB3_CIRCit.pdf
14	Circular product design guide	Ikea	https://preview.thenewsmarket.com/Previews/IKEA/DocumentAssets/512088_v2.pdf
15	Circular toolkit	Danish design council	https://ddc.dk/tools/designing-your-circular-transition/
16	Circular X tools	CircularX	https://www.circularx.eu/en/tool
17	Circularity deck	Konietzko et al. (2020)	https://www.mdpi.com/2071-1050/12/1/417
18	Circulator guide	H&M	https://hmgroup.com/wp-content/uploads/2021/11/Circulator_Guide_v1.0.pdf
19	Circulytics	Ellen MacArthur Foundation (2020)	https://ellenmacarthurfoundation.org/resources/circulytics/overview?utm_term=exclude&utm_source=exclude
20	Cirkularitet: cirkulära möbler	Rise	https://cirkularitet.se/lar-dig-mer/verktyg/
21	Closing the loop by design	Utwente, Remeha BV	https://home.et.utwente.nl/designtool/5d33e8a3cfb35737ec484429954f0ea98fed69d8/index.html
22	Collaborating and networking for a circular economy	CIRCit	https://www.nordicinnovation.org/sites/default/files/documents/2020/WB6_CIRCit.pdf
23	Design manual for circular change	Wasteman team	https://www.imp.gda.pl/wasteman/download/DesignManual.pdf
24	Designing and implementing mission-oriented policies: Tools and resources from the field	UCL Institute for Innovation and Public Purpose (2024)	https://www.ucl.ac.uk/bartlett/public-purpose/sites/bartlett_public_purpose/files/designing_and_implementing_mission-oriented_policies_feb_2024.pdf
25	Designing your circular transition	Danish Design Center (2023)	https://ddc.dk/tools/designing-your-circular-transition/

26	Digital Product Passports mapping	Metabolic	https://wbcsd-dpp-mapping.metabolic.software/
27	Driving design	Distributed Design (2023)	https://distributeddesign.eu/wp-content/uploads/2023/05/DDP_DrivingDesign.pdf
28	Framework circular design	Circo	https://www.circonnect.org/framework-circular-design/
29	Future adaptive design for a circular economy	RISE	https://www.ri.se/en/what-we-do/expertises/future-adaptive-design-for-a-circular-ec
30	Guided choices towards a circular business model	Joustra (2013)	http://www.opai.eu/uploads/Guided_Choices_towards_a_Circular_Business_Model_pdf11.pdf
31	Self assessment tool	TNO, LBP, Circo	https://tno-self-assessment-tool.netlify.app/
32	Sustainability guide	SVID	https://sustainabilityguide.eu/
33	Sustainable growth with circular economy business models: A playbook for businesses	Sitra	https://www.sitra.fi/app/uploads/2022/12/sitra_sustainable_growth_with_circular_economy_business_models.pdf
34	Systemic design toolkit	Systemic design toolkit	https://www.systemicdesigntoolkit.org/download
35	The use2use design toolkit	Rexfelt and Selvefors (2021)	https://www.mdpi.com/2071-1050/13/10/5397
36	The Value Hill	Achterberg et al. (2016)	https://hetgroenebrein.nl/wp-content/uploads/2017/08/finance-white-paper-20160923.pdf
37	Upstream innovation guide	Ellen MacArthur Foundation (2020)	https://ellenmacarthurfoundation.org/upstream-innovation/overview
38	Use2use toolkit	use2use	https://www.use2use.se/

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Matching reuse models to hospitals: Reframing value-chains for reusable medical products

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Keywords: Reuse in healthcare; Medical products; Value-chain; Reprocessing; Circular economy.

Abstract: In the transition towards a circular economy, also critical sectors such as the healthcare sector need to be reviewed. A large portion of hospital waste consists of low-value, disposable consumables. Currently, the circular design strategies of reuse, maintenance, and repair in healthcare are predominantly applied to high-value products. This study proposes four reuse value-chain models specifically for small, low-cost medical consumables. Reuse models are distinguished on reprocessing location (internal or external) and product usage (shared or personal). Business model evaluation and value propositioning are used to gain understanding of the models and a co-creation session with a MedTech company verified these understandings. Our research sought to support manufacturers of reusable medical products by addressing the importance of the fit between the reuse model and the hospital's context (location, infrastructure, staffing, organisational structure, product volume and type). These context features, as well as the hospital's interest in reusable products should be documented in the tendering documents of the purchasing process. Internal reprocessing makes the hospital more self-sufficient but requires additional staffing for reprocessing and quality control. External reprocessing decreases the hospital's workload, but requires the involvement of additional service partners. For all reuse models, continuous communication and collaboration (feedback, training and guidance) between the hospital and value-chain partners are vital.

Introduction

Disposable products used in healthcare are causing excessive waste production and risk the further depletion of natural resources and energy (Janik-Karpinska et al., 2023). Most healthcare professionals have an aversion to the negative impact created as a by-product of their professional activities (López-Medina et al., 2022; Yap et al., 2023). One of the solutions include a transition to product circularity, where a used product is collected, cleaned, inspected, maintained and brought back for a next use-cycle (Keil et al., 2023; Macneill et al., 2020; Ramos et al., 2023). This was historically a common practice, but innovations of new materials, more complex medical devices and safety considerations have pushed the development of new value-chains and product logistics since the introduction of disposable products (European Commission, 2010). In recent years, environmental awareness has grown and some manufacturers and suppliers start to offer reusable products (Chauvet et al., 2024; Drew et al., 2022; Vozzola et al., 2018). However, many companies still face challenges in effectively supporting hospitals and providing more optimised products and services.

Objective

In this study, we focus on reuse of medical products to reduce waste generation. Our analysis will concentrate on small medical consumables including medical textiles, using these to compare different reuse value-chain models for Class I devices according to the Medical Device Regulation (European Union, 2017).

Background

Previous research has highlighted design strategies aimed at increasing circularity in medical design (Hoveling et al., 2024). Kane et al. (2018) identified three key factors influencing circular medical design: hygienic

device criticality in terms of sterilisation requirements, financial product value, and organisational support structure surrounding the device. Based in these factors, design strategies were defined. The principles of the Circular Economy, aim to keep products at their highest utility and value, prioritising repair, maintenance and reuse over refurbishing, repurposing and recycling (Ellen MacArthur Foundation, 2015). Consequently, our interest goes out to **design optimisation for hygienic recovery**, such as reuse through sterilisation, to ensure safety and effectiveness. Building on this, Guzzo et al. (2020) proposed nine circular business models (CBMs) for the medical device industry based on existing cases. Two CBMs stand out from a reuse perspective, but are applied to medium to high-value product categories. In the CBM '*Hospital-based reprocessing support'*, materials and services are provided to facilitate the reprocessing of medical equipment within the hospital (**internal reprocessing**). The service can be provided for various levels of disinfection, ranging from surface cleaning to full sterilisation. In the CBM '*full provision for reprocessed devices'* medical products are collected in the appropriate container at the hospital. Thereafter, a service provider or external sterilisation facility collects the products, verifies, sorts, reprocesses, inspects and repackages the medical products so that they can be put back into circulation at the hospital (**external reprocessing**). Based on our previous research into the reuse of medical (textile) products, some items can be shared and others are preferred or required to be personal. **Shared products** such as surgical gowns, drapes or positioning pillows can be collected together and do not necessarily have to be reused by the same person . For products such as a radiotherapy mask, **personal use** is necessary. Face masks and incontinence briefs are other examples of products where personal use can be selected.

Study objective

Reusable products in hospitals require correct sorting and streamlined reverse logistics. Different stakeholders have to work together to succeed (Sattari et al., 2020). The involvement and coordination of stakeholders shape the reuse value-chain of a product. We hypothesize

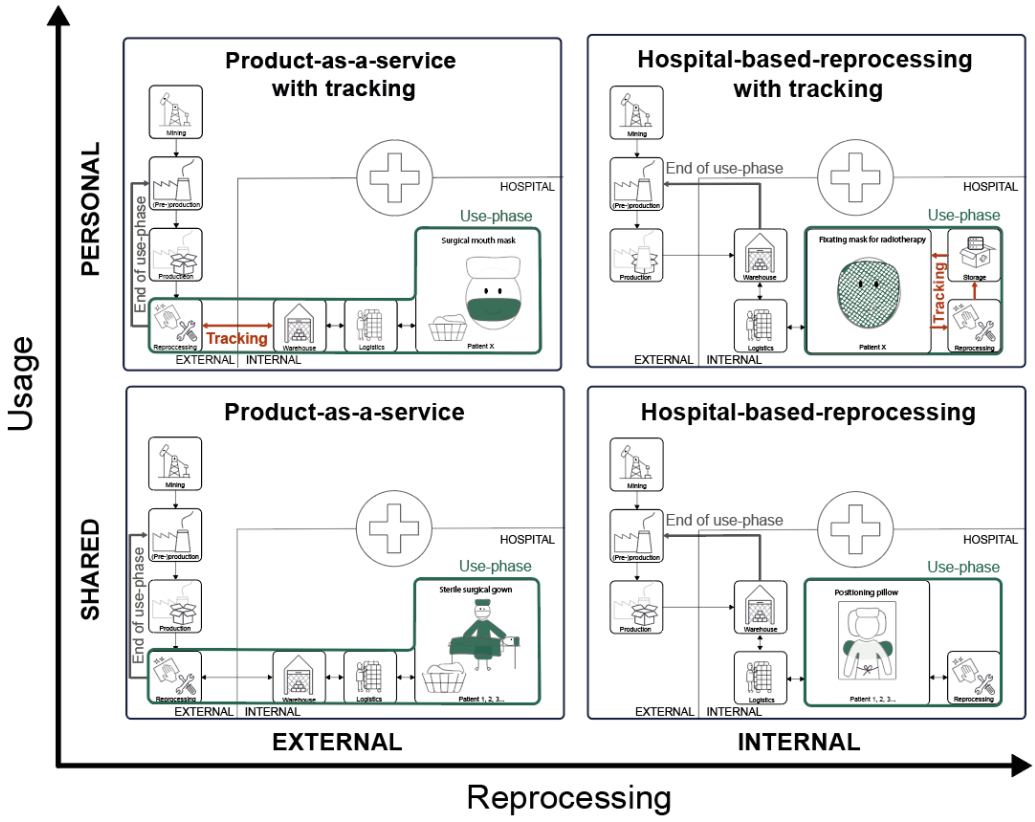


Figure 1. Four reuse value-chain models in hospitals, which cluster around whether the use is shared or personal and whether the reprocessing of the medical product occurs on-site or externally.

that four reuse models are distinguished based on location of reprocessing and the use of the product (Figure 1). Some hospitals have the infrastructure to support reprocessing of products in-house. Others, need to rely on external service partners that can do reprocessing for them. Whether the reprocessing takes place in the hospital itself or not has an impact on which (additional) partner should be involved. Furthermore, some products need to be tracked in order to ensure that a personal product can be returned to the patient it belongs to. The type of use, either shared or personal, also affects the logistical and infrastructural organisation of reuse. To return products to their personal user, the product must be traceable by e.g. a barcode or chip depending on the appropriate situation. This study aims to analyse and compare the four reuse value-chain models by identifying their similarities and differences. We seek to explore whether different reuse models necessitate distinct business models or if they can be integrated. Additionally, we will examine the value propositions of these models and extend the analysis to include the supplier perspective.

Methods

Defining reuse value-chain models

Using the Circular Design Map from Switchrs (2019) a framework of four reuse value-chain models (Figure 1) was hypothesized to position different approaches of reprocessing in healthcare. For each reuse model, a (simplified) value-chain from mining to the use-phase and to the end of use-phase is mapped out and illustrated with an example product.

From concept to value: business model canvas and value proposition

To gain a deeper understanding of how the reuse models differ or align, a workshop (March 2023) with nine design researchers was carried out. First, an adapted business model canvas (Guzzo et al., 2020; Osterwalder & Pigneur, 2010) for each reuse value-chain model was filled out. The canvas consists of 3x3 frames (Table 1 and 2). The value creation is composed of stakeholders, activities and resources. Value capture can be described for: organisational profit, benefits for people and planet. Then, value delivery is achieved by a combination of customer relationships, channels and segments. The business models (BM) were completed from the view of the hospitals. Secondly, a Systems Value Proposition (Jones & Van Ael, 2022, pp. 124–127) was construed for the reuse model for shared products with internal reprocessing and the model for personal products with external reprocessing. The Systems Value Proposition is a tool that can be utilised to present the value proposition for larger systems where multiple parties benefit. Value can be created at three levels: individual (staff and patient), organisational (for the hospital), and societal (society and the value-chain partners). Additionally, there are four dimensions that describe the economic, ecological, psychological, and social value for the system. At the end, a discussion on the differences and similarities of the four reuse models was held. We employed purposive sampling to select participants with relevant expertise in research related to value-chains, product reuse and stakeholder management, ensuring they could provide meaningful input.

Broadening and verifying the reuse value-chain model: supplier perspectives

Additionally, to expand and verify our understanding of the reuse value-chain models a co-creation session with a MedTech company was performed. Currently, the company offers a disposable product (Class I – non-invasive according to MDR) for hygiene reasons, which is unfortunate as high quality materials are used. Additionally, reuse could lead to cost savings by distributing the purchase cost across multiple (re)use cycles. The goal of the co-creation session was to gain a deeper understanding of the value-chain of the specific medical product. Together with the CEO and product engineer of the company, the current value-chain of the single-use product was mapped out. Stakeholders and steps were added to refine the value-chain along the procurement of materials, production, distribution, regulatory requirements, potential for reprocessing during the use-phase (internal/external), options for the end of use-phase, and after-sales services. The involved partners and usage steps were also discussed. By reviewing these stages, the product's value-chain was further detailed. An alternative reuse cycle was then proposed, using a different colour to indicate the partners, materials, energy requirements, and costs. Attention was given to different methods of reprocessing and end-of-use options.

Results

A framework for reuse: value-chain models by reprocessing location and product usage

As shown in Figure 1, four types of reuse models could be identified: **Hospital-based reprocessing:** The hospital manages the medical product reprocessing. Some items require only surface disinfection, such as wipes in treatment rooms, while others need thorough cleaning or sterilisation by central hospital services like the laundry or sterilisation department. Reusable items, like positioning pillows or support blocks for arms and legs in the operating room, can serve multiple patients if properly cleaned between uses. **Hospital-based reprocessing with tracking:** In this reuse model, the hospital manages product reprocessing and assigns each product to a specific patient or user. For example, a radiotherapy mask, custom-fitted to ensure precise targeting during radiation treatment, must be stored for the patient's subsequent therapy sessions. This system requires tracking the product through barcodes or RFID chips, allowing them to be linked to a specific patient or surgeon. This model also applies to surgical instrument sets and loaned products, such as crutches, which require cleaning and maintenance. **Product-as-a-service:** Most reusable textile products, such as staff uniforms, bed linen, reusable nappies, or absorbent pads (also known as incontinence pads), follow the product-as-a-service model. After use, these items are laundered. The following day, a fresh uniform or bed linen is taken from the hospital's stock for use. This model works best when products stay in circulation and are not left unused in storage, ensuring optimal use of available products. Due to the high consumption of these items, hospitals often partner with external services. In the case of textile products, this partner is often a laundry service, which may take over some of the hospital's responsibilities, ranging from core tasks, like laundering, to managing textile logistics and inventory control. **Product-as-a-service with tracking:** This model involves an external partner and requires each textile item to be traceable to an individual user. Personal use demands a higher number of items per user in circulation compared to products are shared among users. However, for certain products, there is often discomfort or distrust in sharing them with others. This usually applies to items in contact with intimate hygiene, such as face masks or incontinence briefs. Despite cleaning processes that ensure rigorously monitoring and thorough removal of contamination, some users may feel more at ease with personal use of such products.

Designing for value: comparing and aligning business models and value propositions

For each reuse model, a BM was created. BM's for shared and personal products showed clear similarities, so they were combined into one canvas for external and another canvas for internal reprocessing. The canvasses are shown respectively in Table 1 and Table 2, with additional notes in same frames distinguishing shared from personal use. Differences between external and internal reprocessing across the three value levels are:

VALUE CREATION: The external reprocessing model requires **additional key partners,** such as laundry and logistics service partners. These external services can be complemented by a Work Integration and Social Enterprise (WISE), that specialises in customised (manual) labour. Internal reprocessing, adds the hospital's responsibility for cleaning and **quality control** of the products (key activities), increasing its workload. This requires additional resources like energy, water, laundry facilities, packaging solutions, storage space, and certifications. Personal products need **tracking** and tracking infrastructure for external and internal reprocessing. When external reprocessing is chosen, the cost for the IT-infrastructure could be divided over multiple hospitals.

VALUE CAPTURE: External reprocessing makes hospitals reliant on the supply chain, while internal reprocessing ensures **self-sufficiency**. With external reprocessing, staff can be sure that the **service partner maintains product quality**, safety and reliability. Additionally, shared products in external systems offer **volume advantages**, as they can be used by different users across multiple hospitals, maximising product use. Lastly, depending on the country, personal products with internal reprocessing may be eligible for (partial) reimbursement of a personal treatment by the patient's health insurance.

Interestingly, the frames for value capture for the planet, and VALUE DELIVERY (channels and customers segments) are similar for internal and external reprocessing, as they align with the overarching goal and remain unaffected by the chosen approach.

Closer analysis of the BM's in Table 1 and 2 reveal that the value propositions are similar. The Systems Value Proposition tool highlights that the most prominent value is created at the organisational level, such as reduced CO2 emissions, resilience to shortages, decreased raw material use, and mindset change. Societal value creation is also significant, including staff flexibility, visibility among colleagues, and shared efforts. At the individual level, value creation is most evident with personal or intimate products, enabling tailored care, improved treatment, and enhanced trust and safety.

Verification study: linking hospital and supplier's perspectives

The co-creation session contributed to a better understanding of the value-chain for a medical product. During the development of an alternative reuse cycle, external and internal reprocessing options were explored.

EXTERNAL REPROCESSING for personal and shared products

Product-as-a-service (with tracking for personal products)

Value creation	Value capture	Value delivery
Key stakeholders *Who are the key partners in the system?* Producer, Social Work Integration Ent., Legislators, Medical personnel, Patient, Logistics partner, Laundry service, Purchaser (tender procedures), Hospital (departments: hygiene, management, logistics)	**Profit** *Potential value captured by organisations* Builds hospital's environmental image, Decreasing waste costs, Decrease purchase cost, Job creation through social work integration **ONLY FOR SHARED PROD.:** Volume advantage	**Customer relationships** *Which relationships need to be maintained to offer the business model?* Delivery of clean products, Reprocessing service, Customer loyalty
Key activities *What is performed to deliver the value proposition?* Stock control and ordering, Collection and transport, Data management, Training (correct use and collection) **ONLY FOR PERS. PROD.:** Tracking	**People** *Potential value captured by individuals, ecosystem and society* Ecosystem society dependence, Qualitative products (comfort), Activation of target groups through job creation, Reliable product, Safety assurance	**Channels** *How do you reach your customer segments?* Experience other hospitals, Raising awareness, Internal consultation, Green deal sustainable care, Exhibitions, Website or (social) media, Sales person, Internal information session
Key resources and capabilities *What resources do you need to deliver the value proposition? (technological, natural resources, energy sources)* Collection recipient, Data infrastructure, Staff (hospital logistics) **ONLY FOR PERS. PROD.:** Tracking infrastructure	**Planet** *Potential value captured by the environment* Decrease in resources/material consumption, Decrease waste and incineration	**Customer segments** *Who are your customers?* Patient, Medical personnel

Table 1. Overview of the business model canvas evaluation for external reprocessing from a hospital's perspective.

INTERNAL REPROCESSING for personal and shared products

Hospital-based-reprocessing (with tracking for personal products)

Value creation	Value capture	Value delivery
Key stakeholders *Who are the key partners in the system?* Producer, Legislators, Medical personnel, Patient, Purchaser (tender procedures), Hospital (departments: hygiene, management, logistics), Waste management company	**Profit** *Potential value captured by organisations* Builds hospital's environmental image, Decreasing waste costs, Decrease purchase cost	**Customer relationships** *Which relationships need to be maintained to offer the business model?* Efficient hospital logistics, Cleaning in minimum time with maximum ease of use, Communication between hospital departments
Key activities *What is performed to deliver the value proposition?* Collection and transport (in and out of storage), Cleaning, Quality control, Data management, Storage, Training (correct use, cleaning and storage conditions) **ONLY FOR PERS. PROD.:** Tracking	**People** *Potential value captured by individuals, ecosystem and society* Ecosystem society independence **ONLY FOR SHARED PROD.:** Access to care for patient due to lower cost **ONLY FOR PERS. PROD.:** A personal health insurance company can be involved for (partial) reimbursement of a personal treatment	**Channels** *How do you reach your customer segments?* Experience other hospitals, Raising awareness, Internal consultation, Green Deal sustainable care, Exhibitions, Website or (social) media, Sales person, Internal information session
Key resources and capabilities *What resources do you need to deliver the value proposition? (technological, natural resources, energy sources)* Energy and water, (Expansion of) laundry dept., Packaging solution, Storage room, Certificates, Data infrastructure, Staff (cleaning, logistics and storage) **ONLY FOR PERS. PROD.:** Tracking infrastructure, A designated storage space is needed for personal items	**Planet** *Potential value captured by the environment* Decrease in resources/material consumption, Decrease waste and incineration	**Customer segments** *Who are your customers?* Patient, Medical personnel

Table 2. Overview of the business model canvas evaluation for internal reprocessing from a hospital's perspective.

The reuse value-chain for *hospital-based-reprocessing* was completed based on input from the co-creation (Figure 2). Notably, the session provided a comprehensive insight into the supplier and producer side. However, it did not enhance our understanding of in-house processes and logistics within hospital departments. This is because the company uses a distributor to supply its product and does not have direct contact with hospitals. Technical, organisational and practical aspects for transitioning to reusable products were identified:

1. VALUE CREATION/DELIVERY: It is generally **easier for distributors to sell** a disposable product because its use is already known to the hospitals. Disposable products provide more margin/sales and an assured purchase flow. At the same time, there is increasing demand from hospitals for durable products. By offering these, the distributor can differentiate themselves positively. However, knowledge on hospital needs are essential to optimise offers.
2. VALUE CAPTURE/CREATION: Reuse in this case can only be achieved by introducing a low-cost auxiliary tool to **ensure hygiene**. Further studies should assess whether this extra activity is acceptable to staff. Technical feasibility should also be **monitored** to ensure patient safety (e.g. counting the reuse cycles).
3. VALUE CAPTURE: Hospitals are currently deterred by the higher price for a reusable product. It is a complex process to correctly estimate price for a reusable product where the price is spread out over multiple uses.

Discussion

This study aimed to identify a fit between hospitals and reuse models, while uncovering valuable insights from the value-chain to facilitate the adoption process of reusable products in healthcare. Each hospital has its own distinct features, such as location, organisational structure, and available infrastructure. Consequently, the hospital must choose the reuse model that suits its context. The purchasing department of the hospital can communicate these context features in a tendering document. To increase the chances that reusable products can be implemented, the hospital should also **include reusability in the tendering process**. Another aspect interesting in the implementation process is the **ownership** of reusable products, as detailed by

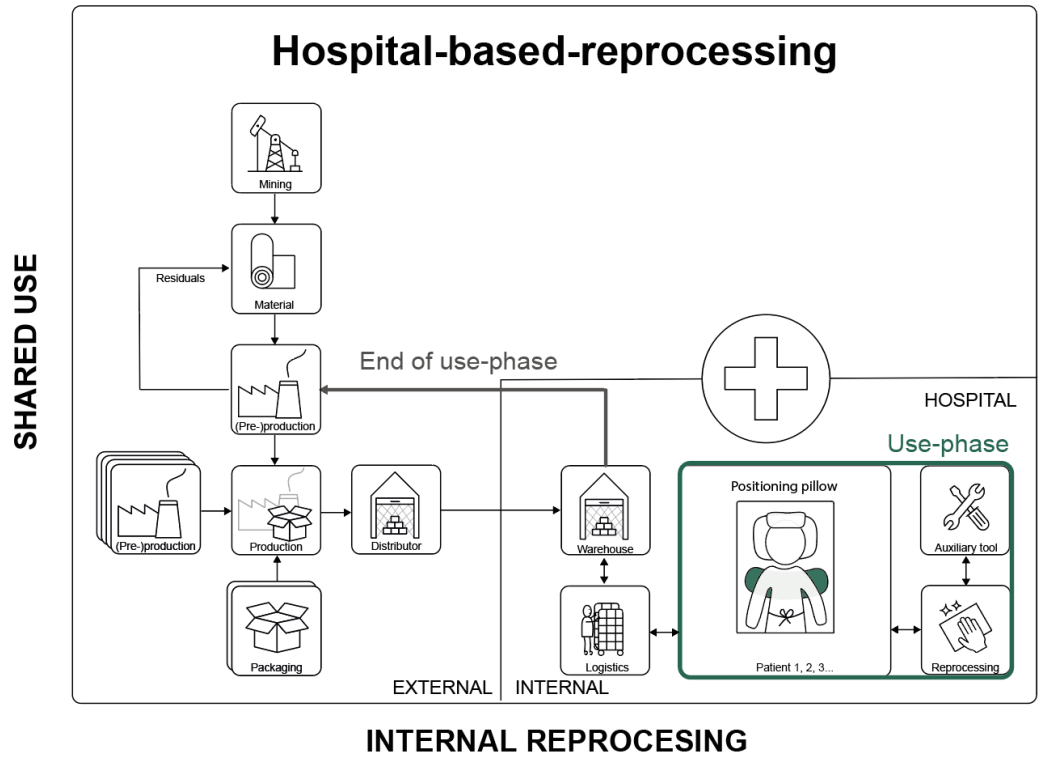


Figure 2. Hospital-based reprocessing model after co-creation. A distributor, different suppliers, recovery of residues, and an auxiliary tool in the use-phase are added to the value-chain.

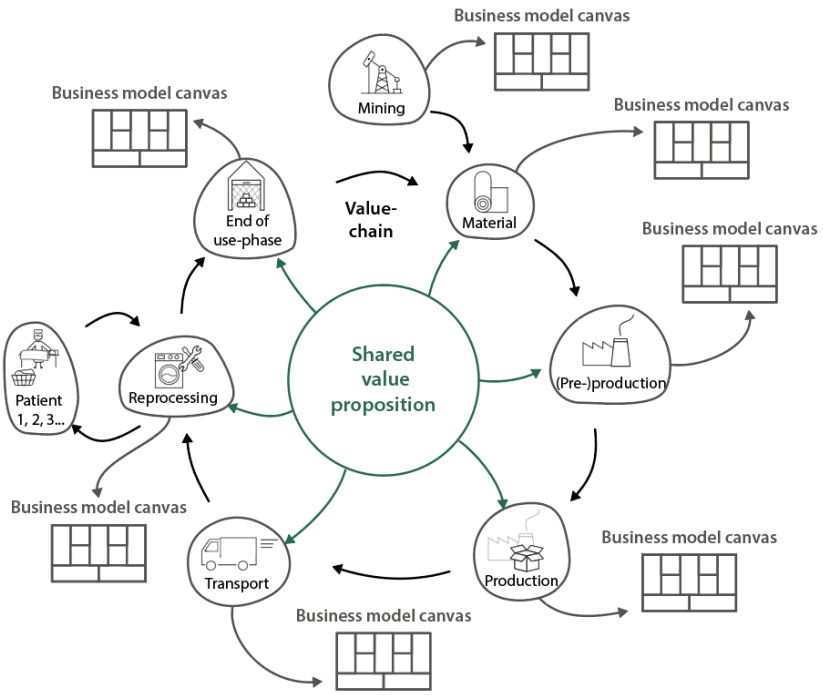


Figure 3 Stakeholders around a shared value proposition

Mahmoudi & Parviziomran (2020). In the case of external reprocessing, hospitals can either lease products owned by the service provider and pay per use, or they can purchase their own reusable products and have them reprocessed by the service partner. Furthermore, to ensure value creation of a reusable medical product, the value-chain is organised around a central, shared value proposition, e.g. the successful reuse of medical (textile) products (Figure 3). This can be a product, service or product-service system (Scholtysik et al., 2023; Tukker, 2015). Each player in the value-chain provides a specific value to another stakeholder, with each holding their own unique BM. To bring a reusable medical product to market, the **desired future value-chain can be mapped out**. This involves considering how the product will reach healthcare institutions and determining the relationships or value exchanges needed between the players within the value-chain. Bressanelli et al. (2019) identified supply chain management challenges for the Circular Economy, suggesting supply chain integration and development of partnerships and trust among partners as a requirement for information sharing. Consequently, knowledge (for every player) on what happens in each step of the value-chain is of critical importance for successful implementation. There are several learnings for the value-chain (manufacturers, reprocessors and potential support partners) that could enhance the introduction and implementation of reusable products. Effective hospital support depends on seamless **collaboration** across the value-chain. For internal reprocessing, collaboration between hospitals and producers is essential, as the producer supplies the reusable products and, where necessary, any supplementary cleaning tools. Ongoing interaction between these partners typically includes training and guidance on proper use and reprocessing methods. For external reprocessing, the primary objective is to reduce the hospital's workload by delivering ready-to-use products through a reprocessing service partner. Manufacturers and reprocessors must coordinate to establish an efficient and consistent cleaning process. Additional partners, such as WISE or automation companies, could further support reprocessing, depending on the nature of tasks involved. For flexible, small-batch cases, WISE partners provide adaptable labor solutions; for high-volume, repetitive cases, automation offers greater efficiency. Collaboration with a WISE enhances local job creation through activation of target groups (these groups typically include individuals with greater distance to the labour market) (Opstal & Borms, 2023). Collaboration across the value-chain could be enhanced

through platforms such as Green Deals at a governmental level (Departement Zorg, 2024), which align industry and government partners toward European Green Deal climate goals (European Commission, 2024). These platforms facilitate initial connections and opportunities for small-scale pilot tests, laying the groundwork for sustainable partnerships in healthcare. Lastly, **product tracking** can offer simplified return processes (Scholtysik et al., 2023), improve coordination among partners and monitor product state and usage. This helps mitigate operational risks and prevent careless behaviour in product usage (Bressanelli et al., 2019). For instance, the number of washing cycles performed or the energy consumed can be tracked and retrieved at any time, supporting effective maintenance though the use of IoT technologies.

Conclusions

In this paper, the goal was to determine whether reusable products in hospitals can be implemented using CBMs for product categories considered less valuable and therefore more challenging to execute as a sustainable business practice. We analysed possible reuse models, along with their respective BM and value proposition. While hospitals play a central role in shaping the reuse model, it is crucial that value-chain partners understand hospital processes and potential challenges. To enrich our insights from the supplier's perspective, we conducted a deep-dive session to address these aspects. The four **reuse models** each have their own advantages, and they can coexist effectively within a single company or hospital. The **choice of the most suitable model** typically depends on hospital-related context such as the location, staffing, the level of responsibility the organisation is willing or able to take on, the volume of product usage, the type of product, and the existing or required infrastructure. Developing reuse models in healthcare **requires close collaboration** between value-chain partners and hospitals, as they share a common value proposition but hold distinct responsibilities. **Hospitals can take a leading role by clearly outlining their specific needs and context**, guiding partners in fulfilling their unique roles. Future research should also consider whether involving a WISE or automation partner could improve value-chain efficiency. Finally, given the importance of collaboration and defined responsibilities among stakeholders, research that is mapping out the specific stakeholders involved in each reuse case could offer valuable insights for a comprehensive overview of the process.

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References

Bressanelli, G., Perona, M., & Saccani, N. (2019). Challenges in supply chain redesign for the Circular Economy: a literature review and a multiple case study. *International Journal of Production Research*, *57*(23), 7395–7422. https://doi.org/10.1080/00207543.2018.1542176

Chauvet, P., Enguix, A., Sautou, V., & Slim, K. (2024). A systematic review comparing the safety, cost and carbon footprint of disposable and reusable laparoscopic devices. *Journal of Visceral Surgery*, *161*(2), 25–31. https://doi.org/10.1016/J.JVISCSURG.2023.10.006

Departement Zorg. (2024). *Green deal: Duurzame zorg*. https://www.vlaanderen.be/green-deal-duurzame-zorg

Drew, J., Christie, S. D., Rainham, D., & Rizan, C. (2022). HealthcareLCA: an open-access living database of health-care environmental impact assessments. *Lancet Planet Health*, *6*, 1000–1012. www.thelancet.com/

Ellen MacArthur Foundation. (2015). *Towards a Circular Economy: Business Rationale for an Accelerated Transition*. https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf

European Commission. (2010). *Verslag van de Commissie aan het Europees Parlement en de Raad Verslag over het hergebruik van medische hulpmiddelen in de Europese Unie, overeenkomstig artikel 12 bis van Richtlijn 93/42/EEG*. https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vj6ipmrzob48

European Commission. (2024). *2050 long-term strategy*. https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

European Union. (2017, April 5). *Regulation (EU) 2017/745 of the European Parliament and*

of the Council of 5 April 2017 on medical devices (MDR). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02017R0745-20240709

Guzzo, D., Carvalho, M. M., Balkenende, R., & Mascarenhas, J. (2020). Circular business models in the medical device industry: paths towards sustainable healthcare. *Resources, Conservation and Recycling*, *160*, 104904. https://doi.org/10.1016/J.RESCONREC.2020.104904

Hoveling, T., Svindland Nijdam, A., Monincx, M., Faludi, J., & Bakker, C. (2024). Circular economy for medical devices: Barriers, opportunities and best practices from a design perspective. *Resources, Conservation and Recycling*, *208*, 107719. https://doi.org/10.1016/J.RESCONREC.2024.107719

Janik-Karpinska, E., Brancaleoni, R., Niemcewicz, M., Wojtas, W., Foco, M., Podogrocki, M., & Bijak, M. (2023). Healthcare Waste—A Serious Problem for Global Health. *Healthcare*, *11*(2), 242. https://doi.org/10.3390/HEALTHCARE11020242

Jones, P., & Van Ael, K. (2022). *Design Journeys though Complex Systems: Practice Tools for Systemic Design*. BIS Publishers. https://www.systemicdesigntoolkit.org/book

Kane, G. M., Bakker, C. A., & Balkenende, A. R. (2018). Towards design strategies for circular medical products. *Resources, Conservation and Recycling*, *135*, 38–47. https://doi.org/10.1016/J.RESCONREC.2017.07.030

Keil, M., Viere, T., Helms, K., & Rogowski, W. (2023). The impact of switching from single-use to reusable healthcare products: a transparency checklist and systematic review of life-cycle assessments. *The European Journal of Public Health*, *33*(1), 56.https://doi.org/10.1093/EURPUB/CKAC174

López-Medina, I. M., Álvarez-García, C., Parra-Anguita, L., Sanz-Martos, S., & Álvarez-Nieto, C. (2022). Perceptions and concerns about sustainable healthcare of nursing students trained in sustainability and health: A cohort study. *Nurse Education in Practice*, *65*, 103489. https://doi.org/10.1016/J.NEPR.2022.103489

Macneill, A. J., Hopf, H., Khanuja, A., Alizamir, S., Bilec, M., Eckelman, M. J., Hernandez, L., McGain, F., Simonsen, K., Thiel, C., Young, S., Lagasse, R., & Sherman, J. D. (2020). Transforming the medical device industry: Road map to a circular economy. *Health Affairs*, *39*(12), 2088–2097. Doi. 10.1377/hlthaff.2020.01118

Mahmoudi, M., & Parviziomran, I. (2020). Reusable packaging in supply chains: A review of environmental and economic impacts, logistics system designs, and operations management. In *International Journal of Production Economics* (Vol. 228). Elsevier B.V. https://doi.org/10.1016/j.ijpe.2020.107730

Opstal, W. Van, & Borms, L. (2023). Work Integration Ambitions of Startups in the Circular Economy. *Social Science Research Network*. https://doi.org/10.2139/SSRN.4253705

Osterwalder, A., & Pigneur, Y. (2010). *Business Model Generation* (T. Clark, Ed.; 1ste ed.). Jhon Wiley & Sons Inc.

Ramos, T., Christensen, T. B., Oturai, N., & Syberg, K. (2023). Reducing plastic in the operating theatre: Towards a more circular economy for medical products and packaging. *Journal of Cleaner Production*, *383*, 135379. https://doi.org/10.1016/J.JCLEPRO.2022.135379

Sattari, S., Wessman, A., & Borders, L. (2020). Business model innovation for sustainability: An investigation of consumers' willingness to adopt product-service systems. *Journal of Global Scholars of Marketing Science: Bridging Asia and the World*, *30*(3), 274–290. https://doi.org/10.1080/21639159.2020.1766369

Scholtysik, M., Rohde, M., Koldewey, C., & Dumitrescu, R. (2023). Designing Business Models for a Citcular Economy. *Proceedings of the Design Society*, *3*, 1347–1356. https://doi.org/10.1017/PDS.2023.135

Switchrs. (2019). *Circular Design Map* . https://switchrs.com/tools/circular-design-map/

Tukker, A. (2015). Product services for a resource-efficient and circular economy – a review. *Journal of Cleaner Production*, *97*, 76–91. https://doi.org/10.1016/J.JCLEPRO.2013.11.049

Vozzola, E., Overcash, M., & Griffing, E. (2018). Environmental considerations in the selection of isolation gowns: A life cycle assessment of reusable and disposable alternatives. *American Journal of Infection Control*, *46*(8), 881–886. https://doi.org/10.1016/J.AJIC.2018.02.002

Yap, A., Wang, K., Chen, E., Melhado, C., Ahmad, T., O'Sullivan, P., & Gandhi, S. (2023). A mixed-methods study on end-user perceptions of transitioning to reusable surgical gowns. *Surgery Open Science*, *11*, 33–39. https://doi.org/10.1016/J.SOPEN.2022.10.003

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Designing a collaborative ecosystem for sustainability transition in the furniture industry: the Opendesk case

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Keywords: Collaborative Ecosystem; Strategic Design; Sustainability Transitions; Furniture.

Abstract: Humanity faces a period of changes, leading to a global transition with unpredictable outcomes. Design can play a key role in guiding society to face these challenges, helping the different socio-technical system stakeholders cope with the sustainable transition. The change towards more sustainable economic and social systems requires the design of products and services and new business models and integrated systems that deliver them. This implies shifting from individual company thinking towards coalitions and partnerships like collaborative ecosystems.

The furniture industry is facing a sustainable transition, therefore, companies and the market are experimenting with new approaches, including collaborative ecosystems. Because of this, it is important to understand how design can contribute to the definition, creation, and development of a collaborative ecosystem for sustainable transition in the furniture industry. The article adopts the single case study methodology, proposing the analysis of Opendesk, a furniture delocalised network.

The research shows how the design mindset has enabled Opendesk to create a collaborative, scalable, and resilient business that values stakeholders in the system and local production. It was possible to address the challenges of building and maintaining a community and network, creating engagement through design. Through the design mindset in the creation of a collaborative ecosystem, it was possible to help local manufacturers to be efficient and economically viable, allowing customers to contribute to the local economy and value. The case study shows the potential of design to catalyse relationships for fruitful collaborations between stakeholders with different goals and provide systemic innovations.

Introduction

The historical period underway is characterised by transformative changes, defined as the Anthropocene, i.e. an era where natural processes at different levels have been impacted by human activities (Crutzen & Stoermer, 2000). This has generated a period of multi-level changes that has led humanity to a global transition, with uncertain outcomes depending on how environmental, economic and social persistent problems are solved (Raskin et al., 2002). These issues concern societal needs and are intertwined with different domains and stakeholders, demanding innovations aimed at sustainability (Rotmans & Loorbach, 2008). In this panorama of transitions, companies represent a fundamental asset for socio-technical systems, as they provide cultural innovation and social well-being and satisfy needs through their products and services (Mosca et al., 2015).

The design discipline can play a key role in helping to address social and business issues of sustainable transitions through design principles (Van Selm & Mulder, 2019). Indeed, transitions towards more sustainable economic and social systems require designing products and services and experimenting with new business models and integrated (eco)systems to offer them (Bocken et al., 2019). Therefore, sustainable design theory is connected to business concepts beyond the individual company, leading to coalitions of organisations working together for change, i.e. collaborative ecosystems (Manzini, 2017). The design of a collaborative ecosystem implies a strategic and systemic effort aimed at testing solutions for sustainable change of entire sectors (Konietzko et al., 2020).
Because of this, it becomes necessary to create customised solutions that look at specific markets. The furniture industry represents an

important sector of the European economy. Nowadays, it faces numerous environmental challenges and is going through a period of transition towards sustainability (Forrest et al., 2017). Furniture companies are exploring different approaches to achieve sustainability and circularity goals, which makes this sector fertile for new analysis and experimentation.
With this in mind, it becomes necessary to understand how design can support furniture industry stakeholders in an economic, organisational and social transition. Therefore, this article aims to answer the question: How can design contribute to defining and creating a collaborative ecosystem in the furniture sector that is driven by the objective of sustainable transition?
To answer this question, the article adopts the single case-study methodology, proposing the analysis of Opendesk. Through the case study, it will be possible to highlight the role of design in creating and developing it and address the barriers that arise.

New models of inter-organisational collaboration in business

In recent years, the business sector has changed. An increasing number of firms have adopted the concept of shared value creation (Porter & Kramer, 2011) and positioned themselves as purpose-driven organisations (Gartenberg, 2021). This change influences the innovation approaches and growth mechanisms in current business practices. Due to the complexity of many of the world's urgent problems, creating and implementing needed solutions require diverse expertise, scalable business models, and inter-organisation collaborations for the private sector. No company could operate isolated and tackle system-wide changes; each exists within an ecosystem where various actors collaborate to achieve a collective impact (Angus-Leppan et al., 2010; Kania & Kramer, 2011). Therefore, the success of implementing new business models for companies also relies on the establishment of collaborative capacities across organisations to co-develop and co-shape the ecosystem (P. Brown et al., 2019). The concept of ecosystems is highly linked to strategic innovation and business models. A "macro" business model, is a collaboration between multiple organisations that create a value network and achieve a competitive advantage by co-delivering value propositions (Talmar et al., 2020). A collaborative shared value at the ecosystem level with governments, social sector, and competitors is essential to guarantee both the corporates' business success and the social progress of society. In this way, companies can effectively tackle complex social issues, leading to sustainable economic opportunities and a redefined role for business in society (Kramer & Pfitzer, 2016).

Design for collaborative ecosystem towards sustainability

Design is well suited to facilitating the understanding of complex systems (Hill, 2017). Buchanan's four orders of design (2001, 2015) serve as a foundational theoretical framework for understanding the different levels of scopes of design problems and practices. This framework not only categorises the evolution of the design discipline but also opens the potential for design to expand its scope into emerging fields and research domains. Over the past decades, design thinking (T. Brown, 2008; Dorst, 2011) has been increasingly acknowledged in both academic research and professional practice as a distinct cognitive framework for creative problem-solving and leading to business success. Design is often considered a process, method, and strategic tool for building organisational capacities and supporting companies in effectively framing and implementing their innovation strategies and activities. In business, design is often defined as a way to understand and manage complex social, environmental, and political problems. Irwin (2018) proposed the concept of Transition Design, proposing a framework to design for system-level change, fostering positive changes toward more sustainable and desirable futures. She developed a methodology and process for designers, stakeholders and organisations to work collaboratively and closely. The discussion of design's role at the systemic and ecosystemic level is also present in the significant framework of Design for Sustainability (Ceschin & Gaziulusoy, 2019). At the socio-technical system level, design concentrates on intervening in large-scale systemic changes, integrating technological innovations, societal norms, policies, and infrastructures to facilitate sustainability transitions.
The transition to new societal or economic systems, such as a circular economy, requires the systemic design approach to strategically define and deliver new products, services

systems, and business models, as well as establish the conditions and collaborative capacities among organisations at the system level (Baldassarre et al., 2019). The current literature on collaborative ecosystem design explores strategies for fostering inter-organisational interactions aimed at transforming entire industries and markets to support the transition toward sustainability (Talmar et al., 2020). Literature extends beyond a firm-centric perspective to integrate with broader networks and systems. Design-driven collaboration can creatively address complex, systemic challenges within innovation ecosystems, emphasising the importance of engaging diverse stakeholders in co-creative processes to develop effective, sustainable, innovative solutions (Quint, 2024). This facilitates the formation of coalitions of organisations collaboratively advancing the transition toward sustainable development (Manzini, 2017). Conversely, the collaborative ecosystem design approach requires designers to embrace a systemic-shifting mindset to carry out their practices (Drew et al., 2022).

Methodology

The case study methodology was adopted to understand how design can contribute to the realisation of a collaborative ecosystem in the furniture industry. Since the research question focuses on 'how' and complex organisational issues, it was considered appropriate to analyse a single case study in detail and develop theories (Yin, 2013) for the furniture sector. Indeed, individual case studies have the potential to investigate complex phenomena in specific contexts and clarify the relationships between constructs and actors (Siggelkow, 2007). Sample selection becomes crucial from this perspective, as the case study must be selected to provide a unique perspective and insight (ibid.).

In this research, the sampling strategy involved an initial phase of case study analysis in the furniture sector at large (Figure 1). Here, the companies that offered products and services or had business models oriented towards sustainability and CE were identified. Subsequently, these were re-analysed to identify firms whose value proposition was based on cooperation with other stakeholders and the collaborative ecosystem. Among these, Opendesk offers a unique perspective. Its offering is based on a network of partnerships with workshops and local manufacturing companies, without which it could not produce the furniture. Through this, Opendesk aims to counter a massified market with global shipments and build a distributed and ethical supply chain.

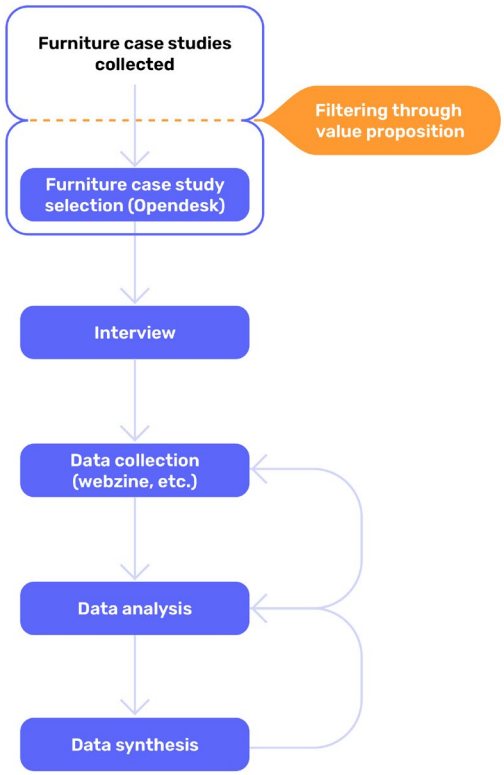


Figure 1: Research process adopted

Once the case study was identified, emphasis was placed on collecting data from multiple sources of information. First-hand data were collected through a semi-structured interview conducted online with an elite company member (Harvey, 2011), i.e. a figure with a strategic overview of the design and production process. As Opendesk is a micro-business, the interviewed figure holds multiple roles in the company, is the CEO, and performs design and supply chain management functions. The interview aimed to highlight the role of design during the experience of creating and scaling up the Opendesk collaborative ecosystem. The interview lasted 1 hour 15 min, and with the interviewee's consent, it was recorded, transcribed, edited to make it easier to read, and finally verified by the interviewee. The interview was complemented with desk research to eliminate bias and facilitate data triangulation. Second-hand data were collected using grey and company literature (e.g.,

company website, magazine and webzine articles).
The information collected was analysed and synthesised to create a coherent narrative of the findings. In particular, the interview was analysed using content analysis to facilitate categorising qualitative textual data into conceptual categories to identify relationships between variables and themes (Harwood & Garry, 2003; Julien, 2008), in this case, between design and collaborative ecosystem. The conceptual categories were first based on what has been defined in the literature, correlating concepts in sustainability and strategic/systemic design, focusing on shared value proposition, collaboration and stakeholder involvement, barriers and enablers. These categories were revised or confirmed after data interpretation. To increase the robustness of the results, the categories and findings were discussed by the authors and afterwards validated by the respondents (Goffin et al., 2019).

Results and discussions

The data highlighted the potential of design in facilitating the creation, implementation, and development of a collaborative ecosystem in the furniture industry, primarily using design at the strategic, tactical, and operational levels. In addition, the interview revealed four main barriers and enabling factors of sustainability transition in which design can play a role. Therefore, this section first describes the Opendesk collaborative ecosystem; then, the results are analysed following two macro clusters [1;2]. Figure 2 emphasises the barriers and connections to the design mindset.

A brief overview of the Opendesk collaborative ecosystem

Opendesk is an online furniture marketplace that connects customers to local makers, creating scalable local manufacturing processes worldwide. The business concept is based on the design for digitalisation; indeed, virtual files can travel the world faster and sustainably than a real piece of furniture. For this reason, the company does not possess any means of production and does not mass-produce furniture in a centralised manner to be shipped worldwide. Instead, it creates partnerships with local workshops to make the products. Because of this, the company relies on principles of trust and flexibility with its manufacturing partners, which do not have to possess a specific machine model but understand the process and the objectives. Hence, the company defines itself as a design-led, value-driven brand based on ethical and social objectives.

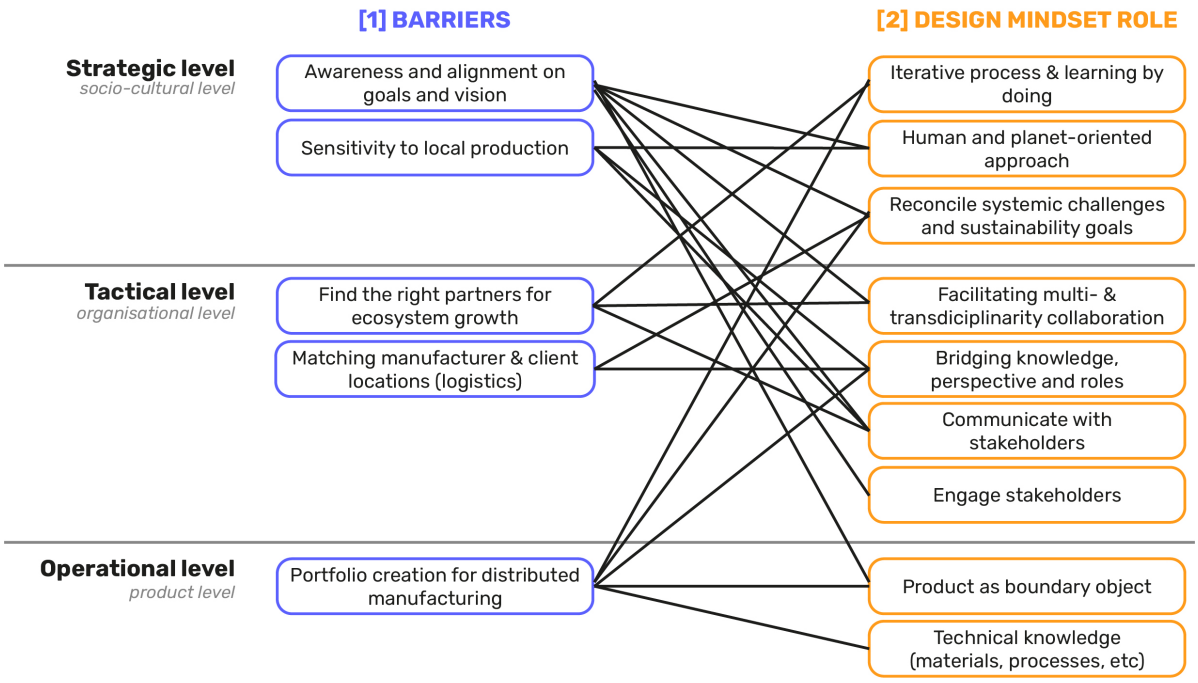


Figure 2: Barriers and the role of design emerging from the results of the case study analysed

Opendesk brings value to local businesses by giving them visibility, improving their efficiency, and connecting them with customers who contribute to their economic sustainability. On the other hand, customers receive local products manufactured according to sustainability standards. For this reason, the partnership principle allows Opendesk to expand and shrink as needed, to experiment in new markets without fear of failure, and not look at the company's growth merely on profit.

[1] Barriers to the establishment of a collaborative ecosystem in the furniture sector

Thanks to the interview, it was possible to highlight the company's barriers while establishing and scaling its collaborative ecosystem. Four can be summarised, varying in breadth of scope, ranging from socio-cultural, organisational and economic barriers to product design.

One of Opendesk's first challenges was to design furniture that could be produced with any machinery and software in different parts of the world. For this reason, there was a continuous and fruitful dialogue with the workshops, through which it was possible to define a design language, standard elements (i.e. panel dimensions, metal fixings, components, finishes) and guidelines the designers must follow. Thanks to this effort, it was possible to develop a portfolio capable of accommodating and enhancing the different capabilities of local manufacturers worldwide.

Logistics was another challenge for Opendesk's collaborative ecosystem. Indeed, a decentralised production hides the need to rely on various organisations and associate each order with a specific supplier, matching both geographical locations and complicating the logistics. Linking customer demand to local production required frameworks to manage cost, efficiency, communication and quality without relying on traditional economies of scale. Therefore, Opendesk has developed bespoke software based on a multi-step process to deal with this problem while at the same time enhancing the dialogue with the customer and local manufacturers, acting as a bridge and relying on a proprietary database. Thus, to govern a collaborative ecosystem, setting up a flexible system and efficient communication channels becomes crucial to govern unpredictability and complexity.

Deciding to decentralise production, not owning the production means, and the ethical values underpinning the collaborative ecosystem have hindered the company's growth. On the one hand, ethical values have led to investor selection - identifying only those aligned with the company's philosophy - on the other hand, the efficient use of resources also has a significant impact. In this regard, the company collaborates with local manufacturers to find efficient solutions.

In large collaborative ecosystems, such as Opendesk, each stakeholder has different priorities and levels of understanding of the collaborative model; therefore, raising awareness among the manufacturing partners and customers about the benefits of this model required targeted efforts to communicate its value and benefits. Aligning ethical visions with economic aspects required strong commitment and consideration regarding investments, especially since profit was not the sole objective.

The consequence of a local manufacturer ecosystem is minor differences in products. This is why Opendesk also aims to propose a cultural change where these differences are enhanced, highlighting the value of local manufacturing and sustainable consumer choice. "*Our challenge was to show these differences as a strength, this means you're making a choice as a consumer*". From this perspective, Opendesk's actions attempt to act on the socio-technical system, linking innovations in production models with a more sustainable consumption model.

[2] Role and application of the design mindset at different levels

From the Opendesk experience, it is possible to highlight how design played a crucial role in the mindset with which the collaborative ecosystem's various steps of conceptualisation, implementation and development were approached. By design mindset, we mean a way of thinking and acting typical of the designer, which values curiosity and exploration, broad observational (ethnographic and ecological) insight, interdisciplinarity, as well as empathy, collaboration, and the ability to embrace and deal with uncertainty and complexity (Dong, 2015; Papile, 2022; Zurlo, 2022; Lavrsen et al., 2024). More specifically, this affected the strategic, tactical, and operational levels.

At a strategic level, the design mindset allowed Opendesk's founders to approach the process of ecosystem creation using an iterative process. This allowed them to move forward and learn by doing (also mistakes), adjusting their focus until reaching optimal solutions. This can be seen in the company's first steps, taken initially on familiar territory and then scaled up to foreign ones, but also in the failure to open up to a foreign market with different logic. Moreover, the design mindset allowed the founders to focus on human and planet-oriented aspects to put these values at the core of the shared value proposition. "*If something's made locally, it has the benefit of local employment, then also brings other benefits. Something made locally benefits the economy, also benefits the environment and travels a short distance*". This is because the designer, prone to collaboration with various disciplines, naturally becomes the carrier of values and aspects of sustainability and ethics, enhancing them and placing them at the centre of his actions (Papile, 2022). Thanks to its approach and mindset, design can be a strategic catalyst for systemic change. It can help to create and sustain collaborative ecosystems, underscoring the importance of an iterative and uncertain path and balancing the needs of different stakeholders (human and non-human). This adaptability demonstrates how design can reconcile systemic challenges with sustainability goals, offering a pathway for other organisations aiming to innovate in complex contexts.

On a tactical level, the mindset and design skills have translated into the need and ability to engage stakeholders and the value chain. As mentioned, the designer is trained and prone to multi- and trans-disciplinarity, collaborating with different figures to integrate knowledge within a project. This translates into involving stakeholders and making them feel part of the process, communicating with different figures, and creating consensus around a common idea or objective. For Opendesk, this meant creating partnerships with local workshops, involving them by respecting their capabilities, giving them value (intellectual and economic) and acting as a bridge and mediator. "*We're trying not to dictate the process, but we're trying to control the outcome, and we're trying to support them and make sure that they're fully aware*"

Design also contributed to the operational level by designing and understanding materials, products, and processes. In particular, the product is a *boundary object* (Oswick & Robertson, 2009) for Opendesk, the local manufacturers and customers; it serves as a medium for dialogue and facilitating connections at a systemic level (like partnerships, logistics, online platform). The product acted as a trojan horse to initiate a dialogue with local manufacturers within their comfort zone, i.e. the product. In addition, capabilities and knowledge about materials, production processes, digital manufacturing, and generative processes also had a direct influence.

Conclusions

The Opendesk case study allowed us to emphasise the transformative potential of design in shaping collaborative ecosystems. The design mindset provides the necessary flexibility to deal with complex processes and systems to develop sustainable organisation and collaboration. Moreover, in practical terms, Opendesk embodies the values of Transition Design, providing a relevant case study to the academic community. By fostering resilience through scalable operations and leveraging localised resources, businesses can reduce environmental impact while enhancing adaptability. In addition, creating stakeholder networks highlights the importance of building shared values and trust, essential for sustaining collaborative relationships over time. The mindset and skills of the design(er) are also crucial in this, thanks to its interdisciplinary, communicative and mediation capabilities. Finally, Opendesk's efforts to redefine consumer perceptions and promote alternative consumption models underline the role of design in driving broader systemic change, influencing both industry practices and societal behaviour toward sustainability.

To validate the results and considerations drawn from this case study, future research may analyse similar collaborative ecosystem case studies, exploring different industries and markets also looking at different point of view from different stakeholder in the same ecosystem. In addition, future research could investigate the role of design in changing companies and ecosystems, which, unlike Opendesk, have integrated sustainability values over time, changing their nature.

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References

Angus-Leppan, T., Benn, S., & Young, L. (2010). A sensemaking approach to trade-offs and synergies between human and ecological elements of corporate sustainability. *Business Strategy and the Environment*, *19*(4), 230–244. https://doi.org/10.1002/bse.675

Baldassarre, B., Calabretta, G., Bocken, N., Diehl, J.-C., & Duygu, K. (2019). The evolution of the Strategic role of Designers for Sustainable Development: Academy for Design Innovation Management Conference 2019. In E. Bohemia, G. Gemser, C. de Bont, N. Fain, & R. Assoreira Almendra (Eds.), *Academy for Design Innovation Management Conference 2019* (Vol. 2, pp. 1–15). Academy for Design Innovation Management.

Bocken, N., Boons, F., & Baldassarre, B. (2019). Sustainable business model experimentation by understanding ecologies of business models. *Journal of Cleaner Production*, *208*, 1498–1512. https://doi.org/10.1016/j.jclepro.2018.10.159

Brown, P., Bocken, N., & Balkenende, R. (2019). Why Do Companies Pursue Collaborative Circular Oriented Innovation? *Sustainability*, *11*(3), Article 3. https://doi.org/10.3390/su11030635

Brown, T. (2008). Design Thinking. *Harvard Business Review*, *86*, 84–92, 141.

Buchanan, R. (2001). Design Research and the New Learning. *Design Issues*, *17*(4), 3–23. https://doi.org/10.1162/074793601526810056

Buchanan, R. (2015). Worlds in the Making: Design, Management, and the Reform of Organizational Culture. *She Ji: The Journal of Design, Economics, and Innovation*, *1*(1), 5–21. https://doi.org/10.1016/j.sheji.2015.09.003

Ceschin, F., & Gaziulusoy, İ. A. (2019). *Design for Sustainability: A Multi-level Framework from Products to Socio-technical Systems*. Routledge. https://doi.org/10.4324/9780429456510

Crutzen, P. J., & Stoermer, E. F. (2000). The International Geosphere–Biosphere Programme (IGBP): A Study of Global Change of the International Council for Science (ICSU). *Global Change Newsletter*, *41*, 17–18.

Dong, A. (2015). Design × innovation: Perspective or evidence-based practices†. *International Journal of Design Creativity and Innovation*, *3*(3–4), 148–163. https://doi.org/10.1080/21650349.2014.943294

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies*, *32*(6), 521–532. https://doi.org/10.1016/j.destud.2011.07.006

Drew, C., Winhall, J., & Robinson, C. (2022). System-Shifting Design: An emerging practice explored. *Proceedings of Relating Systems Thinking and Design*. RSD11, Brighton, UK.

Forrest, A., Hilton, M., Ballinger, A., & Whittaker, D. (2017). *Circular Economy Opportunities in the Furniture Sector*. European Environment Bureau.

Gartenberg, C. M. (2021). *Purpose-Driven Companies and Sustainability* (SSRN Scholarly Paper 3786823). Social Science Research Network. https://doi.org/10.2139/ssrn.3786823

Goffin, K., Åhlström, P., Bianchi, M., & Richtnér, A. (2019). Perspective: State-of-the-Art: The Quality of Case Study Research in Innovation Management. *Journal of Product Innovation Management*, *36*(5), 586–615. https://doi.org/10.1111/jpim.12492

Harvey, W. S. (2011). Strategies for conducting elite interviews. *Qualitative Research*, *11*(4), 431–441. https://doi.org/10.1177/1468794111404329

Harwood, T. G., & Garry, T. (2003). An Overview of Content Analysis. *The Marketing Review*, *3*(4), 479–498. https://doi.org/10.1362/146934703771910080

Hill, D. (2017). *Dark Matter and Trojan Horses: A strategic Design Vocabulary* (3rd Ed.). Strelka Press.

Irwin, T. (2018). The Emerging Transition Design Approach. In C. Storni, K. Leahy, M. McMahon, P. Lloyd, & E. Bohemia (Eds.), *Design as a catalyst for change—DRS International Conference 2018*. https://doi.org/10.21606/dma.2017.210

Julien, H. (2008). Content Analysis. In L. Given (Ed.), *The SAGE Encyclopedia of Qualitative Research Methods* (pp. 120–121). SAGE Publications.

Kania, J., & Kramer, M. R. (2011). Collective Impact. *Stanford Social Innovation Review*, *9*(1), 36–41. https://doi.org/10.48558/5900-KN19

Konietzko, J., Bocken, N. M. P., & Hultink, E. J. (2020). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, *253*, 119942. https://doi.org/10.1016/j.jclepro.2019.119942

Kramer, M. R., & Pfitzer, M. W. (2016). The Ecosystem of Shared Value. *Harvard Business Review*.

Lavrsen, J. C., Carbon, C.-C., & Daalhuizen, J. (2024). Developing design mindset: How individual and contextual factors influence the development of design mindset through method teaching. *Journal of Engineering Design*. Scopus. https://doi.org/10.1080/09544828.2024.2419316

Manzini, E. (2017). Designing coalitions: Design for social forms in a fluid world. *Strategic Design Research Journal*, *10*(2), Article 2. DOI: 10.4013/sdrj.2017.102.12

Mosca, F., Tamborrini, P., & Casalegno, C. (2015). Systemic Design: How to Compete by Leveraging the Value System. *Symphonya. Emerging Issues in Management*. https://doi.org/10.4468/2015.2.04mosca.tamborrini.casalegno

Oswick, C., & Robertson, M. (2009). *Communicating Knowledge: Boundary Objects as Texts*. 20th International Academy of Business Disciplines Meeting, St Louis, USA.

Papile, F. (2022). *OSMOSIS Methods and tools to reframe material selection. A cooperative approach for idustrial companies towards sustainable transition.* Politecnico di Milano.

Porter, M. E., & Kramer, M. R. (2011). Creating Shared Value. *Harvard Business Review*.

Quint, E. (2024). Collaborative Creativity: A design approach to systemic challenges navigating the innovation ecosystem. *Journal of Innovation Management*, *12*(2), Article 2. https://doi.org/10.24840/2183-0606_012.002_L001

Raskin, P., Banuri, T., Gallopín, G., Gutman, P., Hammond, A., Kates, R., & Swart, R. (2002). *Great Transition: The Promise and Lure of the Times Ahead* (SEI PoleStar Series Report No. 10).

Rotmans, J., & Loorbach, D. (2008). Transition management: Reflexive governance of societal complexity through searching, learning and experimenting. In J. C. vd Bergh & F. R. Bruisma (Eds.), *Managing the Transition to Renewable Energy* (pp. 15–46). Edward Elgar Publishing.

Siggelkow, N. (2007). Persuasion With Case Studies. *Academy of Management Journal*, *50*(1), 20–24. https://doi.org/10.5465/amj.2007.24160882

Talmar, M., Walrave, B., Podoynitsyna, K. S., Holmström, J., & Romme, A. G. L. (2020). Mapping, analyzing and designing innovation ecosystems: The Ecosystem Pie Model. *Long Range Planning*, *53*(4), 101850. https://doi.org/10.1016/j.lrp.2018.09.002

Van Selm, M., & Mulder, I. (2019). On transforming transition design: From promise to practice. *Conference Proceedings of the Academy for Design Innovation Management*. Research perspectives in the era of transformations, London, UK. https://doi.org/10.33114/adim.2019.03_323

Yin, R. K. (2013). *Case Study Research: Design and Methods* (5thed ed.). SAGE.

Zurlo, F. (2022). Le strategie del desiderio. In *Il cucchiaio e la città*. Electa.

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No Product Lifetime! Why products fail pre-consumer

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Abstract: Approximately 40% of new product introduction fail when entering the market. Thus valuable resources are spent producing products that never achieve a product lifetime with any users. Companies tend to remove products from their portfolio because of poor sales figures or because they are no longer representing the company's strategies, but they do so without reflecting on why these exact products failed. This tendency might lead to products repeating the same mistakes that are destined to fail. The purpose of this paper is to investigate failed products from small Danish design companies in order to learn from these mistakes and prevent them from happening again. Factors leading to product failure have been studied by analyzing 35 specific products from two small Danish design companies. By examining the companies' own reasons for discontinuing these products, the study identifies key contributing factors, including portfolio management, product insecurities, and reliance on existing product success.

Keywords: Product lifetime; Failure; Design; Framing.

Introduction

Predicting whether a new product will succeed or fail in the market can be challenging. According to Cooper (2017) approximately 40% of new product introduction fail when entering the market. Thus, valuable resources are spent producing products that never reach a consumer. However, businesses continue to overlook their high failure rates producing products that will have no product lifetime with any users.

Given this high failure rate, it remains crucial to investigate the reasons for these failures. Approaching failures constructively and extracting lessons from them, rather than merely tolerating them, can significantly boost product lifetime and future development (Cooper, 1976; Danneels and Vestal, 2020).

Product failures have evolved from being assessed regarding by financial parameters only (Cooper, 1976), to include other aspects. Edmondson (2011) categorized a spectrum of failures into three categories: 1) in routine operations due to deviations from specifications, 2) unavoidable ones in complex systems resulting from unique combinations of factors, and 3) intelligent ones, defined by small-scale failures that test hypothesis and provide information to improve.

Furthermore, Edmondson (2011) stresses the fact that failures are context-specific. In this vein scholars show how the design and adapting the product to the present context is a key element of product success, as in the example of the redesign of the MINI Cooper (Laursen and Barros, 2022).

Considering these premises, research on failure is a fertile ground requiring investigation on case-studies that provide context-specific knowledge that can then be generalized into product categories, industries, design strategies, business models or other defining factors.

This paper takes it offset in the Danish interior design industry. More specifically, in understanding the main reasons why products categories, such as furniture, lighting and interior accessories are removed from companies' portfolios. The study is based on in-depth case studies and analysis of 37 discontinued products from Danish design companies. Data collection includes semi structured interviews with decision-makers from the companies.

The dimensions of failure

Based on a quantitative study comprising 150 industrial product firms, Cooper (1976) determines the reasons and causes of product failure can be summarised into 1) general reasons, 2) specific causes, and 3) latent causes, all relating to each other. First, general reasons encompass excessive investment and development costs and poor sales or poor profit margins when the product is on the market. Second, specific causes describe the causes that led to the general reasons, that is, the

causes for excessive development costs, for low sales and for low profit margins. Examples include the premature launching of a product, the price of the product being higher than what the customer would be willing to pay, misfit of customer requirements or competitive market with similar alternatives. Third, latent causes are activities or resources that describe the deficiencies. Lack of user-research, that may lead to technical difficulties with product, new legislation or lack of marketing research skills or personnel are factors influencing failure under this tier.

Building on this, Hopkins (1981) identified the major weakness influencing product failures as marketing variables. The author emphasizes poor market research as one of the main factors leading to product failure. Inability to cope with technological development of competitors and proper timing for launching the product are the other main causes for failure.

Later Cooper and Kleinschmidt (1987) extended their research to investigate product performance is to understand the factors that separate success from failure. In the study, they studied success vs. failure by analysing 203 new products both containing commercial success and failures. By reviewing past studies and literature ten hypotheses of factors as to why products succeeded were derived and tested. Nine out of the ten hypotheses were found to have an impact on product success.

The top three factors were product advantage, proficiency of predevelopment activities, and protocol. 1) Product advantage describes the unique features that the product offers the customer such as high quality, degree of innovation, and ability to solving a problem. 2) Proficiency of predevelopment activities describes a set of up-front activities such as market and marketing research, technical assessment, and business/financial analysis. 3) Protocol characterises the clear definition of both problem and solution space for product development. In this regard, addressing customer's needs, wants and preferences through a precise product specification and requirements leads to a higher degree of success.

While there are different parameters to assess product success and failure, other studies link the factors to managers involved in decision-making and their respective level of expertise (Rothwell, 1972) and the fit level between company and developed product (Kulvik, 1977).

Existing research has focused more on quantitative studies with few qualitative insights to illustrate examples in the defined categories. However, when considering Edmondson's (2011) premise that failures are context-specific, we can identify a common gap in the literature which is the absence of case-studies in specific product categories or product typologies. Furthermore, most studies come from management, business or production engineering disciplines and not from a product design perspective. Accordingly, this study aims to address this gap by investigating the causes that lead to the decision of product managers in design firms to remove a product from the company portfolio, which, under this framework is considered a failure.

Design DNA

The design DNA is defined as a set of core frames that explicitly capture and reveal the priorities of the design (Haase and Laursen, 2019). The design DNA explicitly encapsulates the conceptual structure across various dimensions of products, including expression, market positioning, technology, and user experience. It is the design DNA that makes the product feel and appear like an Apple product, or the upgrade of the new MINI as being in family with the original MINI Cooper (Laursen and Barros, 2022).

Research on design expertise highlights design processes and practices (Tollestrup et al, 2003), when tasked with developing long lasting products, must ensure strategic alignment with users, the market, and the company. Successful product creation demands meeting user needs, aligning with market demands for sustained competitive-ness, and reinforcing the company's brand and credibility (Haase and Laursen, 2022). Recent analysis involving LEGO Scala and Belville indicate that deviations from a company's design DNA can lead to product failure and subsequent market retreat following launch (Haase and Laursen, 2022).

Methodology

In order to verify what factors influence the decision of considering a product a failure and therefore removing it from the company's portfolio we pursued a qualitative study on two Danish design companies. Both companies sell interior products including furniture, lighting, diverse interior furnishing such as rugs, mirrors, magazine holders, vases, and candle holders.

Company 1 is a medium-sized company, designing furniture and interior products, and selling them in countries all over the world, through several distribution channels. The design and development, marketing, and sales are all in-house. The company is run by two owners who are the primary decision-makers. They have the final say when failed products are removed from the portfolio.
Company 2 is a small international company, also designing furniture and interior products, sold primarily through online sale channels. The company consists of two decision-makers and two committee members. The company employs external designers. Company 2 strategy from development to launch includes a meeting held every six months to evaluate new product launches and to determine if any of the existing products should be removed from the portfolio. These argumentations are based on measurable factors, such as turnover, revenue, product category, and the sales prices. If these expectations are not met, the product is considered a failure.
The data collection can be divided into two main phases. The first included an assessment of both companies' product portfolios to understand further product features and design DNA's. In total, 15 products from Company 1 and 22 from Company 2 have been analysed. The second phase aimed at understanding the decision-making process behind failed products. Failed products were selected based on poor sales performance, with at least one of the following criteria needing to be met: the product had already been or was planned to be removed from the portfolio, or its sales numbers were significantly lower than those of a similar product. Studying these failed products provided insights into the factors contributing to their lack of success, helping to identify common patterns and potential areas for improving product lifetimes.
Semi-structured interviews were performed to understand the reasons behind low sales or removing a product from the portfolio, and the company's reflection on those products. The chosen failed products formed the basis of the semi-structured interview with company employees. The person being interviewed was given images of the specific company's failed products. The employees reflected on each of the selected failed products. During the interview they had the opportunity to express their opinions and were allowed to list numerous possible reasons for failure. Throughout the interview, follow-up questions have been used to elaborate further. Only one person is interviewed at a time to ensure that their reasons are not tainted by the viewpoint of another. We conducted interviews with decision-makers, lead designers, lead marketers, and lead salespeople.
To limit the inaccuracy of misleading information, a selected number of employees from the companies have been selected. Panne et al. (2003) state that when a person is "a part of a failed product, you may take it personally when confronted" and, as a result, this might lead to other reasons being described rather than the real cause of failure. In order to account for this, interviews with staff who were not involved in the design process of the failed products have also been conducted. All interviews were recorded and transcribed.

Lessons from failure

Figure 1 summarizes all the failure causes identified in this study. While external competition, inadequate functionality, and market processing information have been previously discussed in theory, four factors – misfit with the company's design DNA, extending a successful product, internal competition, and lack of joint reflection on failure – have not been explicitly defined.
The observed failure causes can be defined within the category described by Cooper (1976) as specific causes. Furthermore, considering Kulvik's (1977) definition of the fit level between company and developed product, we detail three identifiable insights. We observed that there are reasons that relate to misalignments with the company's design DNA; products that compete with existing products, that is, internal competition; and the extension of an existing product. Another cause for failure relates to the lack of joint reflection about what is failure, amongst employees from different levels of the hierarchy. Not pursuing this, does not provide formalised knowledge to emerge and that is likely to prevent the repetition of the same patterns in the future.

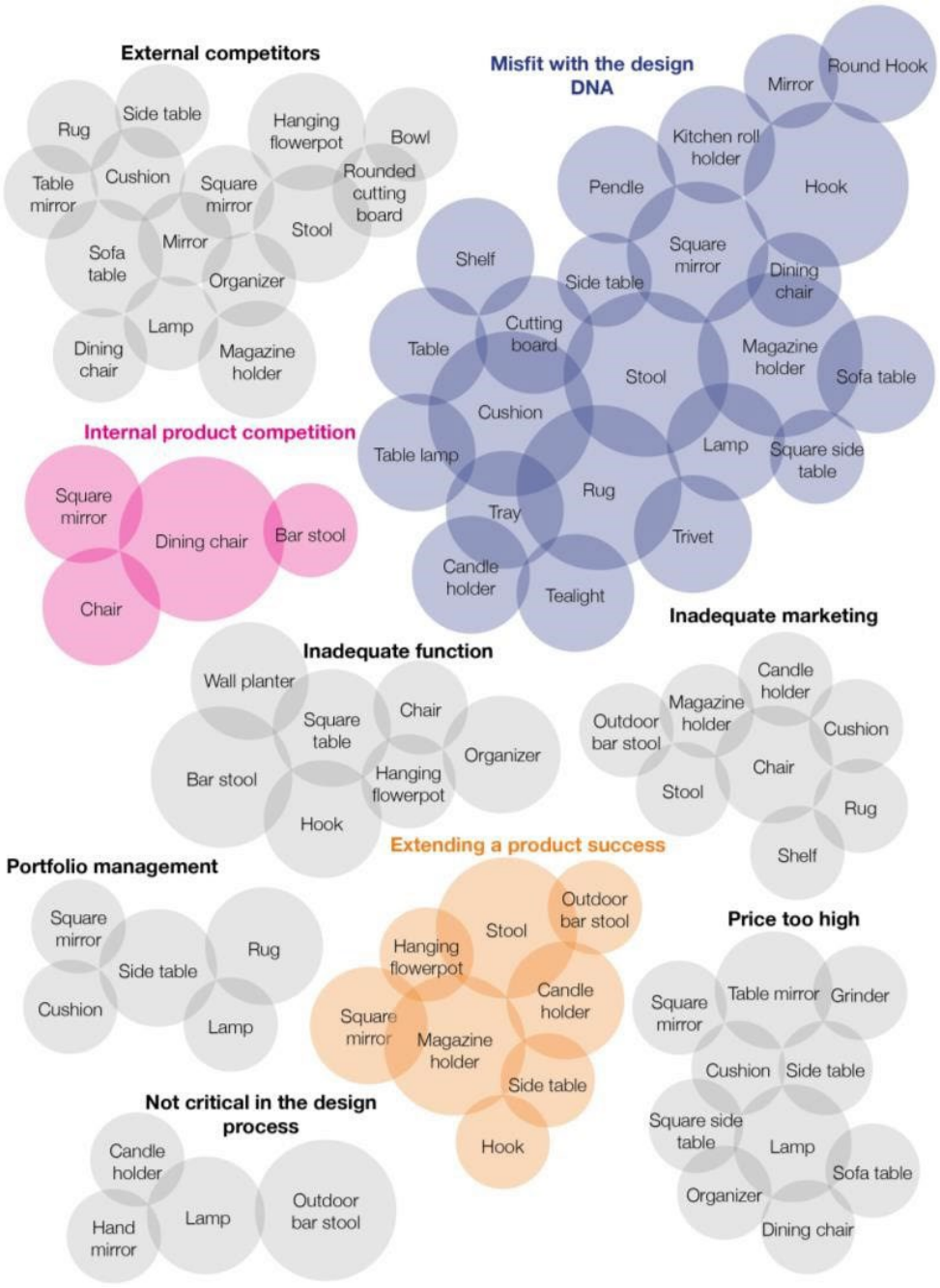


Figure 1: Failure causes in interior design products

Misfit with the company's design DNA

This category represents the reasoning behind product failures that do not align with the companies' design DNA. Both investigated companies invest significant resources to ensure that their launched products reflect their values and design DNA.

Despite this, the companies often used descriptions contrary to their design DNA when explaining why some of their products had failed.

Company 1 has the mission of designing exclusive products that differentiates from the competition due to their sculptural expression that contributes to becoming centrepieces of interior design. While expressing the reasons

for failure, statements such as “too boring”, “not unique”, “too minimalistic” “not bold enough” were used.
Company 2 was rebranded in 2018 by the new owners. During the process the company, opted for a more feminine look to their designs. As a result, several of their products did not match the new vision and were removed from their portfolio. This decision was also based on the product's sales figures.
While describing the reasoning behind removing products from their portfolio, Company 2 used the statement “too masculine” on several instances regarding 10 products, one of which launched in 2021.
There are other instances where statements and expressions used to explain the reason behind removing a product from the portfolio revealed a misfit between their design DNA and the observed features of the failed product. Colour, functionality, design language (industrial instead of classical, elegant instead of playful) were other aspects influencing the design DNA that were mentioned in the interviews.

Extending a successful product

Extending a successful product success can be driven by three main factors: 1) designing the following generation of the product; 2) introducing a new variant (often in a new colour or finishing); and 3) creating a product family.
The first reason can be exemplified by the design of a mirror by Company 1. The company used similar design principles, but the overall shape was square instead of the previous round one. The company expressed regrets in developing the product and considers removing it from the portfolio.
Regarding colour, Company 1 introduced a trendy colour to an established product, but regretted afterwards justifying that the dull colour downplays the product, making it deviate from the company’s design DNA.
The two investigated companies are often introducing families that have the same design language. This has both benefits and disadvantages. Both companies stated instances where the introduction of new products to the family instead of making new unique products did not live up to the expectations and were directly linked to failed products.

Internal product competition

Internal product competition occurs when products within the company compete with each other for various reasons. It can be as in the previously described example of extending an existing product family, but also in the introduction of new products within the same product category. This might lead to issues where the products in the same category compete for the same customers. New product launches should increase overall sales instead of moving sales from one product to another.
In this specific cause of failure we observe two main reasoning that influence internal product competition: 1) products that do not differentiate enough from other products; and 2) too many customisation options to the customer.
The insufficient differentiation from other products can be illustrated by a mirror case from Company 1. This case is based on a squared-shape mirror that was launched without offering no additional advantage to the customers. Because of this, the two products are competing for the same spot in the portfolio, leaving one winner and one loser. “[…] The Round mirror had success because we were one of the first to introduce a product like this, with its small MDF frame, and by challenging the colours […] and then the Square mirror came and had to get in the same spot (as the round mirror). It couldn’t”. “I just think that's what sometimes happens in the design industry, is that you accidentally will outcompete your own products”.
A similar case is seen in Company 1’s dining chair. They introduced the chair in three colours and two of the colours – dark brown and black – are very hard to differentiate from each other. “I think that it is the wrong colour of brown, to be honest, if you look at them in the showroom then you could say; is that black?”
These two cases are contributing to the fact that the companies need to ensure that the products both differentiate themselves from the products in the same product category, but also differentiate themselves enough within the colours available.
Another reasoning for internal product competition is product variation, and more specifically in the number of customisation options given to the customer. “[…] Because what sometimes happens when you have too many variants, is that you also give the customer some uncertainty. Sometimes we have to make the choice for the customer. This is the one we think you should buy […] And sometimes we have to be better at making that

choice for the customer". This statement shows that a wide range of variety within a product is not always a good thing and can lead to the paradox of choice (Schwartz, 2004).

Lack of joint reflection about what is failure

There is a lack of joint reflection across hierarchical levels about the reasons leading to products considered a failure. This insight is supported by designer and marketer in Company 1, who both agree that discussions about failed products rarely or never happen. If it happens it is often in passing and not in a dedicated meeting.

The lack of reflection was posed in the interview with the decision makers, who expressed an opposite view, stating that is something that they do discuss and use time on. Colloquially they often mention marketing as a cause for failure. However, marketing did not play as big of a role as expected in the remaining interviews.

In Company 1, low sales do not determine immediate removal from the portfolio. Instead, when a new product falls short of financial expectations, the company increases efforts in marketing and sales, because according to the interviewees some products need more time to settle on the market and reach the customer. The decision-makers mention that it is important that an alignment in price and quality of the product is crucial to its success, and once a product struggles is challenging to turn it into a success.

product management in the interior design industry.

Misfit with the design DNA is the primary cause of failure observed in the study. The data collected indicates this cause relates to decisions influencing new product development that leads to a bad fit between the features of the developed product and the company design DNA. This cause can be connected to different factors. From the collected data we interpret that because Company 1 is a medium size company with different departments there might be different interpretations of the company's design DNA and how it can be transferred to specific design features. In Company 2 the cause seems to be linked to the rebranding process. This fact led to the removal of several products from their portfolio.

Additional factors might influence an improper fit between a product and a company's design DNA. In medium-size and large companies the interaction within design teams and communication across departments may influence the cohesion of how the design DNA is traduced into product features. It is known that in order to create a meaningful solution, design teams engage in a complex framing that requires the clarification of how aspired values are translated into product features (Haase and Laursen, 2019). In companies, such as Company 2 which outsource the design to consultancies, the issue may reside in the way the design DNA is communicated in the design briefing (Busch et al., 2023).

Table 1. Summary of causes of failure in interior design products

Failure cause	Summary
Misfit with the design DNA	- Primary cause of failure observed in the study - Product features mismatching key aspects of design DNA - Contradictory statements to describe the product/company fit
Extending a successful product	- Challenges in designing the following generation of the product - Challenges in introducing a new product variant (colour, finishing, etc.) - Challenges in creating a product family based on a successful product
Internal product competition	- Products that do not differentiate enough from other products - High number of customisation options to the customer
Lack of joint reflection	- Failures discussed at an informal level only - Failures not discussed across company hierarchical levels

Implications and discussion

This section elaborates on the reasoning behind product failures based on the insights gathered in the study, summarised in Table 1. Next, we discuss the observed failure causes by applying inductive reasoning to achieve general conclusions that can be applied in

Regarding the issues of extending a successful product, we observed challenges in designing the following generation of the product, in introducing a new product variant (colour, finishing, etc.) and in creating a product family based on a successful product. While some of this causes might relate to *similar aspects of*

creating meaningful frames mentioned earlier (Haase and Laursen, 2019), designing the next generation of products requires assessing other factors. Using Karjalainen et al. (2009) key drivers influencing the next generation of products, we believe considering assessing brand position and clarifying the product history may mitigate this cause for failure. Regarding the product history, the redesign of flagship models can follow the guidelines for how frames evolve through time in the renewal of a company's design DNA defined by Laursen and Barros (2022).

We believe that the specific cause of internal product competition, products that compete for the same spot might not always leave a clear winner or loser. There might also be cases where the products are splitting the sales between the two, and thereby a longer period of observation can clarify the strategy to follow. This topic requires critical discussion on the width and structure of the product portfolio (Karjalainen et al., 2009).
Hopkins (1981) and Cooper (1976) both mention the lack of understanding market environment as a big contributor to failed products. However, market environment did not play a big role in our findings. We believe that this might be because interior products are not radically innovative, but rather incremental, serving a market pull need in most of the cases (Verganti, 2003), competing with similar products with the similar features.
The findings in this research show that there are still additional specific causes to uncover regarding product failure in other product categories such as proposed by (Cooper and Kleinschmidt, 1987). The present research demonstrated that the design DNA, product portfolio management and product evolution are very significant factors to account in the design of interior products.

CONCLUSION

Product failure is considered inevitable, however by reflecting upon our failures we can create awareness of the specific causes to avoid product being produced that end up having no product lifetime. Previous research has focused on differentiating successful products from failed ones. The present study detailed the specific causes for failure and contextualise them in the interior design industry.
The insights from this study can assist design managers and designers in identifying areas for reflection during new product development to reduce the likelihood of failures. This includes aligning the company's design DNA with its working principles, clarifying the company's values and evolving the working principles over time, continuously evaluating the product portfolio structure, and considering the role of flagship products in enhancing overall brand recognition.
This study focuses on two different companies in the Danish interior design industry. Future research can use these findings in quantitative studies to determine the frequency of these causes or identify patterns in specific product categories. Additionally, a more extended study on companies undergoing rebranding could shed light on the impact of design DNA in brand consolidation.

REFERENCES

Busch, S., Sander Jensen, N., and Barros, M. (2023), "Decoding design briefs: The role of abstraction levels in textual and visual stimuli", Nordes 2023: This Space Intentionally Left Blank, 12-14 June, Linköping University, Norrköping. https://doi.org/10.21606/nordes.2023.113

Cooper, R. G. and Kleinschmidt, E. J. (1987) "New products: What separates Winners from Losers?", *Journal of Product Innovation Management*, Vol. 4 No. 3, pp. 169-184. https://doi.org/10.1016/0737-6782(87)90002-6

Cooper, R. G. (1976) "Introducing Successful new Industrial products", *European Journal of Marketing*, Vol.10 No. 6, 301-329. https://doi.org/10.1108/EUM0000000005053

Cooper, R. G. (2017) "We've Come a Long Way Baby", *Journal of Product Innovation Management*, Vol. 34 No. 3, pp. 387-391. https://doi.org/10.1111/jpim.12372

Danneels, E. and Vestal, A. (2020) "Normalizing vs. Analysing: Drawing the lessons from failure to enhance form innovativeness", *Journal of Business Venturing*, Vol. 35 No.1. https://doi.org/10.1016/j.jbusvent.2018.10.001

Edmondson, A. (2011), "Strategies for Learning from Failure", *Harvard Business Review,* Vol. 89 No. 4.

Haase, L. M., & Laursen, L. N. (2022). Designing for longevity: expert strategies for creating long-lasting products. Taylor & Francis.

Haase, L. M., & Laursen, L. N. (2019), "Meaning frames: The structure of problem frames and solution frames", Design Issues, Vol. 35 No. 3, pp. 20-34. https://doi.org/10.1162/desi_a_00547

Hopkins, David S. (1981) "New-product Winners and losers", *Research Management*, Vol. 24 No. 3, pp.12-17.

Karjalainen, T.-M., & Snelders, D. (2010), "Designing visual recognition for the brand", Journal of Product Innovation Management, Vol. 27, pp. 6-22. https://doi.org/10.1111/j.1540-5885.2009.00696.x

Kulvik, H. (1977) "Factors Underlaying the Success or Failure of New Products" Helsinki University of Technology, Report No. 29, Finland.

Laursen, L. N. and Barros, M. (2022), "Timely and timeless framing of the new MINI Cooper", *Design Studies*, Vol. 82, 101123. https://doi.org/10.1016/j.destud.2022.101123

Laursen, L. N., and Haase, L. M. (2018). Framing New Product Innovations: How To Make Sense Of Internal And External Insights?. In DS 92: Proceedings of the DESIGN 2018 15th International Design Conference (pp. 1891-1902). https://doi.org/10.21278/idc.2018.0349

Panne, G., Beers, C., and Kleinknecht, A. (2003) "Success and failure of innovation: A literature review", *International Journal of Innovation Management*, Vol. 7, No. 3, pp. 309-338. https://doi.org/10.1142/S1363919603000830

Rothwell, R. (1972) "Factors for success in industrial innovation. From project SAPPHO – A comparative study of success and failure in industrial innovation" Brighton Sussex: S. P. R. U.

Schwartz, B. (2004) The Paradox of Choice: Why More Is Less. Ecco, New York.

Tollestrup, C., Laursen, L. N., Vesti, H. N. (2023) 'Design Expertise: A Structured Literature Review', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.124

Verganti, R. (2003), "Design as brokering of languages: Innovation strategies in Italian firms", *Design Management Journal*, Vol. 14 No.3, pp. 34-42. https://doi.org/10.1111/j.1948-7169.2003.tb00050.x

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Transformative and community-based participation in collaborative business model experimentation for urban upcycling

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Keywords: experimental collaboration; participatory business model innovation; community-based urban upcycling; product and resource longevity.

Abstract:

Across cities and urban regions in The Netherlands unusual collaborations emerge which aim to develop new circular business models that facilitate product and resource longevity through various upcycling strategies, such as reuse, repair, refurbish, repurpose and/or remanufacture. Municipalities, social entrepreneurs as well as multinational enterprises use various experimentation methods to initiate, test or improve new collaborations in urban upcycling. However, little is known about the role of transformative stakeholder participation in these experiments and how they affect business models for upcycling. Therefore, this study investigates how initiators in urban upcycling use transformative and community-based participatory experimentation to develop collaborative circular business models that facilitate upcycling in a city context. Through a multiple case study approach, this research contributes to literature on circular business model innovation by investigating how practitioners in urban upcycling collaboratively develop, test, implement and scale business models for product and resource longevity in a city context.

Introduction

Collaborative urban innovations in upcycling either emerge bottom-up, as social initiatives or top-down, driven by institutions (Prendeville et al., 2017). Innovations are scaled and accelerated through collaborative (open) or internally focused (closed) innovation approaches and resource strategies may be aimed at efficiency optimization (narrowing), product lifetime extension (slowing) or reprocess discarded products to resources (closing) (Bocken & Ritala, 2022). Business model experimentation occurs differently in various collaborative contexts (Brown et al., 2021) and, depending on the type of initiating focal actors involved, collaborative business models develop along different pathways (Oskam et al., 2021).

Unusual collaborative initiatives emerge across Dutch municipalities which aim to reduce waste and stimulate the creation of new value from discarded municipal bulky resources (Faun & Maas, 2019; Faun et al., 2021; MIW, 2023). For example, an increasing number of Dutch municipal so-called 'circular crafts centres' (CCC) aim to facilitate regional entrepreneurial upcycling collaborations (Werner et al., 2020) and promote product longevity by specifically including the educational and social domain to stimulate reuse, refurbishment, repair of products and the exchange and spreading of practical repair knowledge and skills (Ministerie van Infrastructuur en Waterstaat, 2023). Other recent urban business model initiatives include so-called urban maker spaces, used-product exchange platforms, upcycling product-pools and upcycling centres or circular hubs with sorting and disassembly services. These initiatives also facilitate and/or promote multiple strategies for resource longevity, including repurposing discarded products and their materials in new applications.

Research shows that experimentation competences are important for developing initiatives towards circular business models (Bocken et al., 2018; Bocken & Coffay, 2022; Bocken & Konietzko, 2023) and a wide range of tools and approaches have been developed to support the development of circular business models based on experimentation (Bocken et al., 2021). In practice, multinational enterprises (MNE) use experimentation to innovate their business models (Bocken & Konietzko, 2023) and urban local governmental bodies (LGB) use urban experiments to initiate, test and

improve social entrepreneurial initiatives (Scholl & De Kraker, 2021). However, more insight is needed to understand how experiments in urban upcycling, particularly those where collaborative business models are created to reduce waste and enhance product and resource longevity, involve urban communities and how these collaborations aim for transformative participation of internal and external stakeholders. Therefore, this study aims to understand how experimentation occurs in urban upcycling initiatives and investigates the following research question: How do initiators of urban upcycling business model experiments apply community-based transformative participation to reduce waste and extend product longevity in a city context?

Methods

Based on a purposive sample (Bryman et al., 2011) of six organizations that initiated multiple collaborative business model experiments in urban upcycling, this study explores which types of collaborative experimentation approaches are used.

The study used a multiple case-study approach (Yin, 2009) to identify, describe and analyse critical turning points (Pel et al., 2017), types of stakeholder collaboration (Bocken & Ritala, 2022) and community-based transformative participation (Leavy, 2017; Sprague et al., 2019) across the three main stages of the circular business model innovation process (Bocken et al., 2018) .

Two LGB, two MNE and two social small to medium-sized enterprises (SSME), each independently engaged in multiple upcycling projects, were selected to ensure organizational engagement in upcycling and availability of relevant data from the various stages in the business model innovation process. Adapted from literature on business model innovation (Geissdoerfer et al., 2022) and circular business model experimentation (Antikainen et al., 2018), particularly for MNE (Bocken et al., 2017) and SSME (Seelos & Mair, 2017), this study distinguishes three stages to enable cross-case comparison, (1) collaborative prototyping through small-scale experimentation, (2) pilot testing, which entails initial market launch of the collaboration and/or testing the collaboration for future scaling and (3) rolling-out at scale by engaging in additional collaborations (Table 1).

Case	Experiments / Pilots	Interviewees
LGB 1	Urban reuse centre Circular crafts centre	Project manager1
LGB 2	Urban upcycling centre Circular crafts centre	Project manager1 Project manager2
MNE 1	B2C reuse delivery service C2B refurbishment service	Product manager 1 Product manager 2 Sustainability director
MNE 2	Waste donation Circular crafts centre	Product Quality & Safety Specialist Sustainability business partner External project manager
SSME 1	Urban bulky waste collection service Circular crafts centre	Owner
SSME 2	Circular crafts centre initiative B2B wood remanufacture	Owner Project manager

Table 1. Urban upcycling innovation initiatives analysed in this study.

The data collected consists of primary data from semi-structured interviews and secondary data, such as internal archives (e.g. meeting notes and workshop outcomes), and public articles.

Semi-structured interviews were conducted with managers and business owners, engaged in multiple collaborative urban upcycling business model experiments. The main topics of the interview protocol included the role and activities of the organisation, followed by critical incidents that either triggered or guided the initiative (Pel et al., 2017) and identification of collaborative aspects and transformative learning focus in the three phases of business model prototyping (1), piloting (2) and rolling-out (3).

Within-case analysis started with coding primary interview data and secondary data based on participatory and transformative aspects, adapted from literature on community-

based research and business model innovation such as transparency of the innovation process and collaboration with the community, diversity competence development and contribution to community needs and/or social justice. A timeline analysis was used to identify and map most critical incidents (Pel et al., 2017), the collaborative innovation strategy applied (Bocken & Ritala, 2022) and community-based participation (Leavy, 2017) across consecutive experimentation phases of each case.

A cross-case analysis was used to identify which differences and similarities occur between the six cases in relation to the business model experimentation process.

Results

This section first presents a within case analysis with a brief description and a summary in coloured tables with five icons, as explained in Table 2. Next, a cross case analysis presents similarities and differences between the cases.

Phase	1: Collaborative prototyping 2: Pilot testing collaboration 3: Rolling-out with multiple collaborations	
	Time period	Number of years
	Critical incidents	Transformative events or developments (Pel et al., 2017)
	Stakeholder collaboration	ON = Open Narrowing OS = Open Slowing OC = Open Closing CN = Closed Narrowing CS = Closed Slowing CC = Closed Closing (Bocken & Ritala, 2022)
	Level of community involvement	1 = Outreach 2 = Consult 3 = Involve 4 = Collaborate 5 = Shared leadership (Sprague et al., 2019)
	Transformative learning focus (Leavy, 2017; Mezirow, 2009)	I = Internal business model E= External business model (e.g. partners, customers) C = Urban community

Table 2. Explanation of icons used

LGB 1

Following a municipal coalition agreement entailing a circular vision with high ambitions, a physical reuse centre was launched. The project initially survived strong challenges related to COVID by aiming for long-term financial feasibility. The innovation process intended to be open, involving multiple and diverse upcycling entrepreneurs and the local community. A foundation of external management 'pioneers' ("kwartiermakers" in Dutch) was assigned to business development, and in practice, collaborative development focused on practical daily issues. Stakeholders did not appear committed or empowered to take ownership, either taking on a transactional approach or leaving the initiative to continue activities elsewhere. Two years after its ambitious launch, the project was stopped and received nation-wide coverage in the media, which presented the project as a financial and political failure. Based on learnings taken from an official evaluation, the LGB is preparing new plans for a circular crafts centre by empowering existing and stimulating new local upcycling experiments, monitoring national and regional pilots and investigating and testing the municipal and regional infrastructural and collaborative requirements for urban upcycling. Table 3 summarizes the above and illustrates that open and community-based innovation is limited to the roll-out phase and focused on the startup community, while transformative learning is primarily externally focused and aims to include the urban community through education and startup incubation.

Phase	1	2	3
	0	0	2
			1.Coalition agreement 2.Launch of reuse center 3.COVID
			OS, OC
			1
			E, C

Table 3. Collaborative experimentation LGB1

LGB 2

Following the nomination for the organization of an international exhibition, LGB 2 created a plan aiming to showcase existing local upcycling initiatives and a prestigious recycling station with an educational centre and incubating facilities for circular startups. The

collaborative agreement with entrepreneurs entailed a two- year contract of free working space for upcycling business experimentation, and the obligation to engage in educational activities aimed at inspiring local communities and citizens to raise public awareness for waste reduction and engagement for the circular economy. Performance measurement of startups is conducted on a relatively informal and ad hoc basis and exact intended radical difference with a traditional recycling station remain obscure. More recently, LGB 2 has initiated collaborative pilots to test feasibility, viability and desirability of a scaled circular crafts centre infrastructure which integrates a municipal waste station with pro-active resource orchestration and collaborative business model co-creation within a broader community of SSME and services in the social dimension that facilitate upcycling, such as sorting, dismantling, warehousing and selling through local thrift shops. The pilot aims to develop and test more radical business model collaborations and co-creation of new facilities, roles and residual mono streams for upcycling which, when proven effective, will be rolled-out over other locations after a period of five months. Table 4 shows that open and community-based innovation is limited to the pilot phase and targeted at the startup community, while transformative learning is primarily aimed at local consumers.

Phase	1	2	3
	7	5	0
	1.Identify initiatives 2.Nomination WE 2.Plan new recycling station	1.Launch recycling center 2.Study educational options 3.Launch education center 4.Follow-up Circular Crafts Center pilot (other location)	1.Coalition agreement 2.Launch of reuse center 3.COVID
	Local initiatives	**OC, OS**	
	1	3	
		C	

Table 4. Collaborative experimentation LGB2

MNE 1

This digital market place for used products initiated three experiments aimed at (1) a shipment service for bulky items, such as furniture, (2) a refurbishment service and (3) a public-private collaboration with LGBs. Continuous user data analysis triggers new ideas for experiments and pilots. For example, as for upcycling business model experiment (1), data showed that 17 million bulky items were traded without organizational support, while similar collaborative shipping services already existed for smaller items. This insight triggered an experiment to measure 'appetite' for a specialized shipping service for bulky items. In parallel to online experiments, two potential partners were identified, leading to a strategic pilot. Business model experiment (2), refurbishment service, entailed a more radical change to the existing business model. A strategic task force was assigned to explore activities and strategic fit of potential partners which actively trade on the platform. A three month period of user data analysis, business modelling, opportunity assessment and forecasting was followed by five months of pilot testing and roll-out. The pilot collaboration with two potential partners consisted of small steps to monitor effectiveness and to gradually grow allocation of resources. Further IT-integration starts after the collaboration has proven to be successful and aligned to the company strategy. As for upcycling project (3), the company engages in various knowledge exchange platforms, educational collaborations and social media campaigns aimed at professionals in the public sector to explore strategic collaborations with LGB. At the time of this study, the project was still in an early stage, calling for increased public-private collaborations between the MNE and multiple LGB aimed at reducing the destruction of potentially valuable material in municipal waste management. Table 5 indicates that open innovation with potential partners and transformative participation of the community is focused on piloting and roll-out. Online community participation is limited to consent for use of personal data, while the company is actively seeking collaboration with LGB and promoting its services to the public through a narrative that strongly appeals for transformative buying behaviour based on creative and emotional experiences.

Phase	1	2	3
	0,1-0,2	0,5	0
	1.Customer data 2.Analysis business idea 3.Appetite identified 4.Potential partners	1.Strategic Task Force 2.Launch business test	1.Launch service 2.Integrate IT
	CS	OS	
	1	1	1
	I	I	E, C

Table 5. Collaborative experimentation MNE1

MNE 2

An international retail store in furniture and interior products initiated three local experimental upcycling projects. Donation projects entail casual unwritten agreements about direct donations of waste material, mostly solid wood, to be used as resources for organizations in the social domain. The company is not involved in the follow-up upcycling processes and refers to environmental and financial benefits related to avoiding the waste management process of mixed materials. The pilots aim to gain better insight in actual waste streams, to support the green reputation of the company, to develop longer term donation services and create internal legitimacy among local employees for its circular ambitions.

The coordination of an unusual collaborative experimentation project is outsourced to an external mission-driven design consultancy. The project aims to co-create three products from waste. The nine months experimentation phase kickstarted with an internal company “waste safari” to discover availability and workability of waste resources, followed by a brainstorming session to explore options for creating value and a collaborative prototyping workshop. Table 6 provides an overview and shows that the company is selectively exploring open community-based experimentation aimed at internal transformation, Internal compliance and safety regulations limit options for instore roll-out of upcycled product prototypes.

Phase	1	2	3
	0,5-0,6	Recent start	0
	1.Circular strategy 2. “Waste safari” 3.Brainstorm 4.Prototyping 5. Project evaluation	1. Facing limited storage capacity	1. Facing internal constraints
	OC	OC	
	2	2	
	I		

Table 6. Collaborative experimentation MNE2

SSME 1

After many years of informal agreements and experimentation in urban bulky waste collection, a Dutch hybrid organization of urban non-profit WISE and three urban used product stores, received permission from LGB to start a business pilot for an urban bulky waste collection service. Eight years later the collaboration was formalized and rolled-out in an official agreement, allowing the organization to proceed activities, and charge the LGB based on kilograms of municipal bulky ‘waste’ collected. The agreement entails the obligation to collect, monitor and register bulky waste from citizens, and to upcycle potentially valuable products through used product stores. The SSME functions as an extended service to the municipal recycling station, integrates the social domain and collaborates with educational institutions. Therefore, the company applied for a circular crafts centre (CCC) initiative and calls LGB for local community-based bulky waste collection points. Table 7 illustrates that the company is deeply engaged in open and transformative collaboration with the local community across all experimentation phases, but struggles to reach scale, largely due to legislative and contractual dependencies with LGB.

Phase	1	2	3
	10+	8	Recently launched
	1.informal urban bulky waste collection	1.formal permission 2.tender	1.official agreement
	OC, OS	OC, OS	OC, OS
	4	4	4
	C	C	C

Table 7. collaborative experimentation SSME1

SSME 2

A medium-sized work integration social enterprise (WISE) initiative (100 employees), which started as a non-profit bicycle repair shop, built its business model on continuous collaborative upcycling experiments with medium-sized and large enterprises as launching customers. Illustrative examples include collaborations with Dutch building contractors for the collection, sorting, and remanufacturing of hardwood doors, which are resold to the same company as semi-finished upcycled hardwood panels and partly sold as regenerative products, such as bird houses and insect hotels. The SSME recently started an unusual collaborative pilot with the LGB to test a circular crafts centre concept in which the company serves as a sorting gateway to the local recycling stations to rescue valuable material from incineration and raising sustainability awareness among visitors and developing new collaborations with educational institutions. Table 8 illustrates that the company collaborates with LGB, MNE and local SME using the complete spectrum of open circular innovation strategies, but struggles to reach scale, largely due to limited availability of financial resources.

Phase	1	2	3
	0,5-1	5	0
	1.Launching contractor 2.Working protocol 3.Move to other location	1. Launching customer for biodiversity product range	1. Obtain external financial resources for scale up
	OC, OS, ON	OC, OS, ON	
	1, 4	1, 4	
	C	C	

Table 8. Collaborative experimentation SSME2

Cross-case analysis

From a comparison of the findings, the data show that all six urban upcycling initiatives use experimentation as an important means for collaborative business model development. However, actors take surprisingly different routes depending on the type of initiator involved. The data revealed the following differences and some similarities across the cases.

First, initiating actors refer to different events that triggered their engagement in urban upcycling experiments. Whereas LGBs mention opportunities arising from shifts in the political landscape or available subsidies, and MNEs refer to internal strategy and budgeting decisions, SSMEs allude to more transactional incidents, such as a new agreement with a launching customer or an actionable legislative condition.

Second, as for timeline phasing, collaborative urban upcycling experiments initiated by LGBs seem to struggle with a structured step-by-step experimentation process, causing unreliable processes and unpredictable policy, ranging from endless piloting to skipping fundamental experimentation phases. For example, the principal interviewee in LGB 2 suggests that the ambitious municipal urban upcycling project moved straight to a scaling phase without first piloting the concept based on the premise ‘if we do it, we do it right’. Also illustrative, in case LGB 1 and SSME 1, interviewees refer to incidents of delayed decision-making and political hesitation, causing stakeholder disengagement, doubt feelings and risk-averse behaviour among partnering SME upcycling entrepreneurs. In contrast, experimentation phases of MNE 1 and MNE 2 are relatively short, and align with SSME 2, who collaborates with large private companies but faces

difficulties moving from pilot to roll-out, primarily due to a lack of available resources.

Third, all cases embrace selective open innovation strategies, aiming at reaching higher product and resource longevity and/or higher recycling rates. However, while LGBs experiment with a wide range of small and new upcycling ventures in the context of prestigious and ambitious projects, other actors almost do the opposite. MNEs and SSMEs seek and/or test collaborations with proven ventures, established businesses and/or public institutions from their existing network based on relatively modest ambitions. Interestingly, SSMEs primarily refer to external dependency restrictions for roll-out, such as legislation, contractual agreements and access to financial resources, while MNEs particularly refer to internal compliance and strategy.

Fourth, the data reveal that all initiating actors either explore or engage in community-based transformative innovation, but find different ways and have other reasons. For example, [MNE 1] is actively exploring ways to collaborate with LGBs and educational institutions to stimulate local communities towards more circular behaviour and use their platform, while LGBs aim to create circular awareness among their residents through local circular startups and education facilities in circular crafts centres. [MNE 2] directly engages its employees in multiple waste-as-a-resource local charity projects and in a circular design experiment with a WISE to create internal legitimacy for their internal circularity ambitions. And finally, SSMEs integrate continuous experimentation in their day-to-day operations and interactions with individual customers in local communities, thereby implicitly promoting circular practices to local communities.

Discussion and conclusions

This study investigated how initiators in urban upcycling use transformative participatory experimentation to develop collaborative circular business models and infrastructures that facilitate upcycling in a city context.

The cross-case analysis reveals that substantial similarities occur between cases with similar actors, which resonates with state-of-the-art literature on experimentation practices of MNEs (Bocken et al., 2017), SSMEs (Seelos & Mair, 2017) and Dutch LGB city labs (Scholl & De Kraker, 2021). The study also shows that collaborative urban innovations in upcycling emerge bottom-up, from SSMEs, and top-down, driven by LGBs and/or MNEs (Prendeville et al., 2017). However, in line with Oskam et al. (2021), collaborative business model experiments proceed differently depending on the type of initiating actors involved. Where these different approaches of LGBs, MNEs and SSMEs are complementary, they provides opportunities for cross-disciplinary collaboration. For example, collaborative experiments in MNEs are more data-driven and structured, which provides important learnings to LGBs and SSMEs. Similarly, SSMEs already deeply engage in upcycling practices with local urban communities on a personal and transformative level, providing opportunities to MNEs and LGBs for exploring opportunities aimed at transitional innovation (Andriopoulos et al., 2009) based on co-creation. Additionally, while LGBs and MNEs are still exploring and prototyping with new startups based on a top-down approach, they rather may empower and accelerate bottom-up SSME initiatives (Prendeville et al., 2017) by providing required resources and network access to promising existing local SSME upcycling initiatives.

Hence, these findings suggest that differences between experimentation approaches of MNEs, LGBs and SSMEs offer opportunities and space for transformative participatory business model experimentation between these actors. We therefore propose that follow-up research investigates which community-based participatory experimentation approaches would be feasible and desirable to scale and accelerate promising urban upcycling initiatives through cross-disciplinary co-creation between MNEs, LGBs and SSMEs.

The study contributes to research on circular business model experimentation by improving the understanding of the roles that different types of actors play in the context of collaborative experimentation in urban upcycling. The results highlight opportunities for researchers and practitioners to further explore how cross-disciplinary collaborative business model experimentation can accelerate and scale promising urban upcycling initiatives more effectively by integrating complementary

participatory innovation strategies and community-based transformative practices in LGBs, MNEs and SSMEs.

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References

Andriopoulos, C., & Lewis, M. W. (2009). Exploitation-exploration tensions and organizational ambidexterity: Managing paradoxes of innovation. Organization science, 20(4), 696-717. DOI: 10.1287/orsc.1080.0406

Bocken, N. M., Schuit, C. S., & Kraaijenhagen, C. (2018). Experimenting with a circular business model: Lessons from eight cases. Environmental innovation and societal transitions, 28, 79-95. https://doi.org/10.1016/j.eist.2018.02.001

Bocken, N., & Coffay, M. (2022). The circular experimentation Workbench–a lean and effectual process. Circular Economy and Sustainability, 3(3), 1361-1383. DOI: 10.1007/s43615-022-00239-w

Bocken, N., & Konietzko, J. (2023). Experimentation capability for a circular economy: a practical guide. Journal of Business Strategy, 44(6), 406-414.

Bocken, N., Strupeit, L., Whalen, K., & Nußholz, J. (2019). A review and evaluation of circular business model innovation tools. Sustainability, 11(8), 2210. DOI: 10.3390/su11082210

Bocken, N. M., Weissbrod, I., & Antikainen, M. (2021). Business model experimentation for the circular economy: definition and approaches. Circular Economy and Sustainability, 1(1), 49-81 DOI: 10.1007/s43615-021-00026-z

Bocken, N., Miller, K., Weissbrod, I., Holgado, M., & Evans, S. (2017). Business Model Experimentation for Circularity: Driving sustainability in a large international clothing retailer. Economics and Policy of Energy and the Environment (EPEE), 2017(1), 85-122. DOI: 10.3280/EFE2017-001006

Bocken, N., & Ritala, P. (2022). Six ways to build circular business models. Journal of Business Strategy. DOI: 10.1108/JBS-11-2020-0258

Brown, P., Baldassarre, B., Konietzko, J., Bocken, N., & Balkenende, R. (2021). A tool for collaborative circular proposition design. Journal of Cleaner Production, 297, 126354. https://doi.org/10.1016/j.jclepro.2021.126354

Bryman, A., & Bell, E. (2011). Business research methods. 3rd ed. Cambridge ; New York, NY, Oxford University Press. https://doi.org/10.20935/AcadBiol7688

Faun, H., & Maas, K., (2021) Handelingsperspectief sociaal domein circulaire ambachtscentra, Rijkswaterstaat / Panteia Zoetermeer https://vang-hha.nl/kennisbibliotheek/handelingsperspectief-sociaal-domein-circulaire/

Faun, H., Goes, M., Maas, K., Steenland, R. (2019) sociale activatie op Circulaire Ambachtscentra, Rijkswaterstaat / Panteia Zoetermeer

Geissdoerfer, M., Savaget, P., Bocken, N., & Hultink, E. J. (2022). Prototyping, experimentation, and piloting in the business model context. *Industrial Marketing Management*, *102*, 564-575.

Leavy, P. (2017). Research design. New York, The Guilford.

Mezirow, J. (2009) An overview of transformative learning. In Illeris, K. (ed) Contemporary Theories of Learning, London: Routledge, pp. 90-105.

Ministerie van Infrastructuur en Waterstaat (2023), Startersgids circulair ambachtscentrum, ism VNG, NVRD, repaircafé, branchevereniging kringloopbedrijven https://circulairambachtscentrum.nl/slag/starten-circulair-ambachtscentrum/

Oskam, I., Bossink, B., & de Man, A. P. (2021). Valuing value in innovation ecosystems: How cross-sector actors overcome tensions in collaborative sustainable business model development. Business & society, 60(5), 1059-1091. https://doi.org/10.1177/0007650320907

Pel, B., Dumitru, A., Kemp, R., Haxeltine, A., Jorgensen, M. S., Avelino, F., ... & Bauler, T. (2017). Synthesis report: meta-analysis of Critical Turning Points in TSI: Deliverable D5. 4. TRANSIT - Transformative Social Innovation Theory project

Prendeville, S., Cherim, E., & Bocken, N. (2017). Circular cities: Mapping six cities in transition. Environmental innovation and societal transitions, 26, 171-194. https://doi.org/10.1016/j.eist.2017.03.002

Scholl, C., & de Kraker, J. (2021). The practice of urban experimentation in Dutch city labs. Urban Planning, 6(1), 161-170. DOI: 10.17645/up.v6i1.3626

Seelos, C., & Mair, J. (2017). Innovation and scaling for impact : how effective social enterprises do it (1st ed.). Stanford Business Books, an imprint of Stanford University Press. https://doi.org/10.1515/9781503600997

Sprague, L., Afifi, R., Ayala, G., & El-Nasoor, M. L. (2019). Participatory praxis as an imperative for health-related stigma research. BMC medicine, 17, 1-8. https://doi.org/10.1186/s12916-019-1263-3

Werner, A., Albers. J., Verschuren, H, Dierdorp, L. (2020) Onderzoek effecten circulaire ambachtscentra, ism Anteagroup, Rijkswaterstaat Utrecht https://vang-hha.nl/kennisbibliotheek/onderzoek-effecten-circulaire-ambachtscentra/

Yin, R. K. (2009). Case study research: Design and methods (Vol. 5). sage. DOI: https://doi.org/10.33524/cjar.v14i1.73

Extended Abstract
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Implementing reusable packaging systems: lessons from industry

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Keywords: Design, Reusable Packaging; User Experience; Circular Economy; Sustainability; Digital.

Introduction

Despite corporate pledges, reliance on single-use plastics continues to grow (Greenpeace, 2018). In 2023, plastic production reached 413.8mT (Plastics Europe, 2024), with a predicted 152.5mT attributed to plastic packaging (OECD, 2022). An estimated 50% of plastic packaging enters landfill each year, with a projected 1-2mT leaking into the environment (Ritchie et al., 2023). Ill-disposed plastics create a lasting impact on the environment and eco-systems. Despite this, plastic packaging production is expected to triple by 2060 (OECD, 2022). Whilst at-home and in-store initiatives are trailed to stimulate consumer recycling rates, stagnation leaves much to be desired. In the UK, 55% of plastic packaging is recycled per year (WRAP, 2023), and intention to engage in kerbside recycling has decreased by 7% (RECOUP, 2023). Exploring alternative avenues for waste management is necessary to kerb plastic pollution and natural resource depletion further.

Reusable packaging systems are increasingly seen as potential strategies to relieve single-use reliance. Reuse is defined as “packaging which has been conceived, designed and marketed to carry out multiple trips in its lifetime by being refilled or reused for the same purpose in which it was conceived” (EU Directive 94/62). Within reuse, four archetypes are defined: (i) Refill-at-home, (ii) Refill-on-the-go, (iii) Return-from-home, (iv) Return-on-the-go (Ellen McArthur Foundation, 2019). Reuse systems are dependent on meeting pre-defined cycle rates to outweigh the benefits of single-use plastics (Greenwood et al., 2021). The continued usage of materials, with assets confined to a closed loop, ensures minimal energy consumption and carbon contribution along the reusable’s life cycle.

Some businesses are already implementing (successful) reusable packaging systems, however there is limited understanding about their current challenges and best practices. This study aims to address this gap by presenting key learnings from industry partners, highlighting current barriers faced when implementing reuse systems, to streamline the design and implementation of future systems. Three research objectives are defined: (i) to understand the barriers and benefits of establishing reusable packaging systems, (ii) to understand the role and limitation of implementing technologies within reusable packaging systems, (iii) to consider the future of reuse.

This oral presentation presents the findings of 40 industry interviews. Design considerations for future reuse systems are outlined, with key barriers for establishing reusable packaging systems highlighted.

Methodology

To do this, 40 reuse providers and consultants were interviewed (semi-structured), with sessions ranging from 30 to 90 minutes. Each attendee provided primary insights into reusable products within FMCG (Fast-Moving-Consumer-Goods): 5 technology providers, 5 consultants/ facilitators, 5 refill-on-the-go, 3 refill-at-home, 19 return-on-the-go, and 3 return-from-home. Interviews are transcribed. Thematic coding (using the Bradley & Corsini’s analytical framework) identifies common themes discussed. Participants range from founders, CEOs to technical specialists (see Table 2.)

Table 1. Respondents according to primary service provided.

Primary service	Number
Return-on-the-go	19
Return-from-home	3
Refill-at-home	3
Refill-on-the-go	5
Reuse Consultant	5
Technology Provider	5

Table 2. Participants role.

Role	Number
Founder / CEO	23
Senior Management*	7
Consultant / Specialists	5
Project Manager	3
Marketing & Sales	2

**Senior Management incl. Chief Technology Officers, Directors and Head of Departments.*

Findings

Implementing reusable packaging systems requires a systemic shift from linear to circular practices. Industry interviews help to identify popular areas of interest/ concern amongst designers and providers. Table 3 quantifies the popular factors referenced. More mentions infer higher importance. Key factors include: (a) Convenience, (b) Consumer Behaviour, (c) Consumer Perception, (d) Material, Infrastructure and Operational Costs, (e) Customer Retention, and (f) Shrinkage. The emphasis on consumer related factors highlights the importance of designing consumer-centric reusable packaging systems. Some interesting insights include, but are not limited to:

- Funding opportunities are seemingly linked to perceived risk (i.e shrinkage, lack of consumer engagement and consumer retention).
- To reduce asset shrinkage (risk), and improve viability, providers introduce digital technologies within back-end processes. Some companies are expanding to consider how technology can streamline processes (convenience), engage the consumer and motivate repeat adoption.
- Investors (and single-use providers) await legislative reforms which favour circular practices prior to investing in circular systems. Without clear messaging from government, industries stick to the status quo.
- Industries look for guidance on how to implement effective systems, securing profitability and meeting predicted asset rotations.

Table 3. Mentions vs. Sustainability Factors (Bradley & Corsini, 2023).

	Overarching Factor	Freq.*
Env.	Material Selection & Production	20
	Use	2
	Sorting and Cleaning	3
	Transportation	11
	Shrinkage	**34**
	End-of-Life	21
Soc.	Convenience	**36**
	Usability	25
	Awareness	29
	Consumer Perception	**35**
	Consumer Behaviour	**36**
	Consumer Characteristics	33
Econ.	Policies and Legislation	32
	Material, Infrastructure and Operational Costs	**35**
	Labour	22
	Customer Retention	**35**
Tech.	Logistics	28
	Management	20
	Maintenance and Infrastructure	10
	Technology	10
	Product Features	15
	Standards and Protocols	11

**Number of participants referencing overarching factors.*

Providing companies with the tools and information for establishing effective reuse systems prior to implementation can help to reduce financial risk. Ensuring transparency of information between stakeholders and easing the competitive nature within industries to stimulate collective action, will help to expedite reuse adoption within the wider community. Providing accessible, affordable, available and scalable solutions is necessary to stimulate future system growth.

Whilst the future of reusables is pure conjecture, some companies advocate for technologies inclusion, improving asset tracking, container circulation, consumer retention, and engagement. Utilising technologies to prompt or enhance consumer experience is proposed, with added-value necessary for continued adoption (i.e strategies such as gamification). Meanwhile, some see technology as a transitionary tool, a temporary aide to evoke consumer behaviour change. Companies implementing technologies within

reuse systems should consider the role of the technology, as well as the benefits and barriers these technologies will present.

Conclusion

This oral presentation provides preliminary insights into industries learnings for establishing reusable packaging systems. This collates insights from founders, designers and facilitators of reusable packaging systems, with the aim to inform future providers of the challenges awaiting reuse systems. Whilst there is a greater emphasis on refill-on-the-go systems within the dataset, insights gathered form collective insights for reusable packaging systems - learnings may be applicable across all archetypes.

Identifying problematic areas prior to implementation ensures future systems are designed effectively, and expenditure can be optimised and risk reduced. To the authors knowledge this is the first paper to present industry learnings within academia. This oral presentation outlines some key design considerations to aid companies designing and implementing future reusable packaging systems. Future research should explore the potential for technologies inclusion in reuse systems, and how embedding technology can improve reuse sustainability.

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References

C. G. Bradley & L. Corsini (2023). A literature review and analytical framework of the sustainability of reusable packaging. Retrieved December 03, 2024, from https://doi.org/10.1016/j.spc.2023.02.009 [Journal article]

Ellen McArthur Foundation (2019). Reuse-Rethinking Packaging. Retrieved December 03, 2024, from: https://www.ellenmacarthurfoundation.org/reuse-rethinking-packaging [Report]

Greenpeace (Oct 22, 2018). A Crisis of Convenience: The Corporations Behind the Plastics Pollution Pandemic. Retrieved December 03, 2024, from https://issuu.com/greenpeaceinternational/docs/crisis_of_convenience_final [Report]

H. Ritchie, Veronika Samborska and Max Roser (2023) - "Plastic Pollution" Published online at OurWorldinData.org. Retrieved December 03, 2024, from: https://ourworldindata.org/plastic-pollution [Online Resource]

Plastics Europe. (November 5, 2024). Annual production of plastics worldwide from 1950 to 2023 (in million metric tons) [Graph]. In Statista. Retrieved December 03, 2024, from https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/ [Online Resource]

OECD. (May 5, 2022). Plastics use for packaging worldwide in 2019 with projections to 2060 (in million metric tons) [Graph]. In Statista. Retrieved December 03, 2024, from https://www.statista.com/statistics/1342657/plastic-packaging-consumption-worldwide-outlook/ [Online Resource]

S. C. Greenwood, S. Walker, H. M. Baird, R. Parsons, S. Mehl, T. L. Webb, A. T. Slark, A. J. Ryan and R. H. Rothman (2021). Many Happy Returns: Combining insights from the environmental and behavioural sciences to understand what is required to make reusable packaging mainstream. Retrieved December 03, 2024, from https://doi.org/10.1016/j.spc.2021.03.022 [Journal Article]

WRAP (2023). The UK Plastics Pact Annual Report 2022-2023. Retrieved December 03, 2024, from https://www.wrap.ngo/sites/default/files/2023-11/the-uk-plastics-pact-annual-report-2022-2023-0.pdf [Report]

Extended Abstract
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Beyond Ownership: The Environmental Impact of Rent, Repair and Refurbishment of ICT devices

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Keywords: ICT; circular business models; rental; refurbishment.

Introduction

Electronic devices, especially information and communication technology (ICT), are integral to our daily lives. While these devices offer benefits, their production and disposal significantly impact the environment. E-waste is the fastest-growing waste stream (Balde et al. 2024), and many electronic products are replaced before their technical lifespan ends (Magnier & Mugge 2022). Extending the service life of these devices can reduce their environmental impact. Circular business models aim to prolong product life, often through multiple users, and enhance resource efficiency via practices like leasing, resale, and refurbishment.

In our study, we examine the life cycle impacts of circular business models on service life and sustainability, focusing on smartphones, laptops, game consoles, and cameras, utilizing real activity data collected from associated partners in project *Undress Circularity* and conduct user surveys regarding the usage and purchase activities of these products in Germany.

Circular Business Models

A circular business model (CBM) incorporates circular economy principles (such as re-use, recycling) into business operations, contrasting with traditional linear models that follow a 'take, make, dispose' approach. CBMs try to minimize waste and maximize resource efficiency by keeping products in use longer. Our study focuses on existing business models that provide access to ICT devices beyond conventional new sales, rather than on hardware design.

Koide et al. (2022) found that circular strategies like repair and refurbishment offer moderate to high environmental benefits compared to linear models, albeit with potential rebound effects reducing actual benefits. Similarly, Poppe et al. (2024) indicate that savings from circular economy strategies vary widely, with ICT products showing savings of 24-91% compared to new purchases. This variation results from differences in empirical data quality and underlying methodological choices (Poppe et al. 2024).

The potential of reducing environmental impacts through circular business models lays in the reduced number of products needed to fulfil the same useful service life. This can arise from activities such as:

- Reuse and Refurbishment: Extending the life of a product by repairing or refurbishing it avoids the emissions associated with manufacturing a new product.
- Product-as-a-Service Models: Offering products as services (e.g., leasing or renting) can optimize the use of resources and minimize waste, leading to emission reductions.

Thereby there are significant differences in circularity potential between continuously used products (smartphones and laptops) and discontinuously used products (game consoles and cameras).
For continuously used products, extending service life is a primary focus. Maintaining and refurbishing devices can lead to multiple lifetimes of use—encompassing the first, second, and potential third lifetimes—which is vital for reducing environmental impact. In contrast, discontinuously used products present a different challenge; their circular potential lies in reducing the overall number of products required through improved utilization strategies.

Scenario development for impact measurement

Our methodology aligns with life cycle assessment (LCA) principles, focusing on quantifying emissions across different scenarios. The analysis compares a pure linear scenario (purchase, single-user use, disposal) with a baseline scenario reflecting existing reuse in the market. This is contrasted with professional reuse and rental scenarios (see exemplarily Figure 1).

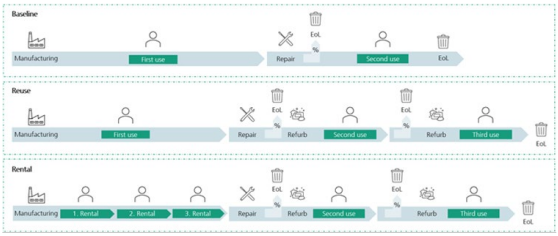


Figure 1: Comparison of different impact models [graphic by IZM]

Given that rental or resale models may appeal to specific user demographics, it's crucial to control for these factors in assessments of avoided emissions (WBCSD 2023). However, a lack of data leads to mixed scenarios that compare user-specific solutions to market averages, which may not accurately reflect avoided emissions.

Our approach thereby has the goal to show the potentials and levers of current circular business models based on real activity data – with all the connected interlinkages – rather than allowing to claim avoided emissions by a single actor.

Current product use in Germany

To establish a realistic scenario for the current product use in Germany compared to the potential benefits a CBM could offer, a user survey was conducted with the project Undress Circularity to assess the current use and flow of devices in Germany and the already existing establishment of CBM in Germany. For private and business users of ICT devices where asked about the time they use their devices, how they buy and dispose them and which factors influence their behaviour. (For the more detailed results of the survey see Circularity e.v. 2024) Based on this user survey and additional literature, the flow of ICT equipment in Germany is analysed. The majority of devices are purchased as new (86%), while 14% of devices are second-hand. Among the devices entering the after-use phase, 27% are being replaced due to defects, whereas 73% are still functional but are no longer used for other reasons. More than 35% of all devices are intended for reuse after-use, leading to a positive net-flow of second-hand devices. 22 percentage points more devices are leaving the system intended for reuse than are entering it. This positive net flow across all product categories indicates that, within the considered market scope, more devices for reuse are leaving the system in after-use than being introduced as second-hand. This surplus highlights the potential for increased circularity across all product groups, but also shows that demand for second-hand devices in Germany is 17% to 28% lower than the after-use supply in this region.

Approximately 18% of all devices are sold, while around 5% are traded in. Notably, only 31% of devices are recycled, whereas 16.5% of devices are stored as backups, and 5.5% are set aside for alternative uses (see Figure 2).

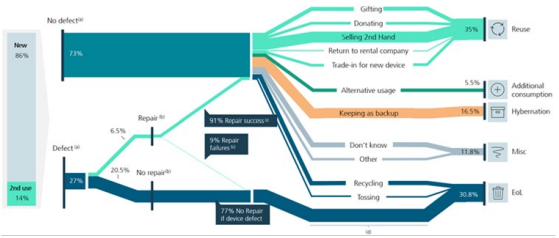


Figure 2: Approximated flow of ICT devices after use in Germany (2020-2024) [graphic by IZM]

Both smartphones and laptops exhibit comparable defect rates before the after-use phase, each around 40%. However, a significant difference emerges in the repair rates: while only 24% of defective smartphones are repaired, laptops show a much higher repair rate of 40%. This suggests that laptops have a longer second life potential through repairs, whereas smartphones are more likely to be discarded or replaced after defect.

Games consoles present a unique profile, with a relatively low defect rate of 19% before after-use. Interestingly, if a defect does occur, games consoles have a high repair rate, with 36% of defective devices being repaired. This combination of low defects and high repair potential positions games consoles as one of the more durable product categories in the analysis.

Conclusions

The research reveals that circular business models are often interlinked, with various stakeholders involved in the rental and resale markets. Notably, rental companies frequently do not directly provide the services associated with product usage (like repair, refurbishment, data deletion between rental periods), leading to complexities in evaluating their effectiveness. While renting tends to be less favorable when considering the actual rental service life, the data indicates that rental services often facilitate second-use opportunities more frequently than traditional sales.

Furthermore, rentals and professional resale services typically concentrate on a select range of high-end devices, which correspondingly exhibit higher rates of private reuse and resale. By analyzing the life cycle impacts of these CBMs, this study will provide valuable insights into optimizing product utilization and fostering sustainable consumption patterns in different electronic product categories.

Acknowledgments

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References

Balde C. P., Kuehr R., Yamamoto T., McDonald R., D'Angelo E., Althaf S. et al. (2024): The Global E-waste Monitor 2024. Bonn, Geneva: International Telecommunication Union, United Nations Institute for Training and Resources

Circularity e.V. (2024): From Consumer Insight to Circular Impact – Market Report of Circular Business Models in the Electronics Market in Germany, online: https://www.circularity.me/wp-content/uploads/2024/10/Circularity_Market_Report_From_Customer_Insights_to_Circular_Impact.pdf

Koide, R., Murakami, S., & Nansai, K. (2022). Prioritising low-risk and high-potential circular economy strategies for decarbonisation: A meta-analysis on consumer-oriented product-service systems. Renewable and Sustainable Energy Reviews, 155, 111858. https://doi.org/10.1016/j.rser.2021.111858

Magnier, L., Mugge, R. (Oct. 2022). "Replaced too soon? An exploration of Western European consumers' replacement of electronic products". In: Resources, Conservation and Recycling 185, p. 106448. doi: 10.1016/j.resconrec.2022.106448.

Poppe, E., Aigner, T.M., Meyer, K., & Molnár, M. (2024). Erweiterte ökologische Wirkungsabschätzung zum Reparaturbonus Thüringen (Ergebnisbericht). Fraunhofer IZM. https://www.izm.fraunhofer.de/de/abteilungen/environmental_reliabilityengineering/projekte/rebo-4-0.html

WBCSD (2023). Guidance avoided emissions. Helping business drive innovations and scale solutions toard net zero. World Business Council for Sustainable Development (wbcsd). https://www.wbcsd.org/Imperatives/Climate-Action/Resources/Guidance-on-Avoided-Emissions

Extended Abstract
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Will it Make it to the Rack? An Investigation of Perceived Retail Value in Second-hand Clothing

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Keywords: Second-hand clothing; perceived value; perceived quality; price; brand availability.

Introduction

In the past several decades, purchasing second-hand has become more widely adopted as a strategy for clothing acquisition, motivated by a desire for access to fashionable garments, an interest in vintage, a search for lower prices, quality garments, and concerns over sustainability (Birtwistle & Moore, 2007; Cassidy, 2012; Welters, 2008; Machado, 2019; Hur, 2020; Kim & Woo, 2022). As well, there has been a marked increase in research interested in the second-hand clothing economy since 2010, from a variety of disciplines (Turunen et al., 2018).

However, with mounting concerns over textile waste, attention is now turning to the quality and quantity of items in the second-hand economy, with reports of thrift shops becoming overrun with unsaleable merchandise (Brooks, 2019; Berry 2022). Concern is often focused on low quality *fast fashion* garments now circulating second-hand (Paz, 2022), with popular online second-hand platform *Vestiaire Collective* even banning fast fashion from its site (Edelson, 2022).

Current research focusing on consumers has addressed the drivers of second-hand clothing consumption (Hur, 2020), shopping practices in this space (Ayres, 2022), as well as disposal and life extension practices (Degenstein et al., 2020; McNeill et al., 2020). Elsewhere, several scholars have addressed the processes and labour that keep second-hand economies functioning, looking at the back-end operations of thrift stores and clothing recyclers (Hawley, 2006; Botticello, 2012; Larsen, 2022; Berry, 2022).

The present study aims to build on the latter stream of literature, interrogating the relationship between *perceived value* (Sihvonen & Turunen, 2016) and the treatment of garments in the second-hand economy. Instead of focusing on the donors and consumers of second-hand clothing, we focus on understanding the decisions that determine which garments make it to the retail floor, and which are simply sent to landfill. Ultimately, this study asks: how does *perceived value* affect sorting, selection, disposal and pricing decisions in second-hand clothing retail?

Methods

Contributing to a larger research project aiming to characterise and study the flow of second-hand clothing and textiles in Canada and New Zealand, this study analyses a data set of 19 semi-structured interviews with key thrift store personnel from both countries. The shops featured in the sample include both large, multinational organisations and small independent charities. This variation adds diversity to the sample, and helps to shed light on the operations of small second-hand businesses, which have received a lack of attention from researchers considering second-hand economies (Berry, 2022).

Thematic coding was used to make meaning from the data. First, an initial coding schema was developed based on collaborative research discussions about our initial impressions of trends present in the interview data. The initial, first-order concept phase of coding was broad, aiming to capture as many important features in the data as possible. As more transcripts were reviewed, the coding schema was revised to second-order concepts. Next, Sihvonen and Turunen's (2016) *six antecedents* of perceived

value were selected as a framework to guide a final stage of coding and strengthen the theoretical grounding of the analysis (Braun & Clarke, 2006). These *six antecedents* were adopted as the main themes; however, additional themes outside of this framework were also created, combined, and refined during the process of re-coding, in order to explore the strengths and limitations of Sihvonen and Turunen's (2016) framework in explaining our data.

Results and Discussion

Thrift shops in this study were found to receive vastly different ratios of unsaleable/saleable donations, with reports ranging from most donations being in "fair to good condition," to as high as 80% of clothing received being unsaleable. Four of Sihvonen and Turunen's (2016) six antecedents of perceived value were shown to be highly applicable to the brick and mortar second hand clothing trade: perceived quality, design, price, and brand availability. Each antecedent, and its sub-categories, was shown to carry different weight depending on the garment and the individual undertaking the evaluation. For example, the relative concept of *condition* was shown to be highly subjective, with many informants referencing the personal perceptions or standards of individual sorters.

As has been shown in the literature, sorters can be thought of as engaging in individual negotiations with each garment, weighing its obvious detractors (e.g., stains, rips, holes, outdated style, poor quality etc.) against characteristics which may add value in the customer's eyes. For example, evidence of newness (e.g., original tags remaining), may mitigate the low desirability of a particular brand name, and fetch a higher price tag. Alternatively, low *brand availability* in a particular location (e.g., Target in New Zealand), makes an item more of a novelty, increasing its value. Furthermore, an attractive brand name was shown to compensate in some instances for the poor condition of an item. Informant comments reveal several reasons why this is the case, such as the initial price of the garment if it were bought new or the quality of the material. On the other hand, brand names that are not regarded well may inhibit sale, regardless of condition, problematizing the inevitable wave of fast fashion entering the second-hand marketplace.

Age was shown to be a highly subjective variable which could either increase (in the case of vintage) or decrease the desirability of the item. Items considered out of date, but that have not yet gained vintage status, were deemed especially challenging to sell by some, with one informant referring to these types of items as the "dead zone of style." Conversely, two of the six antecedents of perceived value were found to be less salient in our data: origin of a brand and authenticity. That said, the issue of the item's *previous owner* was revealed via a distaste for displaying items with the previous owner's name written inside, highlighting lingering hesitations around tangible evidence of shared consumption (e.g., Gregson, 2000).

Conclusions

This study reveals the second-hand clothing economy to be a highly contextual, variable space, impacted by the local environment and the personnel involved. In other words, there is no single deciding factor that guarantees an item will last in the second-hand marketplace; rather, an item needs to have some combination of value-adding factors to save it from the rubbish pile. The variability in approaches, quantity of donations, and quantity of waste complicates the established narrative of uncontrollable cascade of cheap merchandise pervading thrift stores, and suggests that there is value in adopting a more localised approach to addressing the undeniable problem of textile waste in second-hand.

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References

Ayres, J. (2022). The work of shopping: Resellers and the informal economy at the goodwill bins. In K. Tranberg Hansen & J. Le Zotte (Eds.), *Global Perspectives on Changing Secondhand Economies* (pp. 122–154). Routledge. https://doi.org/10.4324/9781003258285

Berry, B. (2022). Glut: Affective labor and the burden of abundance in secondhand economies. *Anthropology of Work Review*, *43*(1), 26–37. https://doi.org/10.1111/awr.12233

Birtwistle, G., & Moore, C. M. (2007). Fashion clothing: Where does it all end up? *International Journal of Retail & Distribution Management*, *35*(3), 210–216.

https://doi.org/10.1108/09590550710735068

Botticello, J. (2012). Between classification, objectification, and perception: Processing secondhand clothing for recycling and reuse. *Textile*, *10*(2), 164–183. https://doi.org/10.2752/175183512X13315695424356

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3, 77-101. https://doi.org/10.1191/1478088706qp063oa

Brooks, A. (2019). *Clothing poverty: The hidden world of fast fashion and second-hand clothes*. Zed Books Ltd.

Cassidy, T. D. (2017). Conceptualizing sustained high quality fashion products in a devalue dominated marketplace. *Fashion Practice, 9*(2), 235–253. https://doi.org/10.1080/17569370.2016.1220136

Degenstein, L. M., McQueen, R. H., McNeill, L. S., Hamlin, R. P., Wakes, S. J., & Dunn, L. A. (2020). Impact of physical condition on disposal and end-of-life extension of clothing. *International Journal of Consumer Studies*, *44*, 586–596. https://onlinelibrary.wiley.com/doi/abs/10.1111/ijcs.12590

Edelson, S. (2022, November 27). Vestiaire Collective Is Banning Fast Fashion From Its Platform. Forbes. https://www.forbes.com/sites/sharonedelson/2022/11/27/the-vestiaire-collective-is-banning-fast-fashion-from-its-platform/

Gregson, N., Brooks, K., & Crewe, L. (2000). Narratives of consumption and the body in the space of the charity/shop. In P. Jackson, M. Lowe, D. Miller, & F. Mort (Eds.), *Commercial Cultures: Economies, Practices, Spaces* (pp. 101–122). Bloomsbury Academic.

Hawley, J. M. (2006). Digging for Diamonds: A Conceptual Framework for Understanding Reclaimed Textile Products. *Clothing and Textiles Research Journal*, *24*(3), 262–275. https://doi.org/10.1177/0887302X06294626

Hur, E. (2020). Rebirth fashion: Secondhand clothing consumption values and perceived risks. *Journal of Cleaner Production*, *273*, 122951. https://doi.org/10.1016/j.jclepro.2020.122951

Kim, S., & Woo, H. (2022). Big data analysis of trends in the second-hand apparel market: A comparison between 2014 and 2019. *Research Journal of Textile and Apparel*, *26*(2), 138–155. Scopus. https://doi.org/10.1108/RJTA-12-2020-0139

Larsen, F. (2022). Valuation in action: Ethnography of an American thrift store. In K. Tranberg Hansen & J. Le Zotte (Eds.), *Global Perspectives on Changing Secondhand Economies* (pp. 155–171). Routledge.

Machado, M. A. D., Almeida, S. O. de, Bollick, L. C., & Bragagnolo, G. (2019). Second-hand fashion market: Consumer role in circular economy. *Journal of Fashion Marketing and Management: An International Journal*, *23*(3), 382–395. https://doi.org/10.1108/JFMM-07-2018-0099

McNeill, L. S., Hamlin, R. P., McQueen, R. H., Degenstein, L., Wakes, S. J., Garrett, T. C., & Dunn, L. (2020). Waste not want not: Behavioural intentions toward garment life extension practices, the role of damage, brand and cost on textile disposal. *Journal of Cleaner Production*, *260*. https://doi.org/10.1016/j.jclepro.2020.121026

Paz, I. G. (2022, July 6). 'The Golden Age of Thrifting Is Over.' *The New York Times*. https://www.nytimes.com/2022/07/06/style/thrift-stores-fast-fashion.html

Sihvonen, J., & Turunen, L. L. M. (2016). As good as new – valuing fashion brands in the online second-hand markets. *Journal of Product & Brand Management*, *25*(3), 285–295. https://doi.org/10.1108/JPBM-06-2015-0894

Turunen, L. L. M., Leipämaa-Leskinen, H., & Sihvonen, J. (2018). Restructuring Secondhand Fashion from the Consumption Perspective. Palgrave Advances in Luxury, In D. Ryding, C. Henninger & M. Blazquez Cano (Eds.), *Vintage Luxury Fashion* (pp. 11–27). Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-319-71985-6_2

Welters, L. (2008). The fashion of sustainability. In J. Hethorn & C. Ulasewicz (Eds.), *Sustainable Fashion: Why Now? A conversation about issues, practices, and possibilities* (pp. 7–29). Fairchild Books. DOI: 10.5040/9781501312250.ch-001

Extended Abstract
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Second-hand smartphones in Finland: Key actors, barriers and enablers

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Keywords: refurbishment, smart phones, value chain

Introduction

The sustainability challenges associated with smartphones include significant social and ecosystem impacts (Zufall *et al*. 2020). Smartphones contain valuable metals, such as gold, silver, copper and palladium (Bookhagen *et al.* 2020). In addition, plastics, which constitute a large share of the device, are challenging in terms of recyclability and contaminants (Eerola *et al.* 2021). Favouring repair and refurbishing of phones would significantly diminish their environmental impacts, which mostly originate from the production of new devices (Pamminger *et al.* 2021; Rizos *et al.,* 2019).

Smartphones tend to be replaced before the end of their technical life (Zufall *et al.* 2020; Wieser & Tröger, 2018) and the lifetimes can be even shorter than 2 years (Cordella *et al.* 2021). Thus, there is potential to extend the lifetime of phones by reusing them either directly or after repair (Kivikytö-Reponen *et al.* 2023; Messmann *et al.* 2019), which is seen in the steady growth of the second-hand phone market size (IMARC, 2025).

However, several challenges, including repairability, updatability, low collection rates and difficulty of disassembly of phones, would need to be solved (Eerola *et al.*, 2021). In addition, consumer concerns, behaviour and attitudes play a role (Mugge *et al.* 2017; Cordova-Pizzarro *et al.* 2020; Wieser and Tröger, 2018; Ruismäki *et al.* 2024).

Significant business potential exists in the global market of used smartphones and the market in Finland is yet underdeveloped, too (Ruismäki *et al.* 2024). Thus, this research addresses the following questions:

- Which actors play a key role in the value chain of used smartphones?
- What factors enable the reuse of smartphones?

This paper adds to the knowledge regarding development needs and identifies topics for further research.

Materials and methods

We carried out a total of nine 30-minute semi-structured interviews (Gillham, 2005), where the focus was on the flows of second-hand smartphones and key barriers and enablers of their refurbishment and reuse. The first interviewees were selected based on the insights gained from the literature review, and additional interviewees were included based on suggestions of the interviewees (Table 1).

Interview questions were prepared by a group of researchers and were specifically targeted for each interviewee. Interview notes were thematically analysed regarding actors, activity types, partners, stakeholders, value chain geographies, enablers, barriers and development needs using Atlas.ti online.

Table 1: Interviewees

Actor type	Description
EPR[1] organization	WEEE management
	WEEE management
	Battery end-of-life management
Telecommunications company	Smartphone sales
	Second-hand phone sales
Leasing company	ICT leasing to organisations
Recycling company	Collection of WEEE, electronics refurbishing
Public sector	WEEE statistics
	Regional council

Results

Value network of refurbished smartphones

Value networks and flows for smartphones are diverse and dispersed (Figure 1).

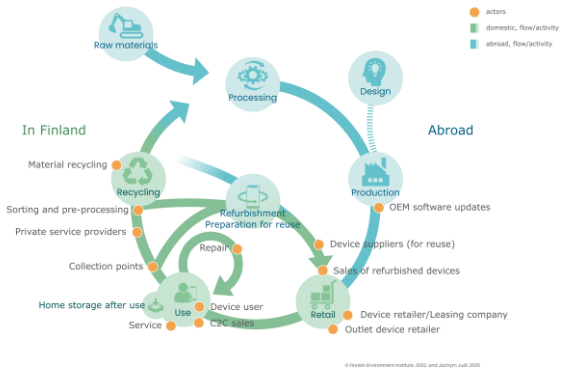


Figure 1 System overview: smartphone value chain and actors

Used devices can be handled locally from consumer to consumer (INT#2) or by actors such as the *Recycling Centre* in Finland and sold back to consumers (INT#1). Typically, used phones are collected at specific WEEE collection sites, electronics retailers, mobile telecommunications companies and private service providers and are then further processed for reuse (INT#1; INT#2; INT#3). Many usable devices are discarded during refurbishment due to being locked (INT#9), which the end user can prevent (INT#5; INT#8). After preparing for reuse (erasing data, functionality check, and repairing eventually broken parts), private service providers may sell them onwards domestically or abroad (INT#1; INT#3;INT#8).

Some activities to prepare for reuse also occur abroad, creating partnerships and value chains that cross borders, even continents. Used smartphones from other markets enter the local market in Finland. They are traded by international wholesalers and then sold by second-hand retailers in the domestic market. (Figure 2).

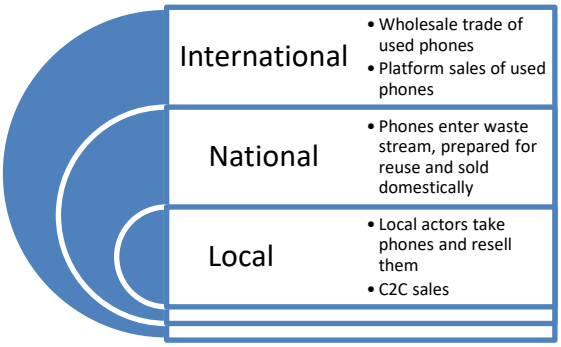


Figure 2: Different geographic scales for used smartphone value chains

Importantly, large amounts of used smartphones are kept by households either as reserve phones, used by family members, or stored for data security concerns (INT#2;INT#3; INT#5; INT#6). A significant opportunity for value creation from used smartphones is therefore lost.

Enablers for a more circular smartphone value chain

Several technical and organizational factors already enable the reuse of smartphones. Technical characteristics of the device, such as high-quality phones (INT#1; INT #3; INT#4; INT#8), as well as long-lasting batteries (INT#5), are crucial enablers. Availability of devices in good condition is improved by add-on solutions, such as protective screens and

[1] Extended Producer Responsibility

protective covers (INT#5; INT#8). When large quantities of devices in good condition are available, it becomes feasible to assess and prepare similar phones for reuse (INT#2), enabling standardized operations and economies of scale. Pivotal partners provide secure erasing software or services (INT#1; INT#9).

The main technical barriers are, most importantly, the limited timeframe during which software updates (operating system) are available (INT#5), data encryption applications that prevent reuse of phones (INT#5; INT#9) and limitations in the logistics and storage capacity for the used phones (INT#4). Further expertise and processes for recognising devices fit for reuse are needed (INT#2, INT#4).

Most importantly, consumer behaviour and attitudes are a significant hindrance (INT#6). For example, consumers hoard their used phones due to a lack of trust (INT#1; INT#4) and fears of spreading their data (INT#1; INT#4; INT#5). Yet, there would be significant potential for circularity from the hoarded phones (#1; #5; #6; #7). The smartphones that are brought to collection points are generally very old models (INT#1) from which the value can no longer be captured.

Discussion and conclusions

The study showed that a value network for improving the reuse and refurbishment of smartphones exists, and capacities are being increased to better capture the potential. A significant barrier, however, is consumer hoarding (also e.g. Wieser & Tröger,2018; Ylä-Mella et al., 2015), which limits an effective value chain of used smartphones. Moreover, as attitudes towards repair vary from country to country (Wieser & Tröger, 2018), studying the local attitudes would be beneficial.

In order to achieve economies of scale, large number of transactions of similar phones is needed. Thus, where domestic market is small, as is the case of Finland, wholesale traders operating in the Nordic, European markets or globally, have a key role in the value network. However,this topic is academically understudied, and therefore, little can be said beyond the information gathered in the interviews. Future studies should focus on differences in environmental impacts between fully domestic value chains and those that involve international brokers, as well as local wholesale business opportunities.

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References

Bookhagen, B., Bastian, D., Buchholz, P., Faulstich, M., Opper, C., Irrgeher, J., Prohaska, T. and Koeberl, C. (2020) Metallic resources in smartphones. Resources Policy 68:101750. https://doi.org/10.1016/j.resourpol.2020.101750

Cordella, M., Alfieri, F., & Sanfelix, J. (2021). Reducing the carbon footprint of ICT products through material efficiency strategies: A life cycle analysis of smartphones. J. Ind.Ecol. 1-17. http://dx.doi.org/10.1111/jiec.13119

Cordova-Pizarro, Daniela, et al. 2020. Circular economy in Mexico’s electronic and cell phone industry: Recent evidence of consumer behavior. Applied Sciences 10.21: 7744. http://dx.doi.org/10.3390/app10217744

Gillham B (2005) Research interviewing. The Range of Techniques. Open University Press, Poland

Eerola et al. (2021). Digitalization and natural resources. GTK open file research report 50/2021.

IMARC Group (2025) Refurbished and Used Mobile Phone Market Report. https://www.imarcgroup.com/refurbished-used-mobile-phones-market Accessed 10.3.2025.

Kivikytö-Reponen, P., Horn, S., Judl, J., Hanski, J., Karhu, M., Uusitalo, T. (2023). Current Challenges in the Lifetime Extension of Smartphones. In: Fukushige, S., Kobayashi, H., Yamasue, E., Hara, K. (eds) EcoDesign for Sustainable Products, Services and Social Systems I. Springer, Singapore. https://doi.org/10.1007/978-981-99-3818-6_20

Messmann, L., Boldoczki, S., Thorenz, A. & Tuma, A. (2019). Potentials of preparation for reuse: A case study at collection points in the German state of Bavaria. J. Clean. Prod. 211, 1534–1546.

http://dx.doi.org/10.1016/j.jclepro.2018.11.264

Mugge, R, Jockin, B., Bocken, N. (2017). How to sell refurbished smartphones? An investigation of different customer groups and appropriate incentives. J. Clean. Prod. 147, 284-296. https://doi.org/10.1016/j.jclepro.2017.01.111

Pamminger, R., Glaser, S., Wimmer, W. (2021) Modelling of different circular end-of-use scenarios for smartphones. The International Journal of Life Cycle Assessment (2021) 26:479-482. DOI:10.1007/s11367-021-01869-2

Rizos,V., Bryhn, J., Alessi, M., Vampmas, A. & Zarra, A. (2019). Identifying the Impact of the Circular Economy on the Fast-Moving Consumer Goods Industry: Opportunities and Challenges for Business, Workers and Consumers- Mobile Phones as an Example. Study. European Economic and Social Committee. DOI: 10.2864/775626

Ruismäki, W., zu Castell- Rüdenhausen, M., Naumanen, M., Orko, I., van den Brink, R., Slotte, P., Lähdesmäki, S. (2024). Arvoketjun mallinnus ja data-analyysi sähkö- ja elektroniikkaromun SER-arvoketjussa alueellisella tasolla. Uudenmaanliitto.

Ylä-Mella, J., Keiski, R.L., Pongrácz, E., 2015. Electronic waste recovery in Finland: consumers' perceptions towards recycling and re-use of mobile phones. Waste Manag. Urban Min. 45, 374e384. https://doi.org/10.1016/j.wasman.2015.02.031

Zufall, J., Norris, S., Schaltegger, S., Revellio, F., Hansen, E.G. 2020. Business model patterns of sustainability pioneers-Analysing cases across the smartphone life cycle. J. Clean. Prod. 244, 118651 https://doi.org/10.1016/j.jclepro.2019.118651

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Circular Fashion Success: Cross-Country Insights on Adoption of Circular Business Model Offerings

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Keywords: circular business model; circular fashion; product-service system; fashion rental; case study.

Extended Abstract

New business models are increasingly recognized as vital for steering production and consumption towards sustainability (Dentchev et al., 2018). Business models that contribute to the realization of a circular economy offer a promising approach to this by emphasizing the reduction, reuse, and recovery of materials (Kirchherr et al., 2017). Indeed, studies indicate a correlation between the adoption of circular practices and reduced CO2 emissions (Linder et al., 2020). Consequently, a growing body of scientific research on circular business models has emerged, aimed at understanding how to design and implement such models. Circular business models have high potential in industries like textiles and apparel, which account for significant environmental impacts due to resource-intensive production and consumption (Tukker et al., 2016). However, widespread adoption of circular business models has yet to take off (OECD, 2019), prompting research into drivers and barriers to their implementation.

Several studies have addressed challenges related to the adoption of circular business model offerings, and case studies on their implementation have been investigated (Rosa et al., 2019; Salvador et al., 2020). Still, knowledge gaps remain. First, current empirical research on circular business models often underlooks 'failures', instead describing success stories (Diaz Lopez et al., 2019; Palmié et al., 2021). This bias highlights a gap and an opportunity to learn more about the adoption of circular business model offerings in critical sectors. Second, there is a need for additional case studies to enhance knowledge of consumer perceptions and behaviors toward circular offers (Bodenheimer et al., 2022; Salvador et al., 2020). Most case studies emphasize the company's perspective while neglecting the consumer's. In fact, the customer perspective has been largely ignored in existing research on the design of circular business models (Salvador et al., 2020).

Moreover, current empirical research highlights the importance of studying barriers to circular business model implementation according to specific archetypes, rather than merging various circular business model types together in analyses (Vermunt et al., 2019). However, studies that do so are limited, especially those comparing specific circular business model archetypes within the same sector (Kanda et al., 2024). Thus, more research is needed to explore specific archetypes and the unique challenges associated with their implementation. Finally, cross-country comparisons of circular business models are limited (Bodenheimer et al., 2022; Kanda et al., 2024; Vermunt et al., 2019). There is an opportunity for further cross-country research on these models across different geographical locations and contexts (Reim et al., 2021).

Current research documents that similar types of circular business models appear across different geographic locations. In the textiles and apparel industry, companies like WOW Closet (Sweden), LENA Library (Netherlands), Ours (Spain), and Rent the Runway (USA) have embraced a similar circular business strategy: offering clothes for lease rather than purchase. Despite sharing this approach, their rates of success and adoption vary significantly, with two of them enduring for nearly a decade while the other two have ceased operations. These differences highlight the central question of this research: Why do similar circular business models succeed while others do not?

To address this question, this research adopts a multidisciplinary approach, integrating business models and consumer research perspectives. It focuses on case studies of both successful and unsuccessful companies across diverse geographic contexts. This analysis aims to 1) identify criteria for case study collection, including a definition of 'success' and 2) present a conceptual framework for analysing the case studies. This is done by a review of academic literature focused on the intersection of circular business models, circular fashion, and related research streams such as consumer research and innovation studies. Moreover, existing conceptual framework(s) for analysing the adoption of circular business offerings are reviewed.

Ultimately, this research aims to advance circular business model knowledge by furthering understanding of how these models can be effectively designed and implemented. By contributing empirical research on circular business model 'failures,' this research works to address the potential bias of success stories in the literature. Moreover, examining drivers and barriers of a specific circular business model archetype from the perspectives of both companies and customer offers a more comprehensive understanding of the factors influencing circular business model adoption.

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References

Bodenheimer, M., Schuler, J., & Wilkening, T. (2022). Drivers and barriers to fashion rental for everyday garments: An empirical analysis of a former fashion-rental company. *Sustainability: Science, Practice and Policy*, *18*(1), 344–356. https://doi.org/10.1080/15487733.2022.2065774

Dentchev, N., Rauter, R., Jóhannsdóttir, L., Snihur, Y., Rosano, M., Baumgartner, R., Nyberg, T., Tang, X., van Hoof, B., & Jonker, J. (2018). Embracing the variety of sustainable business models: A prolific field of research and a future research agenda. *Journal of Cleaner Production*, *194*,695–703. https://doi.org/10.1016/j.jclepro.2018.05.156

Diaz Lopez, F. J., Bastein, T., & Tukker, A. (2019). Business Model Innovation for Resource-efficiency, Circularity and Cleaner Production: What 143 Cases Tell Us. *Resource Efficiency: Concepts, Challenges, Scenarios and Policy Options*, *155*, 20–35. https://doi.org/10.1016/j.ecolecon.2018.03.009

Kanda, W., Klofsten, M., Bienkowska, D., Henry, M., & Hjelm, O. (2024). Challenges of circular new ventures: An empirical analysis of 70 cases. *Journal of Cleaner Production*, *442*, 141103. https://doi.org/10.1016/j.jclepro.2024.141103

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Linder, M., Boyer, R. H. W., Dahllöf, L., Vanacore, E., & Hunka, A. (2020). Product-level inherent circularity and its relationship to environmental impact. *Journal of Cleaner Production*, *260*, 121096. https://doi.org/10.1016/j.jclepro.2020.121096

OECD. (2019). *Business Models for the Circular Economy*. https://doi.org/10.1787/g2g9dd62-en

Palmié, M., Boehm, J., Lekkas, C.-K., Parida, V., Wincent, J., & Gassmann, O. (2021). Circular business model implementation: Design choices, orchestration strategies, and transition pathways for resource-sharing solutions. *Journal of Cleaner Production*, *280*, 124399. https://doi.org/10.1016/j.jclepro.2020.124399

Reim, W., Sjödin, D., & Parida, V. (2021). Circular business model implementation: A capability development case study from the manufacturing industry. *Business Strategy and the Environment*, *30*(6), 2745–2757. https://doi.org/10.1002/bse.2891

Rosa, P., Sassanelli, C., & Terzi, S. (2019). Towards Circular Business Models: A systematic literature review on classification frameworks and archetypes. *Journal of Cleaner Production*, *236*. Scopus. https://doi.org/10.1016/j.jclepro.2019.117696

Salvador, R., Barros, M. V., Luz, L. M. da, Piekarski, C. M., & de Francisco, A. C. (2020). Circular business models: Current aspects that influence implementation and unaddressed subjects. *Journal of Cleaner Production*, *250*, 119555.

https://doi.org/10.1016/j.jclepro.2019.119555

Tukker, A., Bulavskaya, T., Giljum, S., de Koning, A., Lutter, S., Simas, M., Stadler, K., & Wood, R. (2016). Environmental and resource footprints in a global context: Europe's structural deficit in resource endowments. *Global Environmental Change*, *40*, 171–181. https://doi.org/10.1016/j.gloenvcha.2016.07.002

Vermunt, D. A., Negro, S. O., Verweij, P. A., Kuppens, D. V., & Hekkert, M. P. (2019). Exploring barriers to implementing different circular business models. *Journal of Cleaner Production*, *222*, 891–902. https://doi.org/10.1016/j.jclepro.2019.03.052

Repair, Care, and Maintenance



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A Preliminary Review of Service Design for Repair Practices

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Keywords: Repair; Service Design; Circular Economy

Abstract: Repair remains an underutilised strategy in the circular economy, often deprioritised in favor of recycling despite its potential to reduce environmental impact and extend product lifespans (Keulemans et al., 2023). This systematic literature review investigates how service design can be leveraged to strengthen repair practices. By analysing 60 studies, three key levels of intervention emerge: (1) the micro level, where service design can influence consumer engagement, producer-user interactions, and repair motivations; (2) the meso level, focusing on tools, digital platforms, and process frameworks that facilitate repair accessibility and efficiency; and (3) the macro level, where service design has the potential to shape regulatory frameworks, business models, and cultural shifts that embed repair as a societal norm. Despite its potential, repair is hindered by challenges, such as product complexity (Owen et al., 2024) and insufficient legislative support (Cole & Gnanapragasam, 2017). This review highlights the role of service design in overcoming these barriers by fostering co-creation, developing repair-focused services, and integrating repair into broader sustainability initiatives (Rubenis, 2023). By positioning repair as a service rather than an afterthought, service design could offer new possibilities for circularity and resource efficiency.

Introduction

As the global push for sustainability intensifies, the role of design in supporting circular economy processes has gained significant scholarly attention (van Dam et al., 2020). Traditional linear production and consumption models, based on rapid resource extraction and disposal, are increasingly seen as unsustainable. To address this, researchers propose strategies, such as repair, reuse, remanufacturing, and recycling to extend product life cycles and enhance resource efficiency (Mrad et al., 2025; Frahm et al., 2024; Bakker et al., 2014). Among these strategies, repair remains underexplored and underutilised compared to recycling, which is often prioritised despite its high energy demands and material degradation (Keulemans et al., 2023). By contrast, repair offers a more sustainable alternative with a lower environmental footprint, making its integration into circular economy models increasingly critical (Keulemans et al., 2023).

Repair not only extends product longevity and reduces waste but also functions as a social practice, fostering knowledge exchange, skill development, and community engagement. The growing popularity of initiatives such as repair cafés highlights the importance of repair beyond its environmental benefits, positioning it as a practice embedded in social and educational contexts (van der Velden, 2021). However, despite its advantages, repair is often hindered by various challenges, including product complexity, planned obsolescence, and a lack of consumer awareness and education (Kalantidou et al., 2023; Owen et al., 2024; Abdelmeguid et al., 2024). Addressing these barriers requires a more holistic approach that considers repair not only as a technical activity but as an integral part of economic, environmental, and social systems (Rubenis, 2023).

While much research has focused on circular product design, service design is emerging as a crucial tool for enabling repair practices. Traditionally, service design has been concerned with optimising user experiences and improving service efficiency (Penin, 2018; Polaine et al., 2013). More recently, however, its scope has expanded to include broader systemic interventions, such as shaping business models, policy frameworks, and community-driven initiatives (Van Dam et al., 2020). By facilitating multi-stakeholder collaboration and co-creation, service design can play a key role in making repair more

accessible, economically viable, and socially embedded.

This paper aims to bridge the gap in research on how service design can support repair by conducting a systematic literature review of 60 studies. Our findings reveal three key levels at which service design can enhance repair practices: (1) the micro level, focusing on interactions between producers, products, and users; (2) the meso level, addressing tools, frameworks, and platforms that facilitate repair; and (3) the macro level, examining services that drive broader systemic transitions toward repair-centred business and policy models. By exploring these levels, we contribute to the growing discourse on the role of service design in enabling sustainable and circular practices.

Methodology

Our systematic literature review followed PRISMA guidelines (Liberati et al., 2009; Pati & Lorusso, 2018) to ensure a structured and thorough analysis. Using Scopus and Web of Science, we refined our keyword search to focus on repair practices, service design, and the circular economy. An initial search produced 105 papers. After removing duplicates, screening titles and abstracts, and assessing full-text eligibility, 43 relevant papers remained. Through snowballing, an additional 17 articles were identified, leading to a final selection of 60 studies. This approach ensured comprehensive coverage of existing research while capturing key developments in service design for repair practices.

Findings

This review explores the factors influencing repair culture across different levels - micro (consumer behavior), meso (business and industry practices), and macro (policy and systemic frameworks). By analysing the interplay between individual choices, corporate strategies, and regulatory structures, it highlights the key barriers and opportunities for fostering a sustainable repair ecosystem.

Micro Level

Consumer behavior significantly influences sustainable practices, including repair, as it determines how individuals interact with products and services (Munten & Vanhamme, 2023; Van Dam et al., 2020; Zimmermann et al., 2024). Consumers' choices directly impact companies' strategies by shaping demand for sustainable products (Zimmermann et al., 2024). However, Van Dam et al. (2020) argue that designing for repair alone is insufficient, consumers must also be motivated to care for and maintain their products.

A growing body of research explores barriers and motivations for repair from the user perspective. Factors such as emotional attachment, trust in repair services, product category, and customer confidence influence repair culture (Zimmermann et al., 2024). Consumers' decisions are shaped by intrinsic and extrinsic motivations, particularly in sectors like electronics, fashion, and household appliances (Zimmermann et al., 2024). Financial and environmental benefits can either encourage or discourage repair, depending on how they are communicated (Abdelmeguid et al., 2024; Zimmermann et al., 2024; Rudolf et al., 2022; Fachbach et al., 2022). Persuasive communication, including transparent brand messaging, is essential to building consumer trust and fostering repair engagement (Abdelmeguid et al., 2024; Munten & Vanhamme, 2023; Mrad et al., 2025).

Beyond fixing objects, repair services should highlight the symbolic, economic, and functional value of products (Godfrey & Price, 2023; Ackermann et al., 2018). Strategies such as storytelling, product demonstrations, and success stories help communicate this value (Abdelmeguid et al., 2024). Clear and empathetic communication about repair challenges increases consumer satisfaction and trust, whereas poor customer service and unsuccessful repairs discourage further engagement (Godfrey & Price, 2023; Mrad et al., 2025). Engaging consumers in repair workshops fosters material care and emotional attachment (Abdelmeguid et al., 2024). Nostalgia is a key driver for repair among both consumers and volunteers, influencing brand perception and consumer loyalty (Munten & Vanhamme, 2023; Owen et al., 2024; Nielsen & Laursen, 2023). Positive past repair experiences also increase the likelihood of future repair behavior (Fachbach et al., 2022). Perceived product quality affects whether consumers choose to repair or discard items (Maestri & Wakkary, 2011; Nielsen & Laursen, 2023; Munten & Vanhamme, 2023; Roskladka et al., 2023; Jaeger-Erben et al., 2021). Consumers are more likely to repair high-value

items or those with significant monetary investment (Zimmermann et al., 2024; Masclet et al., 2023; Ackermann et al., 2018). In contrast, cheaper products are often discarded, even in volunteer repair cafés (Nielsen & Laursen, 2023). However, fashion consumers present an exception- despite the overconsumption linked to fashion trends, some consumers repair fast-fashion garments due to emotional attachment (McNeill et al., 2020). Encouraging long-term emotional connections with clothing rather than trend-driven consumption could promote repair culture.

Consumers engaged in recycling are more inclined to repair (McNeill et al., 2020), yet repair remains overshadowed by recycling. Increasing consumer awareness about repair's benefits is crucial, as lack of knowledge and transparency serve as barriers (Abdelmeguid et al., 2024; Rudolf et al., 2022; Munten & Vanhamme, 2023; Luukkonen & Van Den Broek, 2024; Godfrey et al., 2022). Simple product designs and flexible materials encourage repair, while complexity discourages it (Lundberg et al., 2024; Godfrey et al., 2022). When repair information is unclear or unavailable, consumers are less likely to attempt it (Fachbach et al., 2022; Miles, 2019). Social acceptance and community engagement also shape repair behavior (Zimmermann et al., 2024; McNeill et al., 2020; Ackermann et al., 2018). Volunteers in repair cafés are often driven by emotional connections to repair (Nielsen & Laursen, 2023). While repair cafés promote anti-consumerism and community building, their financial accessibility remains limited, often attracting those who can afford repair and are ideologically aligned with sustainability (Masclet et al., 2023). Addressing financial and psychological barriers through persuasive communication and economic incentives can enhance repair engagement (Zimmermann et al., 2024; McNeill et al., 2020). Repair fosters creativity by encouraging stakeholder collaboration, user-centric approaches, and repurposing objects (Abdelmeguid et al., 2024; Maestri & Wakkary, 2011). However, electronic waste is growing rapidly due to increasing product complexity and limited repairability, leading to "hibernation" where unused electronics accumulate without being discarded or repaired (Owen et al., 2024; Moreu & Hurtado, 2023; Zimmermann et al., 2024; Kalantidou et al., 2023).

Meso Level

Repair, once a standard practice, is now being re-examined as a critical component of sustainable design and innovation (Rosner et al., 2013; Mejer et al., 2010). Key themes in repairability include consumer engagement, user-centered design, cost and service efficiency, strategic planning, and circular economy approaches. By understanding these aspects, companies and consumers alike can foster more effective and sustainable repair practices.

Interactive platforms, workshops, and clear communication strategies encourage users to engage in repair (Ackermann, 2021). The repair literature, especially in electronics, emphasises challenges posed by technological complexity. Strategies such as push notifications, product modifications signaling the need for repair, and knowledge-sharing platforms help raise consumer awareness (Ackermann, 2021; Lechner et al., 2024). Social engagement, through repair events and collaborative platforms, fosters shared ownership and long-term product care (Ackermann, 2021). Offering repair toolkits and allowing personalisation also enhances consumer involvement (Rosner et al., 2013).

User participation in product design ensures alignment with repairability goals (Mellick Lopes & Gill, 2023). Furthermore, technology enhances transparency, customisation, and service efficiency, with seamless value chain collaboration being key to sustainability (Abdelmeguid et al., 2024). Companies can partner with disassembly-ready manufacturers to enhance circularity. However, transitioning from product sales to service-based models presents challenges, including high labor costs and revenue constraints (Neely, 2008). Resistance from sales teams, customers, and corporate culture remains an obstacle.

Repair services must balance cost and speed to maintain competitiveness. A bi-objective model minimises delays and costs in post-sales repair networks (Yıldız & Soylu, 2019). Financial incentives, such as tax reductions, cash refunds, or repair vouchers, could further encourage repair (Rudolf et al., 2022). Competition between manufacturers and third-party repair services necessitates mathematical optimisation for cost-efficiency and repairability (Sabbaghi & Behdad, 2017). Improving design manuals with better graphics and terminology

enhances efficiency, safety, and customer satisfaction (Nelson & Adams, 1988).

Poor planning of repair centre locations and resource allocation can increase costs and delays (Zhou et al., 2007). Location-allocation models optimise transportation and service coverage. Barriers in ship repair, including poor scheduling and lack of coordination, can be mitigated using web-based planning tools (Siswantoro et al., 2022). Algorithms further refine repair request management (Rossihina et al., 2020). Urban-rural disparities in repair accessibility highlight the need for solutions to bridge these gaps (Fachbach et al., 2022).

Providing standardised repair tools and accessible toolkits supports both consumers and repair professionals (Rudolf et al., 2022; Masclet et al., 2023). Multimedia resources, such as video tutorials, enhance accessibility (Kilic & Sailaja, 2024). Trust in repair services depends on experienced technicians, transparent pricing, and manufacturer support (Lechner et al., 2024). Many modern products are designed for recycling rather than repair, increasing complexity and costs (Masclet et al., 2023). Designing for disassembly reduces repair time and expenses (Miles, 2019). Updated tools and organised repair environments reflect professionalism and reliability (Godfrey & Price, 2023). Data management systems support 'Design for Repair' by providing stakeholders with technical insights (Roskladka et al., 2023).

Harvesting parts for reuse remains underutilised in service industries (Kodhelaj et al., 2019). Frameworks for part harvesting in high-value, regulation-intensive industries like medical equipment demonstrate scalability (Kodhelaj et al., 2019). Reverse logistics models optimise repair service costs and efficiency (Amini et al., 2005). Efficient maintenance in sectors like automotive and aerospace involves balancing costs, repair capacity, and inventory levels (Tursunovic, 2020; Rappold & Van Roo, 2009).

Mechanised diagnostic tools improve service efficiency, as seen in telecommunications repair networks (Dale et al., 1982; Leonard & Zielinski, 1982; Gauthier & Harris, 1982). The ReSOLVE framework incorporates renewable energy, modular design, virtual platforms, and 3D printing into corporate circular practices (Tu et al., 2020).

Thoughtfully designed repair touchpoints foster community involvement and education (Olivastri & Tagliasco, 2024). Hybrid spaces integrate repair stations, bookcrossing areas, and flexible furniture to encourage skill-sharing and social engagement. Elevating second-hand objects through branding reinforces sustainability and repair values.

Macro Level

Repair culture and sustainability demand more than minor adjustments between consumers and manufacturers; they require systemic transformations encompassing legal, infrastructural, and strategic support (Baines et al., 2009; Tukker & Tischner, 2006). Scholars emphasise the need for interdisciplinary insights from business, design, consumer behavior, and innovation studies to align financial and social priorities while embedding repairability into corporate strategies (Rubenis, 2023). This transition entails structural shifts in production and marketing, incorporating life-cycle assessments to evaluate economic, environmental, and social impacts (Mont, 2022). Expanding beyond eco-design towards circular economy models ensures that products and materials remain in use through repair, remanufacture, and recycling, positioning service design as a vital tool for empowering workers and prioritising consumer education (Wiseman & Sanderson, 2023).

Institutional and policy barriers continue to hinder repair accessibility, particularly in consumer electronics, where restrictive intellectual property laws and misleading warranties complicate user interventions (Svensson-Hoglund et al., 2021). Reforming regulations to mandate repair-friendly designs, extend warranty periods, and enhance consumer protections can shift corporate responsibility beyond profit motives, fostering an ethical business landscape (Rudolf et al., 2022; Abdelmeguid et al., 2024). However, challenges such as greenwashing remain prevalent, as companies often superficially align with sustainability without genuine commitment (Abdelmeguid et al., 2024). Strengthened legislation, transparency, and accountability measures are crucial in ensuring that repair becomes an integrated, rather than performative, aspect of corporate strategies (Mrad et al., 2025).

Beyond regulatory frameworks, repair challenges cultural narratives surrounding obsolescence and disposability, transforming imperfections into creative opportunities (Kalantidou et al., 2023). Repair is not merely a technical process but an act of care for objects, materials, and communities (Rubenis, 2023). Current consumption patterns often prioritise symbolic and emotional value over material appreciation, neglecting the integrity of resources (Godfrey & Price, 2023). Therefore, encouraging an ethos of repair - one grounded in empathy, responsibility, and material respect - can redefine consumer engagement. Businesses play a role in this by fostering repairable product guarantees, integrating repair services into their operations, and training employees to approach materials with sensitivity rather than disposability (Godfrey & Price, 2023). Recognising repair as a skill requiring adaptability and creativity can also drive innovation within repair systems and organisations (Godfrey & Price, 2023).

Socially, repair extends beyond individual objects, fostering community resilience and shared knowledge (Moreu & Hurtado, 2023). Recognising repair as a collective rather than an isolated act can empower individuals, particularly those in vulnerable communities, by creating spaces for engagement, education, and skill-building (Mellick Lopes & Gill, 2023). Local governments must support these initiatives, moving beyond consumer-centric models to recognise commoning practices as essential to circular economies (Kashyap et al., 2023). Repair hubs and collaborative spaces strengthen social ties, promote confidence, and challenge the structural forces driving rapid consumption (Kashyap et al., 2023). However, addressing repair at a systemic level necessitates confronting global supply chains, mass production cycles, and corporate pressures favouring low-cost, high-turnover models (Stein et al., 2023). Sustainable design must incorporate long-term resilience, shared ownership models, and extended producer responsibility to create repair ecosystems that are not only accessible but also equitable across economic and cultural contexts (Wiseman & Sanderson, 2023).

Conclusions

Repair culture is an essential component of sustainable consumption, yet it remains constrained by psychological, economic, and systemic barriers. Addressing these challenges requires a multifaceted approach that integrates user engagement, corporate responsibility, and policy interventions. Consumer trust, regulatory support, and corporate transparency are pivotal in shifting repair from a niche practice to a mainstream sustainability strategy. Strengthening education, community initiatives, and economic incentives can further enhance repair accessibility and appeal (Zimmermann et al., 2024). Ultimately, fostering a repair-oriented mindset across all levels - individual, corporate, and institutional - will be crucial in establishing a circular economy and reducing waste.

References

Abdelmeguid, A., Afy-Shararah, M., & Salonitis, K. (2024). Towards circular fashion: Management strategies promoting circular behaviour along the value chain. *Sustainable Production and Consumption*, *48*, 143–156. https://doi.org/10.1016/j.spc.2024.05.010

Ackermann, L., Mugge, R., & Schoormans, J. (2018). Consumers' perspective on product care: An exploratory study of motivators, ability factors, and triggers. *Journal of Cleaner Production*, *183*, 380–391. https://doi.org/10.1016/j.jclepro.2018.02.099

Adams Stein, J. (2023). Conflicting Interpretations of 'Design' and 'Premature Product Obsolescence': Australia's Right to Repair Inquiry 2020–2021. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis, & A. Gill (Eds.), *Design/Repair* (pp. 13–39). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-46862-9_2

Amini, M. M., Retzlaff-Roberts, D., & Bienstock, C. C. (2005). Designing a reverse logistics operation for short cycle time repair services. *International Journal of Production Economics*, *96*(3), 367–380. https://doi.org/10.1016/j.ijpe.2004.05.010

Baines, T. S., Lightfoot, H. W., Benedettini, O., & Kay, J. M. (2009). The servitization of manufacturing: A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management*, *20*(5), 547–567. https://doi.org/10.1108/17410380910960984

Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: Exploring product life extension through design. *Journal of Cleaner Production*, *69*, 10–16. https://doi.org/10.1016/j.jclepro.2014.01.028

Cole, C., & Gnanapragasam, A. (2017). *Community repair: Enabling repair as part of the movement towards a circular economy*. https://doi.org/10.13140/RG.2.2.25267.22569

Dale, O. B., Robinson, T. W., & Theriot, E. J. (1982). *Automated Repair Service Bureau*: Mechanized Loop Testing Design. *Bell System Technical Journal*, *61*(6), 1235–1256. https://doi.org/10.1002/j.1538-7305.1982.tb04340.x

Fachbach, I., Lechner, G., & Reimann, M. (2022). Drivers of the consumers' intention to use repair services, repair networks and to self-repair. *Journal of Cleaner Production*, *346*, 130969. https://doi.org/10.1016/j.jclepro.2022.130969

Frahm, L. B., Boks, C., & Laursen, L. N. (2024). It's Intertwined! Barriers and Motivations for Second-hand Product Consumption. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-024-00441-y

Gauthier, R. F., & Harris, W. A. (1982). *Automated Repair Service Bureau*: Two Examples of Human Performance Analysis and Design in Planning the ARSB. *Bell System Technical Journal*, *61*(6), 1301–1312. https://doi.org/10.1002/j.1538-7305.1982.tb04344.x

Godfrey, D. M., & Price, L. L. (2023). How an ethos of repair shapes material sustainability in services. *Journal of the Academy of Marketing Science*. https://doi.org/10.1007/s11747-023-00993-9

Godfrey, D. M., Price, L. L., & Lusch, R. F. (2022). Repair, Consumption, and Sustainability: Fixing Fragile Objects and Maintaining Consumer Practices. *Journal of Consumer Research*, *49*(2), 229–251. https://doi.org/10.1093/jcr/ucab067

Hjorth Nielsen, A. S. A., & Laursen, L. N. (2023). *Love at first sight: Immediate emotional attachment of volunteers in repair cafés*. 5th PLATE Conference, Espoo, Finland, 31 May - 2 June 2023.

Jaeger-Erben, M., Frick, V., & Hipp, T. (2021). Why do users (not) repair their devices? A study of the predictors of repair practices. *Journal of Cleaner Production*, *286*, 125382. https://doi.org/10.1016/j.jclepro.2020.125382

Kalantidou, E., Keulemans, G., Mellick Lopes, A., Rubenis, N., & Gill, A. (2023). Introduction. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis, & A. Gill (Eds.), *Design/Repair* (pp. 1–10). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-46862-9_1

Keulemans, G., Jansen, T., & Cahill, L. (2023). Luxury and Scarcity: Exploring Anachronisms in the Market for Transformative Repair. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis, & A. Gill (Eds.), *Design/Repair* (pp. 41–64). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-46862-9_3

Kilic, D., & Sailaja, N. (2024). User-Centred Repair: From Current Practices to Future Design. In N. A. Streitz & S. Konomi (Eds.), *Distributed, Ambient and Pervasive Interactions* (Vol. 14718, pp. 52–71). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-59988-0_4

Kodhelaj, I., Chituc, C.-M., Beunders, E., & Janssen, D. (2019). Designing and deploying a business process for product recovery and repair at a servicing organization: A case study and framework proposal. *COMPUTERS IN INDUSTRY*, *105*, 80–98. https://doi.org/10.1016/j.compind.2018.11.002

Lechner, G., Kraßnig, V., & Güsser-Fachbach, I. (2024). How can repair businesses improve their service? Consumer priorities concerning operational aspects of repair services. *Resources, Conservation and Recycling*, *204*, 107501. https://doi.org/10.1016/j.resconrec.2024.107501

Leonard, G. H., & Zielinski, J. E. (1982). Automated Repair Service Bureau: Human Performance Design Techniques. *Bell System Technical Journal*, *61*(6), 1293–1300. Scopus. https://doi.org/10.1002/j.1538-7305.1982.tb04343.x

Lundberg, P., Vainio, A., Viholainen, N., & Korsunova, A. (2024). Consumers and self-repair: What do they repair, what skills do they have and what are they willing to learn? *Resources, Conservation and Recycling*, *206*, 107647. https://doi.org/10.1016/j.resconrec.2024.107647

Luukkonen, R., & Van Den Broek, K. L. (2024). Exploring the drivers behind visiting repair cafés: Insights from mental models. *Cleaner Production Letters*, *7*, 100070. https://doi.org/10.1016/j.clpl.2024.100070

Maestri, L., & Wakkary, R. (2011). Understanding repair as a creative process of everyday design. *Proceedings of the 8th ACM Conference on Creativity and Cognition*, 81–90. https://doi.org/10.1145/2069618.2069633

Masclet, C., Mazudie, J. L., & Boujut, J.-F. (2023). BARRIERS AND OPPORTUNITIES TO REPAIR IN REPAIR CAFES. *Proceedings of the Design Society*, *3*, 727–736. https://doi.org/10.1017/pds.2023.73

McNeill, L. S., Hamlin, R. P., McQueen, R. H., Degenstein, L., Garrett, T. C., Dunn, L., & Wakes, S. (2020). Fashion sensitive young consumers and fashion garment repair: Emotional connections to garments as a sustainability strategy. *International Journal of Consumer Studies*, *44*(4), 361–368. https://doi.org/10.1111/ijcs.12572

Mellick Lopes, A., & Gill, A. (2023). Commoning Repair: Framing a Community Response to Transitioning Waste Economies. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis, & A. Gill (Eds.), *Design/Repair* (pp. 183–212). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-46862-9_8

Mont, O. K. (2002). Clarifying the concept of product–service system. *Journal of Cleaner Production*, *10*(3), 237–245. https://doi.org/10.1016/S0959-6526(01)00039-7

Mrad, M., Semaan, R. W., Christodoulides, G., & Prandelli, E. (2025). Give me a second life! Extending the life-span of luxury products through repair. *Journal of Retailing and Consumer Services*, *82*, 104055. https://doi.org/10.1016/j.jretconser.2024.104055

Munten, P., & Vanhamme, J. (2023). To reduce waste, have it repaired! The quality signaling effect of product repairability. *Journal of Business Research*, *156*, 113457. https://doi.org/10.1016/j.jbusres.2022.113457

Neely, A. (2008). Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research*, *1*(2), 103–118. https://doi.org/10.1007/s12063-009-0015-5

Olivastri, C., & Tagliasco, G. (2024). Servizi per il riuso e il riparo. L'allestimento tra touchpoints e infrastrutture relazionali | Services for reuse and repair. The arrangement between touchpoints and relational infrastructures. *AGATHÓN 15*, 324–331. https://doi.org/10.19229/2464-9309/15272024

Owen, V., Stead, M., & Coulton, P. (2024). Fostering IoT Repair Through Care: Learning from Emotional Durable Gaming Practices and Communities. *Designing Interactive Systems Conference*, 102–105. https://doi.org/10.1145/3656156.3663702

Park, Miles. (2021). *dritte PLATE-Konferenz, 18.–20. September 2019, Berlin DeutschlandPLATE – Product lifetimes and the environment: 3rd PLATE Conference, September 18–20, 2019 Berlin, Germany*. https://doi.org/10.14279/DEPOSITONCE-9253

Penin, L. (2018). An Introduction to Service Design. *London: Bloomsbury*.

Polaine, A., Løvlie, L., & Reason, B. (2013). *Service Design: From Insight to Implementation*. Rosenfeld Media, LLC.

Rappold, J. A., & Van Roo, B. D. (2009). Designing multi-echelon service parts networks with finite repair capacity. *EUROPEAN JOURNAL OF OPERATIONAL RESEARCH*, *199*(3), 781–792. https://doi.org/10.1016/j.ejor.2008.08.006

Roskladka, N., Jaegler, A., & Miragliotta, G. (2023). From "right to repair" to "willingness to repair": Exploring consumer's perspective to product lifecycle extension. *Journal of Cleaner Production*, *432*, 139705. https://doi.org/10.1016/j.jclepro.2023.139705

Rossihina, L. V., Kalach, A. V., Akulov, A. Y., Sysoeva, T. P., & Kravchenko, A. S. (2020). Algorithm design for optimization of service requests for repair. *IOP Conference Series: Earth and Environmental Science*, *548*(3), 032004. https://doi.org/10.1088/1755-1315/548/3/032004

Rubenis, N. (2023). From Roadside Detritus to Communities Painting Pet Portraits: Some Things I Have Learnt About Repair. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis, & A. Gill (Eds.), *Design/Repair* (pp. 241–262). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-46862-9_10

Rudolf, S., Blömeke, S., Niemeyer, J. F., Lawrenz, S., Sharma, P., Hemminghaus, S., Mennenga, M., Schmidt, K., Rausch, A., Spengler, T. S., & Herrmann, C. (2022). Extending the Life Cycle of EEE—Findings from a Repair Study in Germany: Repair Challenges and Recommendations for Action. *Sustainability*, *14*(5), 2993. https://doi.org/10.3390/su14052993

Sabbaghi, M., & Behdad, S. (2017). Design for Repair: A Game Between Manufacturer and Independent Repair Service Provider. *Volume 2A: 43rd Design Automation Conference*, V02AT03A037. https://doi.org/10.1115/DETC2017-67986

Siswantoro, N., Prastowo, H., Nugroho, H. R., Zaman, M. B., Pitana, T., & Priyanta, D. (2022). *A Preliminary Web-Based Intermediary Application Design For Ship Repair Planning Services*. *1081*(1). Scopus. https://doi.org/10.1088/1755-1315/1081/1/012047

Svensson-Hoglund, S., Richter, J. L., Maitre-Ekern, E., Russell, J. D., Pihlajarinne, T., & Dalhammar, C. (2021). Barriers, enablers and market governance: A review of the policy landscape for repair of consumer electronics in the EU and the U.S. *Journal of Cleaner Production*, *288*, 125488.

https://doi.org/10.1016/j.jclepro.2020.125488

Tu, J.-C., Chan, H.-C., & Chen, C.-H. (2020). Establishing Circular Model and Management Benefits of Enterprise from the Circular Economy Standpoint: A Case Study of Chyhjiun Jewelry in Taiwan. *Sustainability*, *12*(10), 4146. https://doi.org/10.3390/su12104146

Tukker, A., & Tischner, U. (2006). Product-services as a research field: Past, present and future. Reflections from a decade of research. *Journal of Cleaner Production*, *14*(17), 1552–1556. https://doi.org/10.1016/j.jclepro.2006.01.022

Tursunovic, R. S. (2020). *Improvement of Operational and Repair Technology of Machine Design in Technical Service by Developing Innovative Constructive Technical Solutions*. *519*(1). Scopus. https://doi.org/10.1088/1755-1315/519/1/012018

Van Dam, K., Simeone, L., Keskin, D., Baldassarre, B., Niero, M., & Morelli, N. (2020). Circular Economy in Industrial Design Research: A Review. *Sustainability*, *12*(24), 10279. https://doi.org/10.3390/su122410279

Van Der Velden, M. (2021). 'Fixing the World One Thing at a Time': Community repair and a sustainable circular economy. *Journal of Cleaner Production*, *304*, 127151. https://doi.org/10.1016/j.jclepro.2021.127151

Wiseman, L., & Sanderson, J. (2023). Design-Led Repair: Insights, Anecdotes and Reflections from Australian Repairers. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis, & A. Gill (Eds.), *Design/Repair* (pp. 67–90). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-46862-9_4

Yildiz, G. B., & Soylu, B. (2019). A multiobjective post-sales guarantee and repair services network design problem. *INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS*, *216*, 305–320. https://doi.org/10.1016/j.ijpe.2019.06.006

Zhou, G., Cao, Z., & Xu, Q. (2007). A Simple Location-Allocation Model on Reverse Logistics for Repair Service System Design. *ICOSCM 2007 - INTERNATIONAL CONFERENCE ON OPERATIONS AND SUPPLY CHAIN MANAGEMENT IN CHINA*, *1*.

Zimmermann, R., Inês, A., Dalmarco, G., & Moreira, A. C. (2024). The role of consumers in the adoption of R-strategies: A review and research agenda. *Cleaner and Responsible Consumption*, *13*, 100193. https://doi.org/10.1016/j.clrc.2024.100193

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Unveiling the Power of Repair Services in Enhancing Consumer Repair Behaviour in the Fashion Industry: A Crucial Step Towards a Circular Economy

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Keywords: Repair; circular economy; repair service; design strategies; consumer behaviour

Abstract: Advocates for reducing the fashion industry's ecological impact emphasize the importance of Circular Economy (CE) principles, with repair being a vital strategy for extending product lifetimes. The current research aims to go beyond merely identifying the factors that influence consumers' perceptions of repair services and their repair behaviour. It explores the types of repair services people prefer and presents actionable and practical design strategies that companies can adopt to facilitate their transition to CE. A quantitative survey (n=265) was set up to identify preferred repair services and factors influencing willingness to repair. Moreover, a focus group with experts (n=10), used the input generated by the survey to further discuss possible design strategies. The survey findings reveal that although consumers strongly support repair, few actually participate in it. While high costs are identified as a barrier, trust and respect for repair professionals serve as motivators for repair behaviour. Additionally, there is a clear preference for local repair services over those offered by fashion brands. The developed design strategies aim at increasing the visibility of repair services, enhancing consumers' repair skills, and leveraging trust in craftsmanship to improve perceptions of quality. The study concludes that improving repair service quality through these design strategies will extend the lifespan of clothing and footwear, crucial for the CE transition. Future research should explore the practical implementation of the proposed strategies and look for possible cultural differences.

Introduction

The fashion industry gained significant attention in recent decades due to its substantial consumption and ecological footprint (Kucińska-Król et al., 2024). Consequently, efforts to reduce this impact have strongly emphasized adopting the principles of the circular economy (CE). According to the Ellen MacArthur Foundation (2020), the core vision of the CE in the fashion industry is to be restorative and regenerative, benefiting businesses, society, and the environment. This approach keeps fashion products and materials at their highest value and reintroducing them into the economy after use to prevent waste (Ellen MacArthur Foundation, 2020). Literature on CE emphasizes repair as a key 'extending-the-loop' strategy because it extends product lifetimes, shapes social interactions, behaviour, and cultural norms, reduces waste, and conserves resources while fostering collaboration, knowledge sharing, and a deeper appreciation of craftsmanship (Henke,2019; Jackson, 2019; McLaren et al., 2020). Additionally, engaging in repair can enhance quality perception which is vital for a CE as high-quality clothes last longer (Connor-Crabb & Rigby, 2019), and the perception of it influences the efforts to extend their lifespan (Niinimäki & Durrani, 2020). Moreover, understanding what defines quality leads to better purchasing and care decisions, ultimately reducing the environmental impact. Here, repair plays a key role in maintaining quality perception. However, introducing repair in the current linear economy is associated with complexities (Parajuly et al., 2024) and so far, it is a relatively recent area of research (Niskanen et al., 2021). A substantial body of research (Frik et al., 2021; Laitala & Klepp, 2018; McNeill et al., 2020; McQueen et al., 2023a; Terzioğlu, 2021) identifies various motivators and barriers consumers face when repairing clothes. The Repair Motivations and Barriers (RMB) model by Terzioğlu (2021) consolidates existing research on repair motivations and barriers into a well-structured format as it outlines repair behaviour, highlighting technical, emotional,

and value-based motivations and barriers. In this model, technical aspects cover the required tools, materials, and knowledge for repair while emotional aspects involve users' emotional responses that influence motivation and value aspects related to the product's aesthetic, symbolic, and functional worth (Terzioğlu, 2021). Due to fast fashion, traditional clothing care skills have decreased, making it harder for people to value and maintain their clothes for long-term use (Hernandez et al., 2024). Additionally, findings show that women and elders are more inclined to self-repair, while younger consumers rely more on unpaid services (McQueen et al., 2023; and McNeill et al., 2020). Furthermore, Niinimäki and Durrani (2020) highlighted that repair professionals significantly influence consumer repair behaviour, encouraging sustainable practices. Lastly, consumers tend to trust retailers, manufacturers, or independent repairers more than repair cafés for electronic device repair (VLAIO Living Lab, 2023). Despite this, little research exists on consumer perceptions regarding clothing and shoe repair professions, their impact on repair behaviour, and preferred services. Therefore, this study combines consumer-focused research with industry-academic collaboration to propose strategies for advancing the transition to a CE through repair (Colley et al., 2024). We formulate following research questions:

RQ1 – What factors influence the consumers' repair behaviour and their perception of repair services for clothing and shoes?

RQ2 - What type of clothing/shoe repair services are preferred by consumers?

RQ3 - What design interventions can fashion brands, and local services adopt to enhance consumer engagement and promote CE?

Method

Case

This research, part of a Flemish Government-funded project, explores consumer behaviour to guide design strategies for longevity and reuse. It brings together academic institutions and fashion companies to advance the transition to CE, focusing on repair services and secondhand goods. Decathlon, a sporting goods retailer, part of this project, aims to support this transition by offering repair, rental, and secondhand options while planning to introduce shoe repair in Belgian stores (Decathlon, 2023). To understand consumer preferences for repair services, Decathlon collaborated with the University of Antwerp, which supports such initiative of slow fashion, ensuring objective and unbiased research on consumer perception.

Research Design

The research design is twofold: first, a quantitative study was conducted to address RQ1 and 2 using a Qualtrics-based questionnaire. The survey comprised of several parts, starting with demographics followed by questions on repair attitudes (5 point-Likert scales), frequency of repair (self- or (un)paid), types of repair one uses and barriers and motivators towards repair) (Terzioğlu, 2021) (RQ1). The last section addressed perception of repair services (RQ2), using a within-subject design to compare perceived quality between brand and local repair (Likert scale). After analysis, a focus group (n=10) was held to brainstorm strategies based on the findings (RQ3). The focus group participants were professional tailors and shoemakers (n=2), an employee at Decathlon (n=1), researchers (n=3), designer (n=1) and employees of the city and province of Antwerp (n=3). The three-hour session included a results presentation, idea generation linked to repair barriers/motivations, and categorization of ideas by implementation complexity. The ideas were noted down on post its and similar ideas were categorized in cohesive categories, which were later summarized in a single slide (see discussion). The survey was sent to 51,500 Decathlon Belgian customers via email (purposive sampling) and shared on social media (convenience sampling) to reach a broader and diverse audience. Ethical approval was granted by the University of Antwerp's Ethics Committee. Participants were informed about the study's purpose and their consent for the use of their anonymous data was taken before beginning the survey. In total, 265 respondents fully completed the survey and passed the attention check. 40% identify as male, 59% as female, and 1% as non-binary. Respondents' ages were categorized and late recoded into two groups: under 50 (49%) and 50+ (51%). Furthermore, 27% of respondents had a low education level (primary or high school), while 73% were highly educated (bachelor's degree or higher). Results of the survey were analyzed using IBM SPSS version 29. The reliability of each variable consisting of multiple item measurement scales (five-point Likert scale, (1) strongly disagree to (5) strongly agree) was assessed through Cronbach's alpha (α) and data reduction took place by using a factor

analysis when a > 0.7. Figure 1 provides an overview of the variables with descriptive information of the items and the final constructs. For the data analyses, we used a paired sample t-test to calculate the preferred repair service and a regression analysis to calculate the influences of different variables concerning repair profession acknowledgement (skill, respect, difficulty, location, easy to find, information, not boring, innovativeness, trendiness) on quality perception of repair services.

Final constructs / items	Mean	SD	Factor loading	α	KMO
A. Repair attitude	4.51	.71		.937	.857
I am positive about repairing clothes and footwear.	4.47	.82	.897		
I like the repair of clothes and footwear.	4.54	.73	.936		
I am comfortable with the idea that clothes and footwear can be repaired	4.52	.75	.947		
Repairing footwear and clothing is sustainable.	4.52	.76	.893		
B. Functional barriers (Terzioğlu, 2021)	2,70	.91		.803	.803
Repair service is not easily accessible.	2,67	1.2	.847		
I know too little about what repair services do.	2,83	1.2	.750		
It takes too much time to get something fixed by a repair service.	2,65	1.1	.625		
C. Emotional barriers (Terzioğlu, 2021)	1.87	.65		.803	.803
In my opinion, repair is not yet socially accepted.	2.16	1.1	.821		
I have a lack of confidence in repair services.	2.01	.94	.560		
I am embarrassed to have my footwear and clothes repaired.	1.45	.68	.683		
D. Value barriers (Terzioğlu, 2021)	2.90	.91		.803	.803
It takes too much effort to get something fixed by a repair service.	2.64	1.2	.602		
I find repair too expensive.	3.05	1.1	.571		
I prefer to replace my broken footwear and clothes with a new one that is in fashion.	3,05	1.2	.801		
E. Quality perception branded repair (Erdoğmus & Büdeyri-Turan, 2012)	3.7	.66		.854	.801
Decathlon repairs no longer have functional defects.	3.59	.79	.811		
Decathlon repairs no longer contain aesthetic flaws	3.42	.80	.813		
Footwear repaired by Decathlon can last for a long time again	3.72	.78	.868		
I think my footwear will be of high quality after the repair at Decathlon.	3.52	.80	.846		
F. Quality perception local repair (Erdoğmus & Büdeyri-Turan, 2012)	3.71	.66		.788	.726
Cobbler repairs no longer have functional defects.	3.75	.85	.776		
Cobbler repairs no longer contain aesthetic flaws	3.41	.90	.727		
Footwear repaired by a standard shoemaker can last for a long time again	3.95	.79	.812		
I think my footwear will be of high quality after the repair at a standard shoemaker.	3.72	.82	.819		

Figure 1. Descriptives and Factor analysis of variables

Results

Repair behaviour and perceptions (RQ1)

Respondents showed a strong positive **attitude toward repair (A-Fig 1)** (mean = 4.51, SD = 0.71), but this rarely translated into action, thus revealing an intention-behaviour gap. Only 15% had items repaired by a third party more than six times in 2023, while 85% were repaired less than five times. Over half rarely or never repair clothing themselves. Pants were the most repaired item (49% self-repair, 60% paid repair), while footwear and jackets were primarily fixed through paid repair. T-shirts and sweaters were repaired the least. Expensive or newer items are repaired more often, as repair costs for cheaper or older items may not be worthwhile. Therefore, the complexity and condition seem to play a role in repair behaviour. Only 31% of respondents felt confident in their repair skills. This gap between repair attitude and behaviour, also common in pro-environmental research (Čapienė, 2019; McNeill et al., 2020), is further explored in the next part of the study.

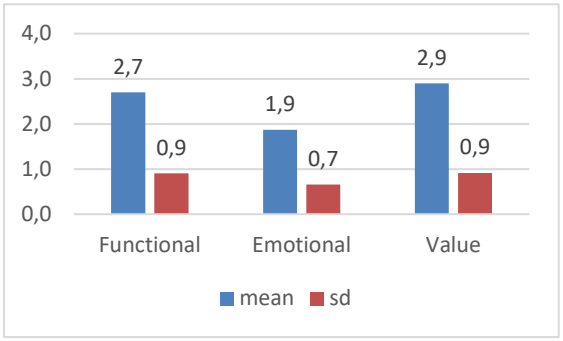


Figure 2. Mean scores and standard deviation of repair barriers

Regarding repair barriers, **(B) functional, (C) emotional** and **(D) value barriers** scored neutrally (Fig 1 (B, C, D) & 2), with the perceived high cost of repair scoring above 3 on the Likert scale, while perceived embarrassment scored below 2 (Figure 1). The neutral scores suggest that respondents may be unaware of what hinders their repair activities or that relevant reasons were not listed in the survey. The results of the barriers are reflected in the motivations, where the highest motivators for repair are the trust in knowledge and skills of the repair service (54%), which also acts as a reason to have an item repaired (63%). Eco-consciousness also has an impact on the motivations towards repair, where 47% of the respondents highlight that repairing footwear and clothes is the right thing to do, and 44% view the reduction of carbon as one of their motivators. Regarding price, 44% see repair as cheaper than buying new, yet only 18% view repair costs as low. This aligns with the earlier findings, which indicate that value barriers are seen as the most significant.

While barriers to repair remain unclear, results show (Figure 3) that repair is socially accepted, and respondents hold a positive view of repair services. They acknowledge repair skills as specialized and challenging, expressing respect for those with these. However, factors such as information about repair services and their accessibility/location scored neutrally. Additionally, while repair shops aren't seen as boring, respondents are neutral about their innovativeness and trendiness, as well as the nice location in the city. The internal correlation was insufficient (α = 0.387) for factor analysis, so each item was analyzed independently

instead of reducing it to a smaller set of factors. Therefore, we can conclude that while respondents highly value and trust the expertise of repair professionals, they do not frequently utilize these services, with cost being the main barrier.

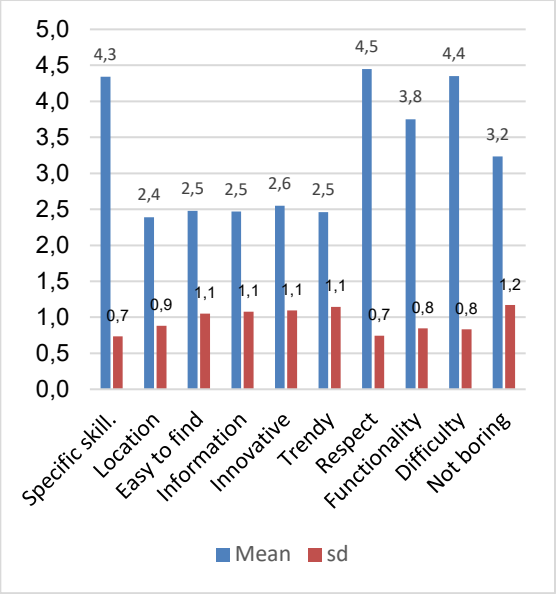


Figure 3. Mean scores of items measuring the acknowledgement of repair

Preferred repair service (RQ2)

As fashion brands expand their repair services, understanding consumer perceptions of both **brand-provided (E- fig 1)** and **local options (F- fig 1)** is essential, as both contribute to the CE. In this study, respondents viewed both services positively, but a paired sample t-test revealed that local repair is preferred over branded repair for three aspects: (1) no functional defects after repair ($t=3.342$; $p<0.001$), (2) durability post-repair ($t=4.945$; $p<0.001$), and (3) high quality after repair ($t=3.914$; $p<0.001$). For "no aesthetic flaws," there was no significant difference, as both services scored equally.

Lastly, we examined what influenced the quality perception of the local repair service using a regression analysis. Only two of the nine items measuring the acknowledgement towards repair services have a significant influence on the quality perception of repair: respect towards repair services ($b = 0,192$; $p=0,006$) and nice location in the city ($b = 0,130$; $p=0,047$). We conclude that there are other factors next to respect towards repair services and their nice location that influence the quality perception of the local repair service.

Design interventions (RQ3)

These survey results were presented to a focus group of experts (see research design). Later the ideas were discussed in a brainstorming session where all ideas were summarized on a single slide. Subsequently, these insights were categorized as strategies based on shared objectives (see discussion). These strategies aim to increase the visibility of repair services, improve consumer repair skills, and highlight the value of repair, aligning with CE principles by maximizing product reuse and minimizing waste. The strategies were later grouped into four design interventions: (i) enhancing repair service visibility, (ii) improving repair skills, (iii) ensuring quality control of repairs, and (iv) increasing the perceived value of repair.

Discussion

Though respondents express a strongly positive attitude towards repair as a sustainable practice, it rarely translates into action, with clothes and footwear seldom repaired. This discussion will explore the four design interventions that were identified in the focus group workshop of experts based on survey results (See methods), to pinpoint key innovations and needs for expanding repair services. To effectively implement these strategies, we suggest that fashion brands adopt a Product-Service System (PSS) approach as it integrates products and services to fulfil customer needs while promoting the CE principle. By offering repair services alongside their products, fashion brands can create a cohesive system that enhances the visibility, accessibility, and quality of repair services.

Design interventions for visibility of repair services

Clothes are seldom being repaired through self-repair or a third party. To promote actual repair behaviour, it's important to enhance the visibility of repair services, highlight craftsmanship, present available options, and leverage the respect and trust consumers have for repair professionals (Lee & Wakefield-Rann, 2021). Building on the survey results and the focus group discussions, we can conclude that visibility can be achieved in different ways:

-**Physical visibility**: Locating repair services more prominent and strategic within the store (for branded repair) or city (for local repair), or redesigning their visibility ensures they are easily identifiable and inviting to customers. Fashion brands can collaborate with local repair to increase the quality perception and establish familiarity with the local repair shops

-**Visibility of the process:** Enhancing trust and quality perceptions of repair services by (Güsser-Fachbach et al., 2023; Singh et al., 2022) improving interactions between repair professionals and customers and provide valuable insights and tips to boost confidence in self-repair skills.
-**Online visibility of repair:** Leveraging social media platforms (Instagram and TikTok) to effectively engage younger generations by showcasing the benefits and possibilities of repair, thus fostering a culture of sustainability and normalization of repair.
-**Collaboration:** Fashion brands can collaborate with local repair to increase the quality perception and establish familiarity with the local repair shops (Singh et al., 2022).
-**Early repairability insights**: Providing customers with information on repair possibilities during purchase to encourage informed decisions and a more sustainable approach to product ownership.

Design for repair skill improvement

We found that repairs are more often conducted by professionals than individuals, likely due to consumers' low confidence in their skills and high trust in repair professionals. We reason that empowering individual to improve their repair skills is essential for increasing self-repair activities and overall repair rates. This could be achieved by:
-Basic skills: Organizing workshops for various repair tasks, from simple (e.g., fixing a button) to complex (e.g., darning), can boost confidence and foster a community of participants with different skill levels (Durrani, 2018).
-Education: Introducing repair workshops in schools can instil care and maintenance habits early, promoting self-sufficiency and sparking interest in repair professions like cobbling and tailoring (Özkan & Wever, 2019). More insight is needed on how this can be integrated into not only basic education but also design education.
-Community skills: Repair cafés can provide repair resources (e.g. sewing machines, fabrics, patches) to further practice repair skills without needing to make (expensive) material costs. Moreover, skilled repairers at repair cafés can assist with troubleshooting (Milstein et al., 2017; Moalem & Mosgaard, 2021; Niinimäki & Durrani, 2020).

Design for repair quality control

Trust in the repair service's knowledge and skills emerged as the primary motivator for repair. Local repair services are favored over branded ones, likely due to unfamiliarity with brand repair offerings and the perception that fashion brands prioritize selling new products. This situation contrasts with other sectors, such as automobile repair, where trust in the brand to repair exists (Hong & Kim, 2020). In contrast, local services build trust through personal relationships and visible repair equipment. Unlike sectors like automobile repair, branded repair often lacks direct interaction with repair professionals, which can diminish trust. Brand sales assistants have different skills than those needed for repair. Therefore, the perception might be that they are going to miscommunicate with the repair service (Ben Amor, 2019). Strategies to increase the quality control of repair can decrease the fear that repaired products cannot last as long as their new counterparts. However, further research is needed to understand how quality is perceived in repair services and products. We suggest:
-Durability claim: Offer warranty for repaired items to assure durability and reliability.
-Quality of repairers: Leverage trust in skilled repair professionals as this elevates the perceived quality of repaired items, reinforcing the value of repair services.
-Quality through transparency: Maintaining transparency in the repair process by clearly communicating methods and standards used to achieve high-quality repairs can build trust and encourage more widespread acceptance of repaired products.
-Quality partnership: Dao et al., (2021), emphasize the need for collaboration between business stakeholders and customers to achieve successful business innovation in repairability. To simplify repairs, fashion brands can partner with repair professionals to analyze their products and identify design improvements that enhance repairability. Incorporating insights from experienced repairers can result in more accessible and durable designs.

Design for repair value

In the study, the perceived high cost of repair remains the most important barrier towards repair. Therefore, it is interesting to highlight the added value of repair.
-Upgrade cost: Customization can increase the added value of repair and emotional value attached towards the product (‘The Rise of Personalised Sneakers’, 2024) which enhances better care and influences clothing longevity

and more sustainable future clothing selection (Maguire & Fahy, 2023).

-Transparent costs: Transparency in repair costs offers pricing insight and could reduce frugality. It also allows personalized pricing by letting customers perform simple tasks (e.g., removing a zipper), decreasing repair service hours and overall costs (Bunodiere & Duflou, 2023; Mohan et al., 2014).

Limitations of the research

A key limitation of this study is the use of quantitative data to capture consumers' repair behaviour and perceptions as it may not capture the depth of respondents' perceptions and behaviors. Moreover, the nature of data collection through Decathlon's mailing list of their Belgian customers may provide limitations in the diversity of perspectives and may reflect the views of more motivated respondents rather than the entire target population.

Conclusion

This research explores consumer repair behaviour and perception of clothing and footwear, highlighting the vital role of skilled repair professionals who are highly regarded for their craftsmanship and expertise. Despite this recognition, consumers rarely use repair services due to high costs (RQ1). Both brand-provided and local repair options are effective, with a preference for local services, and both support the CE (RQ2). To improve repair practices, four design interventions are proposed: (i) increasing repair service visibility, (ii) enhancing repair skills, (iii) ensuring quality control, and (iv) boosting the perceived value of repair (RQ3). In conclusion, repair services are key to advancing the CE by maximizing the reuse of products, materials and, reducing the need for new purchases. Though focused on Belgian consumers, this study offers valuable insights for future research on cultural differences and the practical application of repair strategies. Further research is needed to explore how consumers assess repair quality and whether a hierarchy exists to further develop quality assurance, as well as how to integrate repairability into design education to educate designers to design for repairability.

References

Ben Amor, N. E. H. (2019). What Skills Make a Salesperson Effective? An Exploratory Comparative Study among Car Sales Professionals. *International Business Research*, *12*(11), 76. https://doi.org/10.5539/ibr.v12n11p76

Bunodiere, A., & Duflou, J. R. (2023). Parameterising and Personalising Repair to Decrease Repair Price. *Procedia CIRP*, *116*, 113–118. https://doi.org/10.1016/j.procir.2023.02.020

Čapienė, A. (2019). Theories, models and trends of sustainable consumption attitude-behaviour gap. *Management Theory and Studies for Rural Business and Infrastructure Development*, *41*(3), 332–342. https://doi.org/10.15544/mts.2019.27

Colley, K., Hague, A., Chen, J., Lorenzo-Arribas, A., Wooldridge, T., Somervail, P., Martínez Sánchez, G., Assefa, S., Bender, F., & Craig, T. (2024). Putting people at the centre of the circle: An agenda for behavioural research on the circular economy. *Frontiers in Sustainability*, *5*, 1423912. https://doi.org/10.3389/frsus.2024.1423912

Connell, K. Y. H., & Kozar, J. (2014). *Roadmap to Sustainable Textiles and Clothing: Environmental and Social Aspects of Textiles and Clothing Supply Chain*. Springer Singapore. https://doi.org/10.1007/978-981-287-110-7

Connor-Crabb, A., & Rigby, E. D. (2019). Garment Quality and Sustainability: A User-Based Approach. *Fashion Practice*, *11*(3), 346–374. https://doi.org/10.1080/17569370.2019.1662223

Dao, T., Cooper, T., & Watkins, M. (2021). *Business Innovation for Product Repairability: Implications for Future Policies*. University of Limerick. https://doi.org/10.31880/10344/10205

Decathlon. (2023). *Sustainability | DECATHLON*. https://www.decathlon.be/nl/sustainability_lp-DV3PB3

Durrani, M. (2018). "People Gather for Stranger Things, So Why Not This?" Learning Sustainable Sensibilities through Communal Garment-Mending Practices. *Sustainability*, *10*(7), 2218. https://doi.org/10.3390/su10072218

Ellen MacArthur Foundation. (2020). *Vision of a circular economy for fashion*. https://www.ellenmacarthurfoundation.org/our-vision-of-a-circular-economy-for-fashion

Frik et al. (2021). *dritte PLATE-Konferenz, 18.–20. September 2019, Berlin DeutschlandPLATE – Product lifetimes and the environment: 3rd PLATE Conference, September 18–20, 2019 Berlin, Germany*. https://doi.org/10.14279/DEPOSITONCE-9253

Güsser-Fachbach, I., Lechner, G., Ramos, T. B., & Reimann, M. (2023). Repair service convenience in a circular economy: The perspective of customers and repair companies. *Journal of Cleaner Production*, *415*, 137763.

https://doi.org/10.1016/j.jclepro.2023.137763

Hernandez, L., Petreca, B., Baurley, S., Bianchi-Berthouze, N., & Cho, Y. (2024). Examining clothing repair practices, core competences, techniques, tools and community structures involved in extending the life of garments. *International Journal of Sustainable Fashion & Textiles*, *3*(1), 99–121. https://doi.org/10.1386/sft_00041_1

Hong, J., & Kim, B. (2020). Service Quality, Relationship Benefit and Experience Value in the Auto Repair Services Sector. *Journal of Open Innovation: Technology, Market, and Complexity*, *6*(2), 30. https://doi.org/10.3390/joitmc6020030

Kucińska-Król, I., Festinger, N., Walawska, A., & Kulczycka, J. (2024). Study of Lodz Society's Knowledge of the Circular Economy in the Textile and Clothing Industry. *Fibres & Textiles in Eastern Europe*, *32*(3), 10–20. https://doi.org/10.2478/ftee-2024-0015

Laitala, K., & Klepp, I. G. (2018). Care and Production of Clothing in Norwegian Homes: Environmental Implications of Mending and Making Practices. *Sustainability*, *10*(8), 2899. https://doi.org/10.3390/su10082899

Lee, T., & Wakefield-Rann, R. (2021). Conspicuous and inconspicuous repair: A framework for situating repair in relation to consumer practices and design research. *Journal of Cleaner Production*, *294*, 126310. https://doi.org/10.1016/j.jclepro.2021.126310

Maguire, H., & Fahy, F. (2023). Unlocking insights in the everyday: Exploring practices to foster sustainable maximum use of clothing. *Cleaner and Responsible Consumption*, *8*, 100095. https://doi.org/10.1016/j.clrc.2022.100095

McNeill, L. S., Hamlin, R. P., McQueen, R. H., Degenstein, L., Garrett, T. C., Dunn, L., & Wakes, S. (2020). Fashion sensitive young consumers and fashion garment repair: Emotional connections to garments as a sustainability strategy. *International Journal of Consumer Studies*, *44*(4), 361–368. https://doi.org/10.1111/ijcs.12572

McQueen, R. H., Jain, A., McNeill, L. S., & Kozlowski, A. (2023a). The role of resources in repair practice: Engagement with self, paid and unpaid clothing repair by young consumers. *Textile Research Journal*, *93*(3–4), 576–591. https://doi.org/10.1177/00405175221123067

McQueen, R. H., Jain, A., McNeill, L. S., & Kozlowski, A. (2023b). The role of resources in repair practice: Engagement with self, paid and unpaid clothing repair by young consumers. *Textile Research Journal*, *93*(3–4), 576–591. https://doi.org/10.1177/00405175221123067

Milstein, T., Pileggi, M., & Morgan, E. (Eds.). (2017). *Environmental Communication Pedagogy and Practice* (1st ed.). Routledge. https://doi.org/10.4324/9781315562148

Moalem, R. M., & Mosgaard, M. A. (2021). A Critical Review of the Role of Repair Cafés in a Sustainable Circular Transition. *Sustainability*, *13*(22), 12351. https://doi.org/10.3390/su132212351

Mohan, B., Buell, R. W., & John, L. K. (2014). Lifting the Veil: The Benefits of Cost Transparency. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2498174

Niinimäki, K., & Durrani, M. (2020). Repairing Fashion Cultures: From Disposable to Repairable. In *Transitioning to Responsible Consumption and Production*. MDPI. https://doi.org/10.3390/books978-3-03897-873-2-8

Niskanen, J., McLaren, D., & Anshelm, J. (2021). Repair for a Broken Economy: Lessons for Circular Economy from an International Interview Study of Repairers. *Sustainability*, *13*(4), 2316. https://doi.org/10.3390/su13042316

Özkan, N., & Wever, R. (2019, July 9). Integrating repair into product design education: Insights on repair, design and sustainability. *Insider Knowledge - Proceedings of the Design Research Society Learn X Design Conference, 2019*. Design Research Society LearnXDesign 2019. https://doi.org/10.21606/learnxdesign.2019.16117

Parajuly, K., Green, J., Richter, J., Johnson, M., Rückschloss, J., Peeters, J., Kuehr, R., & Fitzpatrick, C. (2024). Product repair in a circular economy: Exploring public repair behavior from a systems perspective. *Journal of Industrial Ecology*, *28*(1), 74–86. https://doi.org/10.1111/jiec.13451

Singh, C., Park, H., & Joyner Martinez, C. M. (2022). Love letters to Patagonia: Fostering sustainable consumption via consumer–brand relationships. *International Journal of Sustainable Fashion & Textiles*, *1*(1), 41–62. https://doi.org/10.1386/sft/0003_1

Terzioğlu, N. (2021). Repair motivation and barriers model: Investigating user perspectives related to product repair towards a circular economy. *Journal of Cleaner Production*, *289*, 125644. https://doi.org/10.1016/j.jclepro.2020.125644

The Rise of Personalised Sneakers. (2024, July 30). *Gumtoo*. https://gumtoo.sg/blog/the-rise-of-personalized-shoes

VLAIO Living Lab. (2023). Herstelgedrag voor elektro. *Repair & Share*. https://repairshare.be/campagnes/ror/herstelgedrag-voor-elektro/

Research paper
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"Spring Cleaning": skill-sharing towards conscious clothing consumption

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Keywords: Co-learning; Communal platform; Repair; Skill-sharing; Social connectedness.

Abstract: This article discusses the case study of "Spring Cleaning", a one-off event comprising workshops sharing different approaches on extending the use-time of clothing and textiles. Through a qualitative approach, the study aimed to explore if a one-off event can have an impact on the application of skills learnt and how social connectivity contributes to that aim. A secondary aim was to determine if there was a demand for future iterations of this kind of event, in or beyond the university setting. Through the diversity of workshops offered, the event aimed to open up what the parameters of repair, reuse and revival in the clothing and textile sector can be, drawing attention to various timely topics through discussion and practice. These included the preservation of repair skills, celebrating the aesthetics associated with repair and fostering more caring, longer-term relationships with the material world.The findings, gathered through participant observation, a survey and follow-up questionnaire with both participants and facilitators, indicated that for the most part, the event had a positive and lasting impact on attitudes and behaviours around skill-sharing as well as benefits on the social and emotional sides. The sense of opportunity, fulfilment and inspiration was felt from all involved, regardless of their role. Limitations came in the one-off nature of the event, the participant demographic largely having previous experience in clothing or textile repair and in the amount of participant responses only accounting of one third of the total.

Introduction

"Spring Cleaning" was an experimental clothing and textile repair and exchange event taking place at Aalto University's Arts and Design campus from 23.4.–3.5.2024. In this article we frame the event as a case study on the facilitation of a communal platform for skill-sharing in the clothing and textile fields. The study aimed to test the event's potential as a positive behavioral intervention which can lead to empowerment and inspiration for extending product-lifetimes. The programme, generated through an open call, included the exchange of skills such as mending, quilting, collaging and upcycling, in a socially connected, co-learning environment.

The study aims to contribute towards Pugh et al. 's (2024) Just Transitions in the fashion and textile industry, under the concept of new exchange systems, which focus on 'better care and repair of existing clothing' (Pugh et al., 2024, p. 230), as well as on 'facilitating the availability of physical space…and accessibility… to design and repair services, clothing swaps…supporting wide access to training and skills for clothing repair and re-design.' (Pugh et al., 2024, p. 235)

Background

The "Spring Cleaning" event came about as part of the citizen engagement activities work package in the EU research project Textile Recycling Excellence (T-REX). The fast fashion industry is the world's second largest polluter (Castro-López, Iglesias & Puente, 2021), generating 92 million tonnes of waste per year (Niinimäki, Peters, Dahlbo, et. al, 2020), largely caused by the obsolescent nature of mass-produced clothes. As a counteraction to this, the event was structured as a temporary platform to enable skill-sharing on extending the lifetimes of textiles and clothes, from a variety of angles and in an accessible way.

This article builds upon previous studies on localized, decentralized workshops which aim to spread or revive skill sets enabling garment longevity within a group dynamic. The event aimed to contribute to the societal shift towards

slow fashion, 'a practice that decreases clothing purchases and increases garment lifetimes' (Liu, Baines & Ku, 2022, p.1), with emphasis equally on the communal, interactive experience as much as on the skills being shared and the work being crafted.

"DIY groups not only activate people to learn new skills, but the organizers themselves believe in giving people a sense of joy in making while also helping to build relationships with others." (Niinimäki et al., 2021, p.19)

The article also answers Durrani's (2021) call for explorations into an area she describes as being under researched,

"…earlier scholarship has remained limited within the domains of understanding perspectives on domestic mending instead of exploring the practices of communal mending" (Durani, 2021, p.798).

Hirscher, Niinimäki & Armstrong (2017) found that items crafted in a workshop setting become infused with the meaning of the social experience, the emotional attachment making them less likely to be disposed of. Mazzarella & Black (2022) emphasise the importance of 'collaborative activities' to restore disappearing skills, for the benefit and well-being of local workforces and communities in general. Odabasi et al., (2022) echo the notion of the sharing and practicing of repair skills potentially having wider societal impact, aligning it with the 'mending' of relations within society and with the environment. Pugh et al. (2024) discuss the term 'wellbeing economy' as an alternative system to work towards, based around concepts which prioritise the health of individuals and the planet over financial gain.

According to Gwilt (2013), the problems caused by the overproduction and overconsumption of fast fashion are exacerbated by contemporary Western society's lack of repair skills. This could be remedied if 'the repair of fashion garments [was] accepted as a cultural norm' (Gwilt, 2013, p.82). Gwilt argues for the potential benefit of designer, producer and wearer sharing the responsibility of extending garment lifetimes. Odabasi et al. (2022) emphasize the active promotion of textile-based repairs, increasing citizens' agency by circulating making skills between designers and local participants.

'The collective nature of taste enables making visible the interplay that occurs between the individual, the material, and the social, and the lines between what a professional and a vernacular mender can do often become blurred.' (Durrani, 2021, p.788)

Research Method

The "Spring Cleaning" workshop series was organized as a way to carry out practice-led research around a two-part question: Can a one-off intervention increase consumers' long-term interest in and practice of repair skills? Can a workshop experience increase feelings of social connectedness, which in turn, strengthens the impact of the skills learnt?



Figure 1. "Spring Cleaning" event, featuring the 'Exquisite Corpse' communal sculpture created in the first workshop. © Aalto University

Nine different workshops took place during the event, brought together through an open call in the university's internal and external channels. The call for facilitators was a point of emphasis in this study, as it enabled us to use the platform to equally draw out those who had skills to share, alongside those who wanted to learn. The call, circulated via e-mail, invited proposals on sharing methods of clothing and textile repair, reuse and revival, from facilitators with skill levels ranging from hobbyist to professional. A fee was offered to selected applicants. Acceptance was intentionally low threshold, in order to embrace unexpectedness and a plurality of approaches. Seven out of eleven proposals were accepted based on practical feasibility and having a balance of traditional and experimental topics. The Helsinki-based collective Seams, which organizes workshops and events to promote sustainable fashion cultures (Seams, 2024), was invited to host two additional workshops as part of the programme, drawing in participants

from more established and experienced workshop facilitators.

Through the final event programme we aimed to open up ideas about what repair, reuse and revival can be and the variety of forms they can take, creating wide appeal. Workshops were free and open for the general public to attend with each one allocated a running time of two and a half hours. The event was located in a temporary workspace set up in the main lobby of the Arts and Design campus, enabling exposure of the activity to passers-by, as well as inviting walk-in attendees. Two domestic sewing machines, an ironing board and a fabric scrap box were included in the set-up.

The facilitators had varied levels of experience – about one third were running a workshop for the first time. The more traditional topics included: upcycling old or unwanted trousers into bags, hand-quilting with fabric scraps, applique sock mending, darning for knitwear, Sashiko & Kintsugi mending and guidance for repairing cut and sewn garments with signs of wear. The more exploratory topics included: a hands-on learning exercise about differentiating garments' suitability for upcycling vs. recycling, the assembly of a spontaneous, communal soft sculpture from waste material and a sensory, reflective brainstorming session exploring tacit knowledge as a method of critique on current clothing and fashion systems.



Figure 2. Detail, "Material Library" workshop © Aalto University

Alongside the workshop space, a durational clothing exchange area was also included, with items being left and taken freely throughout the event, adding another layer of engagement from passersby. In terms of wider context, the event coincided with Fashion Revolution Week.

Approximately ninety participants took part in the "Spring Cleaning" workshops, five - twenty per workshop. Participant observation in the form of field notes and photography took place.

An online survey about the participants' experience was taken directly after the event, containing mostly multiple-choice questions, about motivation for attending, satisfaction level and skill competence level after the workshop. Facilitators were also sent a survey at this point, but not enough responses were gathered to be included in the data analysis. Follow-up email questionnaires with three or four open ended questions were sent out four months later to both participants and facilitators. The participant questionnaire focused on the continued impact on behaviors or attitudes around the skills learnt or repairing and upcycling habits more in general. The facilitator questionnaire focused on the motivations for running the workshops and reflections on how they went.

The research was conducted qualitatively and the data analyzed thematically by the authors. Key topics were identified around the activities that took place and how participation or facilitation influenced actors.



Figure 3. "Applique Sock Mending" workshop © Aalto University

Findings

Findings from the survey and questionnaires help to answer the study's questions on the impact of the event on feelings of social connectivity and on the subsequent application of the skills learnt. Through reflection on the event's benefits and shortcomings, the findings also help to inform the authors if a demand exists for future iterations and how to best shape these.

Survey
The survey garnered approximately twenty responses, the vast majority indicating the experience had been a positively impactful one. 60% of respondents attended one workshop, while 40% attended several, indicating that there was interest to learn a variety of skills and to repeat the experience. Most of the respondents had some previous experience in clothing repair, with the main motivator for attending the event being to learn a new skill. Many were very satisfied with the workshop/s they attended and all stated they felt more able to repair or upcycle their clothing and textiles after attending. Freeform feedback included remarks about the event's 'cozy' and 'convivial' atmosphere, lots of interest to join in future if the event ran again, the joy of meeting new people whilst learning a new skill, the convenience of some workshops being scheduled after office hours and informative and effective assistance from facilitators. There were also some useful critiques on some workshop facilitators being hard to hear due to the openness of the location, there being a lack of specific enough information on what equipment or materials to bring and that certain workshops could have had a longer duration. A suggestion was made that the workshops could be structured with an introductory lecture on a screen in the beginning, to ensure the core information is made clear and accessible to all participants.

Questionnaire
Seventeen participants and seven facilitators responded to the questionnaire. Feedback from facilitators on their motivation for applying confirmed a demand for this kind of platform, to **test and launch** new ideas:

'…Spring Cleaning was a very good way for us to test this kind of workshop as we had more sewing machines than normal and more material at hand.' (F2)

'I have been wanting to expand my knowledge and skills to more communal work, so I found this opportunity perfect and 'safe' for facilitating my first ever workshop.' (F4)

'I thought the event provided a nice platform and ready audience to try something new.' (F5)

Regarding the question of the impact of a one-off workshop experience, feedback indicated that participants and facilitators were **inspired and activated** to continue with the activities, beyond the event. The continuation of these activities can potentially help to counter society's lack of repair skills, as identified by Gwilt (2013).

'The workshop inspired me a lot to learn more about caring for clothes and garments, and to learn mending & darning. After the workshop I've actively sought information on those.'

'…after the workshop I have fixed my nieces and nephews clothes and my own clothes too… even more often I will think twice how to fix something before tossing it away.'

'The feedback I got directly from the participants as they were leaving was excellent. I think the hop-on-hop-off way works well for this workshop, as it is rather fast to get started and towards the end there's a lot of work that can be done individually without instruction and a participant can also easily continue the work home.' (F1)

'… this experience has inspired me to share [the skill of hand-quilting] with others in the future.' (F6)

Durrani's description of mending as 'a gateway between the old and the new, the broken and the fixed, the wasted and the restored' (Durrani, 2021, p.798), is echoed in the feedback which emerged on discovering **new potential** in damaged or unused garments. The ability to influence consumers' perception and identification of what can still revived, paired with the skills on how to action it, can potentially lead to the extension of product use-times:

'I've loved old garments for a long time, but this workshop made me see more possibilities in broken garments as well.'

'The workshop inspired me to look at some old clothes that belonged to my family members who no longer use them and now I have got them upcycled to new dresses for myself.'

A sense of **wellbeing and appreciation** for the social aspect of the workshop was noted by participants and facilitators, affirming the event's positive impact on feelings of social connectedness, as discussed by Mazzarella & Black (2022), Odabasi et al. (2022) and (Niinimäki et al. (2021).

'Repairing and mending clothes is actually really fun and makes you feel good afterwards. Also, it would be nice to mend clothing together with friends, as we did in the workshop.'

'The workshop wasn't only an opportunity to learn new skills and gain another point of view on sustainability of clothing but also to socialize because I was a foreigner in Finland it was also nice to spend time with other foreigners and exchange experiences. So it was both an educating and a social experience, I really enjoyed it.'

'I think the location was also really nice, I was a bit concerned in the beginning that it would be too loud in the lobby or that people might feel "watched" but it was a really comfortable environment.' (F2)

A feeling of **fulfillment and surprise** was felt amongst facilitators upon reflection on the act of skill sharing in practice:

'Many of the beginner participants were really happy with the workshop, and I could see their excitement and joy through learning the new skill of fixing their own clothes by themselves.' (F4)

'We mostly have to show them everything step by step but are always surprised of how fast they learn and are then able to repair the garments on their own…Throughout the workshop, they all talked and chatted with each other which was really beautiful to see.' (F2)

'It's good to spread the word about the importance of mending and reducing textile waste.' (F3)

'This was my first mending workshop. …after the Spring Cleaning event I have organized the same sock mending workshop twice…I think the method has been equally inspiring for both beginners and advanced crafters: it's an easy, zero-pressure and almost zero-cost project for beginners and something new for the advanced sewists who pretty much make all other clothes except socks themselves. (F1)

'Hands-on techniques often lead to surprising results, and in this case, I was impressed by how quickly the participants grasped the technique, despite it being a morning session. Additionally, the materials used in this workshop resulted in a very different aesthetic compared to what I've seen in India, which added an interesting contrast.' (F6)



Figure 3. Detail, "Quilting" workshop © Aalto University

Discussion

The event "Spring Cleaning" proved effective as a starting point for skill-sharing and social encounters to emerge. The continued impact of the seeds of interest, capability and inspiration, planted during the workshops, was evident in the participants' and facilitators' feedback.

From the facilitators' side of things, structuring a task in a way that it can be continued at home helps to extend the activation of the skill beyond the workshop setting. Inspiration was recurrent and mutual between those who experienced the workshop, regardless of their role. For participants, there was an equal appreciation of the educational side and the social opportunity, with feedback indicating positive feelings during and after the workshops. These findings support Liu, Baines & Ku's (2022) observations that activities which satisfy the needs of autonomy, competence and social connectedness directly contribute and correlate to feelings of well-being.

The event was successful in its goal of empowering consumers towards slow consumption and stewardship of products whilst celebrating the aesthetics of repair and individual creativity. Ideologically, it helped to promote alternatives to fashion as a status symbol, trends and pristine-looking products, which can contribute to shifting agency from global brands into the hands of consumers.

Limitations for tracking benefits and impacts come with the one-off, short durational nature of the event, along with the fact that

only approximately one third of the total participants who attended, submitted feedback.

Since the majority of attendees had previous experience in repair, there could be efforts made to target those less familiar with it. The various critiques on the event which emerged from the survey would be taken into account, if or when the event was to run again. There was a clear demand and from, and benefit for, both facilitators and participants of this event, so the authors would also encourage others to explore further iterations of the same model in different contexts and in a more regular frequency.

Conclusion

Through this case study we can conclude that a short-term, one-off skill-sharing experience can increase consumers' interest in and application of repair-related skills while increasing feelings of social connectedness. In relation to product-lifetime context, an event such a "Spring Cleaning" has the potential to change consumers' mindsets and behaviours whilst improving their social well-being. In turn, a culture of active consumers, extending product-lifetimes in practice, can grow.

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References

Castro-López, A, Iglesias, V & Puente, J. (2021). 'Slow Fashion Trends: Are Consumers Willing to Change Their Shopping Behavior to Become More Sustainable?' *Sustainability* 13, no. 24: 13858. https://doi.org/10.3390/su132413858

Durrani, M. (2021). "Like Stitches to a Wound": Fashioning Taste in and Through Garment Mending Practices. *Journal of Contemporary Ethnography*, *50*(6), 775-805. https://doi.org/10.1177/08912416211012031

Gwilt, A. (2013), "Valuing the Role of the Wearer in the Creation of Sustainable Fashion", *Research Journal of Textile and Apparel*, Vol. 17 No. 1, pp. 78-86. https://doi.org/10.1108/RJTA-17-01-2013-B008

Hirscher, A., Niinimäki, K., & Armstrong, C.M. (2018). Social Manufacturing in the Fashion sector: New value creation through alternative design strategies? *Journal of Cleaner Production, 172*, 4544-4554. https://doi.org/10.1016/j.jclepro.2017.11.020

Liu, A, Baines, E & Ku, L. (2022). Slow Fashion Is Positively Linked to Consumers' Well-Being: Evidence from an Online Questionnaire Study in China. *Sustainability*. 14. 10.3390/su142113990.

Mazzarella, Francesco & Black, Sandy. (2022). Fashioning Change: Fashion Activism and Its Outcomes on Local Communities. *Fashion Practice*. 15. 1-26. 10.1080/17569370.2022.2095729.

Niinimäki, K, Peters, G, Dahlbo H, et al. (2020). 'The environmental price of fast fashion. *Nat Rev Earth Environ* 1, pp189–200, doi: 10.1038/s43017-020-0039-9

Niinimäki, K., Durrani, M. & Kohtala, C (2021). Emerging DIY Activities to Enable Well-being and Connected Societies, *International Journal of Craft Research*, 12:1, pp. 9–29 DOI: 10.1386/crre_00038_1

Odabasi, S., von Busch, O., Moon, C., Sansone, L., & Rissanen, T. (2022). Transition Design and Fashion. *Fashion Practice*, *15*(2), 349–367. https://doi.org/10.1080/17569370.2022.2133183

Pugh, R., Brydges, T., Sharpe, S., Lavanga, M. & Retamal, M. (2024) The 'Wellbeing Wardrobe' as a tool to promote just transitions in the fashion and textile industry, Contemporary Social Science, 19:1-3, 223-243, DOI: 10.1080/21582041.2024.2341143

Seams Helsinki. (2025) https://www.seamshelsinki.org/

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Mobile Fixer Studio: How to repair one item at a time on campus

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Keywords: Repair Workshops; Design for Circularity; Sustainability Education; Zero Waste; Design for Sustainability.

Abstract: The belongings at the Arizona State University (ASU) residence halls often have a short lifespan. At the end of each year, dumpsters around campus fill up with discarded personal items, many of which are still in good condition. Despite the efforts of ASU's Zero Waste Initiative to mitigate this issue, the systematic barriers of municipal infrastructure in waste sorting and recycling significantly limit progress. In addition, students often face challenges with practical repair skills, limited resources, and perceived obsolescence. Initial research conducted by the PI of this study through campus-based repair workshops supported the concept of prioritizing repair and offered a potential change of course for personal belongings. This paper explores the conceptualization and implementation of a mobile repair station based on the university's campus through a collaborative case study on the accessibility of repair tools and education on repair techniques. The convergence of campus-based repair initiatives, with the accessibility of a mobile repair station, seeks to cultivate a culture of conscientious consumption amongst the campus community.

Introduction

The circular economy is advocated as an environmental solution by reintegrating discarded materials and products into production and consumption cycles to minimize waste (D'Urzo & Campagnaro, 2023). The circular economy concept, prioritizing repair over recycling, offers tremendous potential for shaping consumer behavior. However, the prevailing focus has primarily centered on material recycling, sidelining the advantages of repair and reusing (Bracquene et al., 2018). Historically, repairing was the standard solution for broken products, but globalization and planned obsolescence undermined this practice (Chapman, 2021).

Fischer (2013) points out a time when fixing everything was standard, in stark contrast to today's disposable culture. In recent times, there has been a surge in the repair of everyday items, fostering social interaction and community bonding (Mattern, 2018). The resurgence of repair gains momentum from trends such as fixer-upper shows and the call for self-sufficiency during the COVID-19 pandemic, positioning repair as a bridge to resilience and sustainability. Scholars studying product life cycles, sustainable consumption, and the circular economy have unearthed layers of repair activities (Goldmark, 2020; Wackman&Knight, 2020). The comeback of repair is exemplified by the global spread of repair cafes and initiatives (Wackman&Knight, 2020), such as The Levi's Tailor Shop and Patagonia, marking the rise of circular design strategies. Repair cafes and innovative service providers, such as Re-Action Collective and Menddie, signify the emergence of repair-centered ecosystems. Repair cafes now serve as public education and connection stations to fix clothes, garments, electronics, electrical devices, and furniture, contributing to social infrastructure. The right-to-repair movement (Repair.eu, n.d.) and the proliferation of repair-focused content on social media further underscore the communal aspect of repair.

Repair cafes often face limitations in physical set-up, scheduling, the volume of repairs, and the types of products repaired (Moalem & Mosgaard, 2021). Campus-based repair workshops conducted by the PI of this study revealed challenges in attaining a broad range of participants. This limitation inspired the concept of a mobile repair station, with the intention to improve the accessibility of repair on campus. Related work, such as The Mobile Repair Café designed by Simon Frémineur, has addressed some of these limitations with a collaborative mobile workshop built into a converted trailer. The cafe is intended to serve places without repair resources, provide a co-repair experience, and raise awareness about repairs; highlighting the significance of the mobile repair area (The Repair Café Mobile,

2025). This case study builds upon this concept by exploring the repair potential on university campuses through the design, fabrication, and implementation of a mobile repair station.

Methodology for *Designing a Repair Station*

Groundwork for The Mobile Fixer Studio

Scholars have examined various layers of repair activities in product life cycles, sustainable consumption, and the circular economy (Parajuly, et al., 2024; Hernandez et al., 2020). As someone interested in crafts and making, the first author of this paper aimed to explore how her expertise contributes to the repair practice. The repair workshops the PI organizes distinguish themselves from repair cafes by necessitating participants to actively repair their possessions whereas in the repair cafes volunteer experts will fix the broken stuff (Repair Café, 2024). This research started with organizing the repair workshops — which would act as "field site, research instrument, and research account" (Rosner, et.al., 2016, p. 1131) — to inspire people to repair their garments. There have been fifteen repair workshops for participants aged 18 and above. The objectives of these workshops were to:

1. Document different repair techniques.
2. Understand how clothes and garment repair services can be designed.
3. Design a system that facilitates access to repair services.
4. Initiate a debate about the right to repair.
5. Foster responsible decision-making among designers and consumers.
6. Document the repaired items and exhibit them to a broader audience.

According to Earth Day, 87% (equivalent to 40 million tons) of fashion items are thrown into "landfills or incinerators" every year (earthday.org, 2022). So in 2023, the PI of this research started to organize repair workshops which is not the main topic of this paper. These free-to-attend workshops comprised two parts: an initial presentation using a slide deck to provide an overview of repair, highlight its importance, discuss different techniques with a designer mindset, and showcase examples of creative and visible repairs. This presentation aimed to change participants' perspectives on repair. The second part involved group discussions, during which attendees shared their repairable items and identified the repairs they could actively perform during the workshop. All participants were provided with mending tools such as needles, scissors, embroidery floss, felt, glues (e.g., Sugru), pre-made patches, and access to a Cricut machine. Discussions among the workshop groups provided insights into participants' motivations for participating and their intentions to continue repairing. The workshops introduced various repair approaches, including visible and invisible mending methods. Most of the time, the participants got their inspiration from the initial presentation and at times they came up to the PI if they had technical questions. These sessions lasted for two hours each and most of the repairs were successfully finished during the time except for a backpack and a porcelain saucer. Eventually, these workshops inspired the idea of a mobile repair station which would ease the access campus-wide instead of staying put at the workshop venue.

The Mobile Fixer Studio had many challenges to solve in the repair landscape. First, it had to address and mend the limitations that repair initiatives faced in general; then serve a unique location, population need, and project. Initial research into the repair movement brought forth a few crucial limitations: location, schedule, and types of repairs. After conducting interviews with the target population, a few participants shared a feeling of guilt behind throwing away objects that are broken. They often remedy the guilt by quickly disposing of the product to get it off of the conscious mind or store it away, sometimes for years, in hopes of a better future. There appears to be a link between perceived value, cost of the item, and motivation to repair it. There are a few types of products that are overwhelming– those that don't look like they should be taken apart, things with lots of components and wiring, and plug-in small appliances. One hindrance towards repair is a lack of confidence stemming from a lack of knowledge and/or fear of failing or making things worse. These insights became the foundation for the design of the repair station.

The Mobile Fixer Studio

As an extension of the project, the PI and a senior-year industrial design student started

working on a mobile repair station design to travel across campus. This station was inspired by the repair kits of IFixit (2023), and the clothes mending kit Mend.It (Kucher, 2020), and Re-action Collective's bicycle sewing machine (Fernie-Jones, 2023) projects. We also had several meetings with the campus's Zero Waste Initiative to comprehend the waste, recycling, and repurposing situation more in-depth. We had a chance to see the amount of waste gathered closely and attended one of the recyclables sorting events as volunteers.

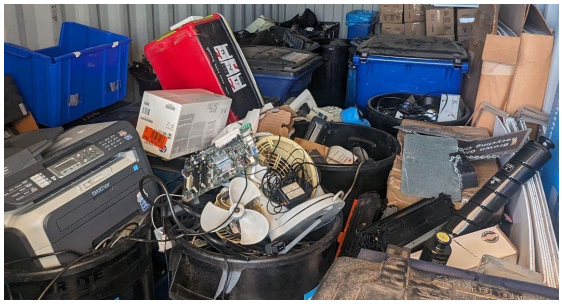


Figure 1. One of the Campus Zero Waste Storages (Photo Credit: Author 1, 2024).

The design of the mobile fixer studio started in the Spring semester of 2024. As mentioned above, the repair workshops provided the necessary tools such as a Cricut Maker 3 machine, various types of needles, hand looms, scrap fabric, felt pieces, and the felt and iron-on vinyl pre-made patches that the PI created. Therefore, the mobile station was required to host these materials and tools. Moreover, the PI requested to have a full toolbox and potentially a sewing machine added to the mobile station. Preliminary findings from the repair workshops were:

1. There is a joy of repairing together,
2. Return on investment for repairs differs for everyone (e.g., emotional aspects, financial gains, and skill development),
3. Negotiations with materials and tools are required before and during the repairs,
4. Fixing is ad hoc designing,
5. Mending can be an outlet for creative expression.

These findings, and the way the workshops were conducted, informed the design of the Mobile Fixer Studio. The design had to act as a gathering space, storing the required equipment and materials and turning into a workstation when needed. After the ideation phase of the mobile station (Figure 2), the 2nd author produced the initial ¼" scaled model (Figure 3).

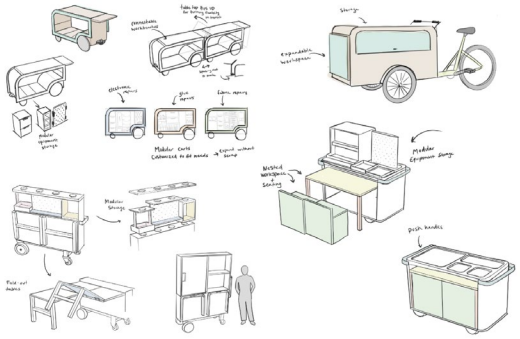


Figure 2. Ideation Sketches (Image Credit: Author 2, 2024).



Figure 3. Initial model (Image Credit: Author 2, 2024).

The design of the repair station took on many iterations. It not only needed to serve a functional purpose but an emotional one as well. The main goals for the prototype were to have a mobile workstation with plenty of comfortable working space, seating, and storage. This was achieved while keeping the principles of modularity, accessibility, and approachability in mind. Initial concepts focused on creating a transformable workstation that is condensed for transport. With the given time frame and resources, we designed the Mobile Fixer Studio to be fabricated using 16GA (1.6mm) Mild Sheet Steel and half-inch (12.7mm) birch plywood. This material choice allowed for the cart to be durable, easily manufacturable, and affordable.

In condensed form, the workstation measures 45 inches long, 24 inches wide, and 43 inches tall 114.3cm x 61cm x 109.2cm). Inspired by street vendor carts, it opens up to a 90-degree counter, allowing the repair instructor and their equipment on one side, and the 'repairee' on

the other side. This not only secures the equipment but makes the experience less overwhelming for the 'repairee'. The unit also features two folding worktables that measure 33 inches by 26 inches (83.9cm x 66cm) when extended and two counter height stools that disassemble flat. In addition, it has a mini mobile workstation that nests inside the main cabinet. The mini workstation gives an additional mobile working surface and is a suitable height for repairers with limited mobility, allowing for more participants.

The station has a set of drawers on one half to store smaller items and materials. These drawers hold three different-sized modular boxes that can be customized to the items to be stored. On the other half of the cart, it has storage for larger equipment such as a sewing machine, and a peg board for easy accessibility of hand tools.

This nomadic unit is far from a traditional working cart. It takes on a more organic shape with prominent curves and circular motifs. While more challenging to fabricate, this softer form made the cart more approachable. The goal was to help alleviate the overwhelmed and intimidated feeling that the population appeared to have towards repair. As for color, we selected it to be eye-catchingly bold; to draw attention without being intimidating. The main cabinet is a vibrant coral with washed red accents, paired with light-toned plywood workspaces and accessories. The color scheme aims to bring a fresh perspective to the traditional red tool cart that is often a symbol of the home workshop.

The fabrication portion of the cart was done with limited time and resources. From conception to fruition, it was fabricated in six weeks primarily using low-tech tooling except a CNC router. The primary fabrication techniques included bending sheet metal with a magnetic hand brake, MIG and TIG welding, rolling sheet metal into curves, metal jigsaw cutting, and CNC routing for the wood. For finishing, the smaller pieces were powder-coated, and the larger cabinet bases were sprayed with urethane paint for durability.

The first review of the prototype was three weeks into fabrication. The intention was for the design to undergo user testing at the Zero Waste Earth Month event to gain feedback for further refinement. With the short timeline only, the base of the cart debuted (Figure 4). The cart had all the critical functional components, wheels, extendable workstations, and the hinge mechanism that allowed it to expand– however, it did not have interior storage, seating, or a mini workspace. While the event did not have as much user interaction as anticipated, the cart was used for a textile repair in its intended manner and was visually evaluated by the population which gave invaluable insights.



Figure 4. Initial prototype and the first Mobile Fixer Studio event on campus (Photo Credit: Author 1, 2024)

After collecting insights from the first debut, it was clear that the original cart was too big in length and width to be efficiently mobile. The original design measured 48 inches long, 30 inches wide, and 43 inches tall (122cm x 76.2cm x 109.2cm); while it had plenty of working and storage space, it was difficult to move with a single person. For the refinement, reducing the size became a priority. This proved challenging in many aspects, the cart not only had to be entirely disassembled and reassembled but cut apart in a way that made a considerable impact on the final size, reduced material waste, and was achievable in three weeks. The second author brought back the design into CAD and experimented, then cut the material down in strategic locations until a method of disassembly was discovered where every piece was to be reused, and the cuts were minimal. This experimentation resulted in a reduction of the overall size by 3 inches in length, and 6 inches in width. After reducing the size and rebuilding the base, every offcut and scrap was reused to make the internal storage and mini cart. The cart became symbolic in the sense that it inherently repaired itself, so remnants of the rebuild on the cart itself were intentionally left visible.

After six weeks of fabricating, modifying, and rebuilding, the prototype (Figure 5) was on exhibition as part of the senior show at Arizona State University during the summer of 2024. While exposure was limited to a design-centered audience, it drew positive feedback from those who interacted with it. The most rewarding experience was seeing a crowd of people autonomously interacting with it, not necessarily in a working repair sense, but in a social sense. It was used as a space for meeting and conversation among the attendees where there was no hesitation to use the table and seating space.



Figure 5. Final 3D Renders of the Mobile Fixer Studio and Final Prototype at the Senior Show (Credit: Authors, 2024).

Future Work

The Mobile Fixer Studio was realized with the help of ASU Herberger Institute's Research Building Investment funds and launching the pop-up workshops was made possible with the help of ASU's main library's (Hayden Library) Learning Resources and Makerspace departments. As soon as the project is published, the design will be open-access and the initial Mobile Fixer Studio will continue to travel across the ASU campus to conduct the pop-up workshops. The first two pop-up workshops of the Mobile Fixer Studio happened in the Spring of 2025 at the Hayden Library on campus where foot traffic is said to exceed 15.000 students daily. These events will create opportunities for campus visitors, faculty, staff, and students to do their repairs when they need it and to get informed about how they can repair their belongings. This research is ongoing, and the PI will continue to gather data to build repair manuals to be used during pop-up workshops and collect information to improve the mobile version of the Fixer Studio (Figure 6).



Figure 6. Timeline of the Repair Research.

Conclusions

Design is not only an act of problem-solving but also an act of changing perspectives, manipulating materials, unraveling complexities, and creating a range of diverse options for both the world and living beings. Repairing and caring for things have a strong relationship with design in terms of the abovementioned acts. Mattern (2018) reflects, "To study maintenance is an act of maintenance. To fill in the gaps in this literature, to draw connections among different disciplines is an act of repair or, simply, of taking care — connecting threads, mending holes, amplifying quiet voices". With this project, we aspire to find more opportunities to make connections both between people and between items and offer a vision for a sustainable, circular future.

Observing individuals who display motivation and inspiration to repair their possessions highlights the potential of design to convince people that there are multiple approaches to fixing things tailored to different skill levels and aspirations. Repair, much like creation, necessitates effective communication and negotiation with materials, demanding substantial time and dedication. Notably, while participants perceived repairing as time-consuming in pre-workshop surveys, their post-workshop responses did not view time as a negative aspect. This indicates that the workshops fostered the development of tacit knowledge, proficiency in tools, expertise in materials, and the cultivation of creative confidence in the realm of repair (Author 1 et al., 2023). With the Mobile Fixer Studio, these events will be more widespread and accessible with the full implementation and integration into the campus system expecting more engagement from campus residents for repairing their broken items or repurposing unwanted products.

Acknowledgments

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References

Bracquene, E., Duflou, J., & Dewulf, W. (2018). Sustainability assessment of product lifetime extension through increased repair and reuse: a case study for laptops. https://doi.org/10.14279/depositonce-9253

Chapman, J. (2021). Meaningful stuff: Design That lasts. The MIT Press. ISBN: 9780262045728

D'Urzo, M., & Campagnaro, C. (2023). Design-led repair & reuse: An approach for an equitable, bottom up, innovation-driven circular economy. *Journal of Cleaner Production*, 387, 135724. https://doi.org/10.1016/j.jclepro.2022.135724.

Earthday.org. (2021). Fashion for the Earth. Retrieved March 10, 2023, from https://www.earthday.org/campaign/sustainable

Fernie-Jones, G. (2023). Outdoor gear repair in the Italian Alps. LinkedIn. Retrieved 27 October 2023, from https://www.linkedin.com/posts/gavin-ferniejones_re-action-co-founder-heather-daviescommunicating-activity-7100801208847581866lf?utm_source=share&utm_medium=member_desktop

Fischer, A. (2013). What Falls to Hand. *Places Journal*. https://doi.org/10.22269/130108

Goldmark, S. (2020). Fixation: How to have stuff without breaking the planet. Island Press. ISBN : 978-1642830453

Hernandez, R. J., Miranda, C., & Goñi, J. (2020). Empowering Sustainable Consumption by Giving Back to Consumers the 'Right to Repair'. Sustainability, 12(3), 850. https://doi.org/10.3390/su12030850

IFixit (2022). IFixit: The Free Repair Manual. Retrieved 25 June 2023, from https://www.ifixit.com/Guide

Kucher, I. (2020). Mend.It. Association for Industrial Design. Retrieved June 25, 2023, from https://www.adidesign.org/2020_z00165

Mattern, S. (2018). Maintenance and care. *Places Journal*. https://doi.org/10.22269/181120

Moalem, R.M.; Mosgaard, M.A. A Critical Review of the Role of Repair Cafés in a Sustainable Circular Transition. *Sustainability* 2021, 13, 12351. https://doi.org/10.3390/ su132212351

Parajuly, K., Green, J., Richter, J., Johnson, M., Rückschloss, J., Peeters, J., Kuehr, R., & Fitzpatrick, C. (2024). Product repair in a circular economy: Exploring public repair behavior from a systems perspective. *Journal of Industrial Ecology*, 28, 74–86. https://doi-org.ezproxy1.lib.asu.edu/10.1111/jiec.13451

Repair Café (2024). Retrieved May 5, 2024, from https://www.repaircafe.org/en/about/

Repair. Eu. (n.d.) Right to Repair Europe. Retrieved 21 March 2025, from https://repair.eu/

Rosner, D. K., Kawas, S., Li, W., Tilly, N., & Sung, Y. C. (2016, February). Out of time, out of place: Reflections on design workshops as a research method. In Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (pp. 1131-1141). https://doi.org/10.1145/2818048.2820021

The Repair Café Mobile. (2025, March 5). Retrieved March 15, 2025, from Repair Together website: https://repairtogether.be/le-repair-cafe-mobile/

Wackman, J., Knight, E. (2020). Repair Revolution: How Fixers Are Transforming Our Throwaway Culture. United Kingdom: New World Library. ISBN: 978-1608686605

Research paper
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Worthy or not worthy? Repair motivations and barriers from consumers across fashion, furniture, and consumer electronics in Denmark

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Keywords: repair; survey; barrier; motivations.

Abstract:
Never has human consumption and demand for products been this high, and the growing demand for products puts a strain on the finite resources available. Therefore, the need for prolonging the lifetime of existing consumer products has received increasing attention from governing bodies such as the European Commission e.g. shown in the 'right-to-repair' directive. While 77% percent of European citizens state they want to repair products before buying new, only 64% state that they have done it – and ~90% have never purchased clothing, smartphones, or televisions secondhand. Prolonging the lifetime of consumer products through repair is therefore an important point towards more sustainable consumption. Yet, a lot of broken products never enter a repair process. This paper aims to shed light on the barriers and motivations for repair to help increase the understanding of how more repairable products can get repaired. Through a Danish national survey (N=1068) and 11 semi-structured interviews, we identify main barriers and motivations for entering a repair process within three main product classifications: *Consumer electronics*, *Fashion*, and *Furniture*. We confirm existing findings that price of repair/replacement is a main motivator/barrier. We also identify *perceived repairability* and *ease of cassation or replacement* as barriers not previously described.

Introduction

'Sustainability' is increasingly a guiding star for governments and companies alike. A Baker McKenzie survey revealed that 73% of companies surveyed expressed willingness to collaborate with competitors to reach 'net-zero', taking away as much greenhouse gas as they emit (Auberger, n.d.). A definition of sustainable development was eloquently worded in the 'Brundtland Report' as development that *"meets the needs of the present without compromising the ability of future generations to meet their own needs"* (United Nations, 1987, p. 15).

However, the 'take-make-waste' approach to products on a large, global scale is positioning many companies far from sustainable development and contributes to large waste of resources. Take textiles as an example; a recent report outlined the volume of returned or unsold textile products that ended up getting destroyed. 20% of textiles sold online are estimated to be returned, where one third of that ends up getting destroyed. Moreover, 4-9% of textiles put on the European market are estimated to be destroyed before ever being used (Duhoux et al., 2024).

Extending the lifespan of products is therefore an important aspect of sustainability, alongside other resource efficiency, waste reduction, and low-carbon strategies (Cooper, 2010). One way to extend product lifespan is through repair. The 'right to repair' movement advocates for empowering individuals by providing them with more opportunities to repair their objects instead of disposing them (European Commission, 2023). However, many repairable consumer products never enter a repair process and instead are discarded and/or replaced by new products (Magnier & Mugge, 2022). Studies conducted on citizens from the EU-28 countries revealed that 77% of consumers are willing to attempt product repair before buying new (European Commission, 2014), yet, only 64% actually engage in repair activities (European Commission, 2018; Laitala et al., 2021). With products like vacuum cleaners, dishwashers, televisions, smartphones and clothing, studies reveal that

~90% have never bought them second-hand (European Commission, 2018). This indicates that if broken products are not repaired, consumers purchase new.

Repairable IT products stay at home

A Danish national survey from 2024 revealed how a large portion of Danish citizens store old IT products (e.g., smartphones, PCs, tablets etc.), which are no longer used, instead of repairing them or making sure they arrive at a recycling station. In the age group between 16-74, 52% stated that their old smartphone is stored at home, while 44% stated that their old laptop or tablet was stored at home (Statistics Denmark, 2024). This is an issue from a resource standpoint as valuable materials then lie dormant in people's drawers rather than re-entering value streams to be used to produce new and relevant products that are needed today. This may also indicate that people tend to store other product categories at home without having them repaired or responsibly discarded of e.g., for recycling or reuse.

In this paper we aim to study the pre-steps before the actual repair process begins to identify determinants and barriers for repair. We investigate this through a Danish national survey and semi-structured interviews of consumers' experiences and attitudes towards repair.

The repair process

According to Bracquene et al., (2019) repairing a product can be portrayed as a 5-step process:

1) Product identification
2) Failure Diagnostic
3) Disassembly & Reassembly
4) Spare Part Replacement
5) Restoring to Working Condition

However, before the repair process can begin, some barriers need to be overcome. This can be interpreted as a decision-making process to decide whether a product is even 'fit' for repair. Among these barriers, a valuation process often occurs to determine whether it is worth spending time or money on a repair rather than a replacement, as perceived product value depreciates over time (van den Berge et al., 2023).

Once this choice has been made, there is a need to determine whether access to the right tools is present or not – this also includes (knowledge of) available offers for repair like local repair cafes. A person's willingness to repair a product rather than dispose of it therefore have multiple thought processes and possibly actors that influence the repair outcome – before a conventional repair process commences. See Figure 1 for a visualization of how the decision-making processes combined with the repair process may result in failure to repair in nearly every step.

Hindrances prior to repair

Despite the value of repair, the repairability of products has decreased considerably in recent years (Fachbach et al., 2022). Additionally, as the number of businesses offering repair has decreased, consumer spending on new products has gone up (Korsunova et al., 2023). There is a need for skills and resources to combat the decline in consumer interest and involvement in the repair process (Hernandez et al., 2020). Some of the common barriers faced by consumers when it comes to product repair are financial constraints, lack of time, knowledge, and skills (E. Dewberry et al., 2016; van den Berge et al., 2023), see also Table 1 for an overview of motivations and barriers that people experience with product repair. The hindrances are many, therefore, it is very beneficial to have repair opportunities that

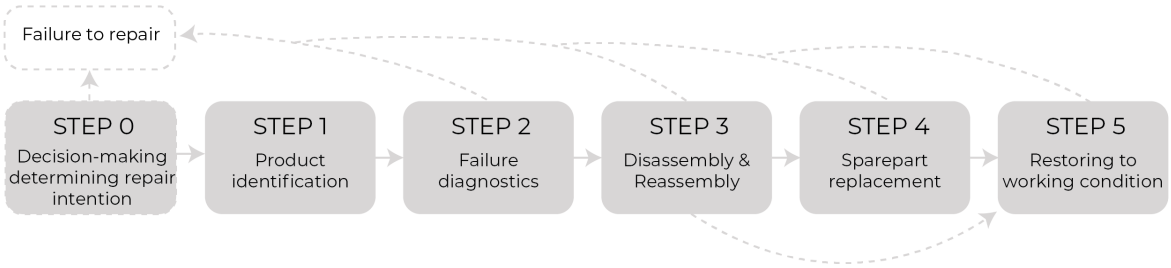


Figure 1. Depiction of the repair process in six steps. Adapted from Bracquene et al. 2019

Table 1 Barriers and motivations for repair

Barrier/ motivation for repair	Description	Reference
Barrier	Lack of time	(E. L. Dewberry et al., 2017; Diddi & Yan, 2019; McCollough, 2020; Mclaren & McLauchlan, 2015)
Barrier / motivation	Financial cost	(Diddi & Yan, 2019; Hernandez et al., 2020; McCollough, 2020; Mclaren & McLauchlan, 2015; Terzioğlu, 2021)
Barrier	Lack of skills	(Cooper & Salvia, 2018; E. L. Dewberry et al., 2017; Diddi & Yan, 2019; Mclaren & McLauchlan, 2015)
Barrier	Lack of product knowledge or available technical specifications	(Hernandez et al., 2020)
Barrier	Negative stigma	(Cooper & Salvia, 2018; Diddi & Yan, 2019; Terzioğlu, 2021)
Barrier	Ease of access to new products and desire for new functionality	(Diddi & Yan, 2019; McCollough, 2020)
Barrier	Low quality materials or condition of the product	(Cooper & Salvia, 2018; Terzioğlu et al., 2015)
Barrier	Spare part availability	(Hernandez et al., 2020; Terzioğlu et al., 2015; Van Der Velden, 2021)
Barrier / motivation	Design for disassembly	(Cooper & Salvia, 2018; E. L. Dewberry et al., 2017; Hernandez et al., 2020; Park, 2021)
Motivation	Environmental footprint	(Diddi & Yan, 2019)
Motivation	Emotional attachment	(Diddi & Yan, 2019; Hernandez et al., 2020; Terzioğlu et al., 2015)
Motivation	Longer lasting product	(Diddi & Yan, 2019)
Motivation	Interest, hobby or perceived satisfaction	(Nielsen & Laursen, 2023; Terzioğlu, 2021; Terzioğlu et al., 2015)
Motivation	Utilitarian need	(Terzioğlu et al., 2015)

may lower the identified repair barriers or increase repair motivation. Community repair initiatives, especially Repair cafés, have emerged to address the repair barriers and the throwaway culture by enabling repair and reducing the number of discarded products (Charter & Keiller, 2016; Pit, 2020; Rosner & Ames, 2014). In repair cafés, people volunteer to repair products free of charge to extend product lifespan. These volunteers provide the necessary skills, knowledge, tools, and experience to overcome some barriers faced by consumers (Madon, 2022). However, multiple factors are influencing whether a product needing repair is repaired. The choice to repair initially lies with the consumer (Terzioğlu, 2021). Thus, if the barriers experienced are too great, the products will not be repaired and likely be discarded and/or replaced. The findings by Terzioglu et al., (2015) also suggest that repair motivations and barriers differ between product categories. Though, such product differentiation is not always included in literature on barriers to product repair.

We argue that it is important to better understand what happens *before* the hands-on repair process begins. The repair decision making, to gain insights into the reasoning behind repairing or replacing a product. To the best of the authors knowledge, a study investigating barriers and motivations for repair within different product categories have not

been conducted before. In this paper, we look towards consumer product classifications that currently generates most of the consumer product waste: 1. Consumer electronics, 2. Furniture, and 3. Fashion (e.g., clothing and footwear) (Ministerie van Algemene Zaken, 2023).

To investigate this, we conducted a Danish national survey within these three classifications of consumer products. The dataset was used to better understand why people replace products in different product categories instead of repairing or recycling. Additionally, semi-structured interviews were done to get richer data on the reasoning behind consumers' decision to repair or not repair a product.

Methodology

The survey was designed around 21 different product classifications within the overarching product classifications (Consumer Electronics, Furniture, and Fashion).

The survey was distributed to a representative Danish population of 1068 people (age distribution: 19% under 30 yrs, 16% between 30-39 yrs, 15% between 40-49 yrs, and 50% between 50-99 yrs). Respondents were asked questions related to the product categories within the three classifications. The following are a select set of questions from the survey that are relevant for this study:

- *Has your household had any of the following products break in 2023-2024?* [Product categories], See Figure 2.
- *Was the product repaired?*
- *Why did you or your household repair or intend to repair the product?*
- *Where was the product repaired?*
- *Why was the product not repaired?*

To supplement the findings from the survey, a semi-structured interview guide was developed and 11 people who have engaged in repair activities (ages between: 24-65) were interviewed about which products they repair, how, and why they repair them. The interview data was initially transcribed were then inductively coded following a thematic analysis protocol inspired by Braun & Clarke's reflexive thematic analysis (Braun & Clarke, 2019).

Findings

Most survey respondents experienced defect products in the *fashion* product classification (Mean 25%, SD 0,12), while the experienced defects within *consumer electronics* were roughly half (Mean 13%, SD 0,06). The *furniture* classification had by far the lowest number of reported defects (mean 5%, SD 0,015). See Figure 2. A fraction of survey respondents noted how they stored products that they intend to repair in all product categories except *power tools* and *household appliances (blender, vacuum cleaner etc.)*. The

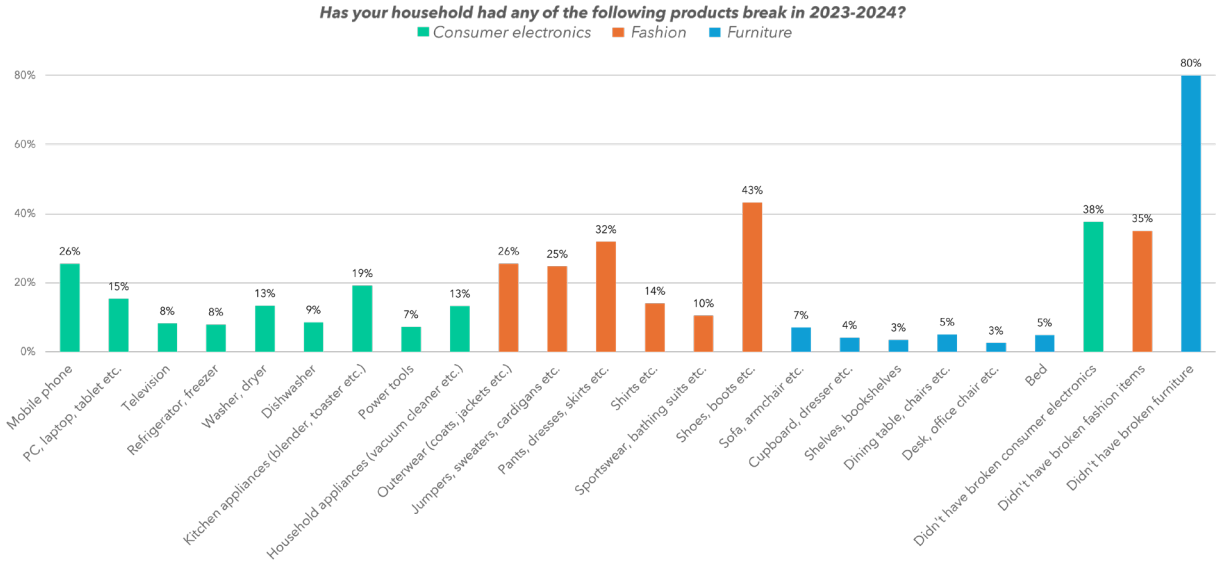


Figure 2. Overview of product categories with reported percentages on broken products (N=1068)

only product categories where the *repair* fraction was larger than the *not repaired* were within furniture *(dining table, chairs etc.; cupboard, dresser)* and consumer electronics *(washer/dryer; Computer, PC laptop etc.)*. See Figure 3. The fashion category had the highest number of reported defects with the overall lowest reported fraction of repairs. This underlines a large potential for prolonging the lifetimes of fashion items through repair activities.

Why was the product repaired (or intension to repair)?

When looking across the product classifications, the reasoning behind repair were apparent in three main categories:

i) *price-related:* a newer product would be more expensive
ii) *Emotional reasons for repair*: expression of deep care for the product
iii) *Inability to replace:* Deemed impossible to find a similar replacement in a new product.

Price-related reasons for repair were dominated by the consumer electronics category, whereas emotional reasons were strictly related to the fashion classification. For furniture, it stood out how people repaired the products because they were not able to find a similar product to replace the furniture. A person commented on the general reasoning behind repair: *"[repair] is really exciting to experiment with. There is something satisfying about saying 'I did that'. It's gold [valuable]"*. Likewise, for repair tasks like sewing, a person's interest (or lack thereof) was noted as both a barrier and a motivation: *"I love to sew and I do it a lot […]. It is a hobby of mine"*, tapping into the pleasure dimension of repair.

Where was the product repaired?

Repair Cafés are now showing up as an option that some respondents used in order to repair their broken products, albeit an underrepresented one. This could indicate that awareness of these repair cafés is slowly increasing, compared with an earlier survey conducted in 2020 (Jørgensen, 2021). Most

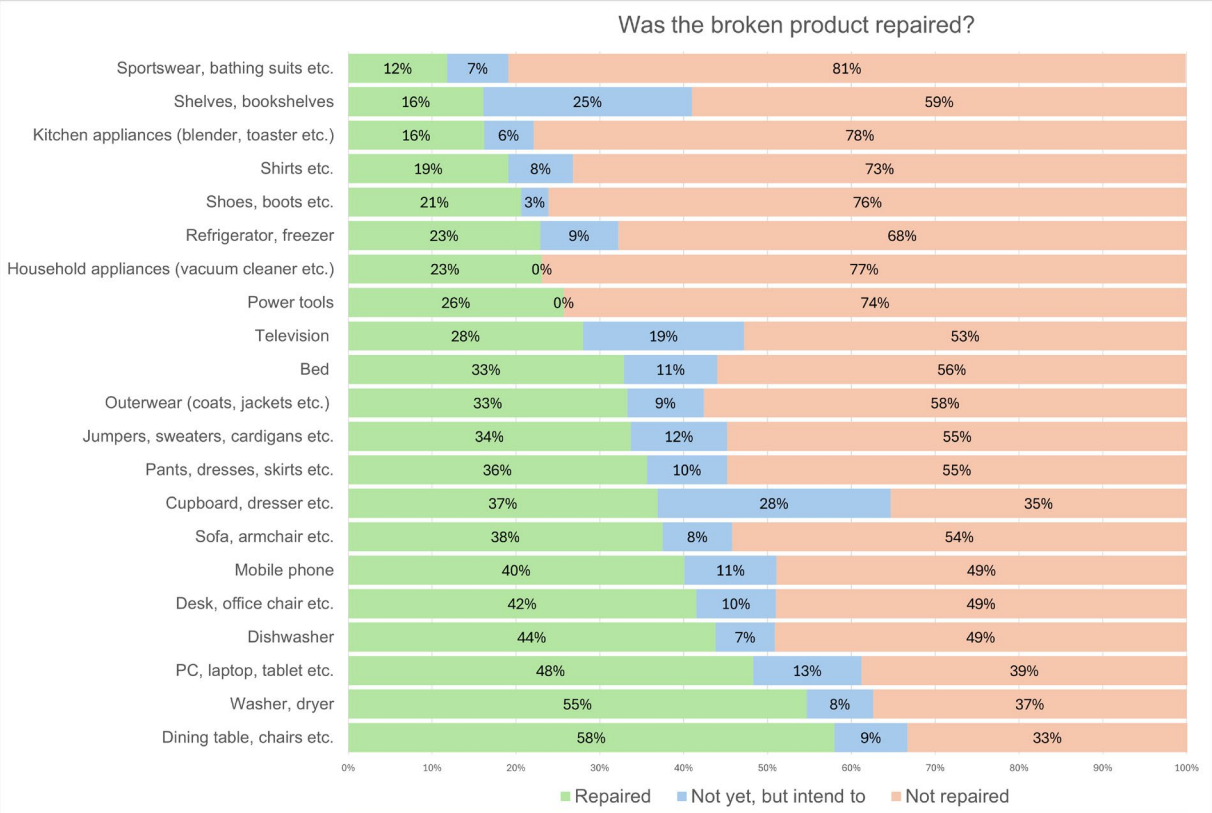


Figure 3 Overview of which of the broken products people repaired, intended to repair or did not repair

consumer electronics were repaired externally by professionals.
The results further complement previous studies indicating that consumers are more likely to attempt self-repair of clothing and furniture (Laitala et al., 2021). These products are previously categorised as static products with lower complexity over mechanical, electromechanical and electrical products (Nielsen et al., 2023)

Why was the product not repaired?

In the consumer electronics classification, the respondents mainly deemed that the product would be too expensive to repair or perceived it as unrepairable. The interviewees confirmed this: "*if it costs too much to repair my old phone, I'd rather pay for a new one. But if it is significantly cheaper to repair, I will always do that".* Consumer electronics was the only classification where a notable group of people marked that they still store the product at home, but do not use it anymore except for large household items such as fridges, dishwashers and vacuum cleaners, which compliments the findings from (Statistics Denmark, 2024). Consumers seem more inclined to get rid of fashion items and furniture items compared to consumer electronics. In the fashion classification, most deemed the product unrepairable, too expensive to repair, or listed the primary reason for not repairing the product to be because they had already gotten rid of the product.
The main reason for not repairing furniture was shared between the respondents who deemed their product unrepairable or too expensive to repair. For dining tables and chairs the main hindrance was noted as being too time-consuming to repair. Notably, most respondents in the desks/office chairs category reported how it was not possible to find a place to have them repaired.

In addition to economic considerations, all 11 interviewees mentioned that time is a big factor in determining if a repair is worthy or not: *"it is often not the repair itself that takes time. It is the research on how to do the repair that takes time"*. Time was also mentioned in relation to browsing for spare parts and waiting for them to arrive when no physical stores nearby offered the right parts. Interviewees also mentioned a specific lack of tools and facilities to properly repair their products: *"There is a loose screw in my speakers, but I don't have the specific tool to fix it, and I don't want to use the time and money on buying the right tool"*. Especially for the respondents living in apartments, the lack of facilities showed: *"right now I don't have a workshop to complete the repair".* These barriers were not picked up in the survey.

A sense of material respect was expressed by the interviewees and a feeling of gratification achieved from repairing their products. This was mainly from people with an interest in the type of repair or related hobby, which in turn acts as a barrier when missing. Upbringing and social environment appear to affect their motivation for repair: *"My interest probably stems from my upbringing. I am affected by what I was given to play with. I had a toolbox when I was a kid"*.

Discussion and Conclusions

Based on the survey results and the interview data, the top barriers and motivations that affect the decision-making process prior to a repair process were summarised in Table 2.

What motivates or hinders repair differs depending on the product classification. For consumer electronics, the main reason for having the product repaired is related to the *price of repair* compared to buying a new product. For fashion people are more *emotionally attached* to the products and thus more motivated to repair the items, though cost is also a big factor. For furniture, the *inability to replace the product* with a similar one was prevalent.

Interviewees expressed the lack of access to tools and facilities to be a barrier. If repair cafes were more accessible it could result in increased product repair. For example, hiring a mobile repairman through an app like it has become normalised for food bringers. In recent years, such a service-based business model for repair has gained traction for electronic devices like smartphones (e.g. https://samsungrepair.com/).

Table 2 Main barriers (B) and motivations (M) identified from the survey and interviews. *Derived from the interview data. **Not described in literature from Table 1

	Consumer electronics	Fashion	Furniture
B	1. Financial cost (Repair too expensive) 2. Perceived repairability** 3. Did not consider repair 4. Ease of cassation or replacement** 5. Financial cost	1. Perceived repairability** 2. Financial cost (Repair too expensive) 3. Ease of cassation or replacement** 4. Did not consider repair	1. Perceived repairability 2. Ease of cassation 3. Financial cost (Repair too expensive) 4. Did not consider repair
M	1. Financial cost (Repair cheaper than new) 2. Emotional attachment 3. Environmental concerns 4. Perceived interest* 5. Perceived pleasure*	1. Emotional attachment 2. Financial cost (Repair cheaper than new) 3. Inability to replace *AND* Environmental concerns 4. Perceived interest* 5. Perceived pleasure*	1. Financial cost (Repair cheaper than new) 2. Inability to replace 3. Emotional attachment *AND* Environmental concerns

We have yet to see the trend spread to other common everyday products that people own in their home, which may come down to the price for repairs if performed by a professional. Retailers typically do not repair when the cost of repair surpasses 50% of the price to replace with new (Scott & Weaver, 2014). Some replace rather than repair if the rice for repair is higher than just 20% percent of a new product (McCollough, 2007). This underlines the importance of access to affordable repairs. Here it is worth noting that Repair Cafes in Denmark are free, however, not easily accessible with opening hours only once or twice per month. Next after repair price, *perceived repairability* of a product is the biggest barrier, which was not found described in previous literature. This refers to how easy or difficult a user believes a repair will be – this means that easily repairable products may never be repaired due to a low perceived repairability from the user. Likewise, the ease of cassation or replacement barrier was also not documented as a barrier previously. This barrier indicates a tendency to replace before repair. The survey revealed how a large fraction of broken products was never even considered for repair, already replaced with new or not deemed repairable. This underlines a large repair potential in everyday products. Further studies are needed to determine ways to positively affect the perceived repairability of different product categories to increase the fraction of broken products considered for repair. The recent Ecodesign for Sustainable Products Regulation from the European Commission (European Commission, 2024) may help affect the perceived repairability of everyday products by increasing awareness of repair and availability of affordable spare parts.

References

Auberger, A. (n.d.). *The Race to Net Zero: Is the global business community on course to beat the clock?* Https://Insight.Bakermckenzie.Com/. Retrieved 19 September 2024, from https://insight.bakermckenzie.com/race-to-net-zero

Bracquene, E., Peeters, J. R., Burez, J., De Schepper, K., Duflou, J. R., & Dewulf, W. (2019). Repairability evaluation for energy related products. *Procedia CIRP*, *80*, 536–541. https://doi.org/10.1016/j.procir.2019.01.069

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Charter, M., & Keiller, S. W. (2016). *The second global survey of repair cafés: A summary of*

findings. https://api.semanticscholar.org/CorpusID:113441181

Cooper, T. (2010). The Significance of Product Longevity. In *The Significance of Product Longevity* (1st ed., pp. 3–36).

Cooper, T., & Salvia, G. (2018). Fix it: Barriers to repair and opportunities for change. In *Subverting Consumerism*. Routledge.

Dewberry, E. L., Sheldrick, L., Sinclair, M., Moreno, M., & Makatsoris, C. (2017). Developing scenarios for product longevity and sufficiency. In *PLATE: Product Lifetimes And The Environment* (pp. 108–113). IOS Press. https://doi.org/10.3233/978-1-61499-820-4-108

Dewberry, E., Saca, L., Moreno, M., Sheldrick, L., Sinclair, M., Makatsoris, C., & Charter, M. (2016). *A landscape of repair*. Sustainable Innovation 2016: Circular Economy Innovation and Design, Epsom, UK. http://www.research.ucreative.ac.uk/3272/1/MC Top 30 paper.pdf

Diddi, S., & Yan, R.-N. (2019). Consumer Perceptions Related to Clothing Repair and Community Mending Events: A Circular Economy Perspective. *Sustainability*, *11*(19), Article 19. https://doi.org/10.3390/su11195306

Duhoux, T., Lingås, D. B., & Mortensen, L. F. (2024). *Volumes and destruction of returned and unsold textiles in Europe's circular economy* (ETC CE Report 2024/4). European Environment Agency; European Topic Centre; Circular economy and resource use. https://www.eionet.europa.eu/etcs/etc-ce/products/etc-ce-report-2024-4-volumes-and-destruction-of-returned-and-unsold-textiles-in-europes-circular-economy

European Commission. (2014). *Attitudes of Europeans towards waste management and resource efficiency*. Publications Office of the European Union. https://data.europa.eu/doi/10.2779/14825

European Commission. (2018). *Behavioural study on consumers' engagement in the circular economy: Executive summary*. Publications Office of the European Union. https://data.europa.eu/doi/10.2818/921596

European Commission. (2023, 03). *Right to repair: Making repair easier for consumers* [Text]. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1794

European Commission. (2024). *Regulation (EU) 2024/1781 of the European Parliament and of the Council*. http://data.europa.eu/eli/reg/2024/1781/oj/eng

European Parliament. (2024, March 21). *Stopping greenwashing: How the EU regulates green claims*. Topics | European Parliament. https://www.europarl.europa.eu/topics/en/article/20240111STO16722/stopping-greenwashing-how-the-eu-regulates-green-claims

Fachbach, I., Lechner, G., & Reimann, M. (2022). Drivers of the consumers' intention to use repair services, repair networks and to self-repair. *Journal of Cleaner Production*, *346*, 130969. https://doi.org/10.1016/j.jclepro.2022.130969

Hernandez, R. J., Miranda, C., & Goñi, J. (2020). Empowering Sustainable Consumption by Giving Back to Consumers the 'Right to Repair'. *Sustainability*, *12*(3), Article 3. https://doi.org/10.3390/su12030850

Jørgensen, M. S. (2021). Erfaringer hos borgere i Region Hovedstaden med reparation og genbrug af elektriske og elektroniske produkter, beklædning og møbler. In *Erfaringer hos borgere i Region Hovedstaden med reparation og genbrug af elektriske og elektroniske produkter, beklædning og møbler* [Report]. https://vbn.aau.dk/da/publications/erfaringer-hos-borgere-i-region-hovedstaden-med-reparation-og-gen

Korsunova, A., Heiskanen, E., & Vainio, A. (2023). Consumer decision-making on repair in a circular economy: A process model based on experiences among young adults and stakeholders in Finland. *Journal of Cleaner Production*, *405*, 137052. https://doi.org/10.1016/j.jclepro.2023.137052

Laitala, K., Klepp, I. G., Haugrønning, V., Throne-Holst, H., & Strandbakken, P. (2021). Increasing repair of household appliances, mobile phones and clothing: Experiences from consumers and the repair industry. *Journal of Cleaner Production*, *282*, 125349. https://doi.org/10.1016/j.jclepro.2020.125349

Madon, J. (2022). Free repair against the consumer society: How repair cafés socialize people to a new relationship to objects. *Journal of Consumer Culture*, *22*(2), 534–550. https://doi.org/10.1177/14695405219908 71

Magnier, L., & Mugge, R. (2022). Replaced too soon? An exploration of Western European consumers' replacement of electronic products. *Resources, Conservation and Recycling*, *185*, 106448. https://doi.org/10.1016/j.resconrec.2022.106448

McCollough, J. (2020). The impact of consumers' time constraint and conspicuous

consumption behaviour on the throwaway society. *International Journal of Consumer Studies*, *44*(1), 33–43. https://doi.org/10.1111/ijcs.12545

Mclaren, A., & McLauchlan, S. (2015). Crafting sustainable repairs: Practice-based approaches to extending the life of clothes. In *Product Lifetimes And The Environment (PLATE): Conference Proceedings* (pp. 221–228). Nottingham Trent University. https://www.research.ed.ac.uk/en/publications/crafting-sustainable-repairs-practice-based-approaches-to-extendi

Ministerie van Algemene Zaken. (2023, February 3). *National Circular Economy Programme 2023—2030—Beleidsnota—Rijksoverheid.nl* [Beleidsnota]. Ministerie van Algemene Zaken. https://www.rijksoverheid.nl/documenten/beleidsnotas/2023/02/03/nationaal-programma-circulaire-economie-2023-2030

Nielsen, A. S. H., & Laursen, L. (2023, June 6). *Love at first sight: Immediate emotional attachment of volunteers in repair cafés*.

Nielsen, A. S. H., Laursen, L. N., & Tollestrup, C. (2023). *Can you fix it? An investigation of critical repair steps and barriers across product types*. Product Lifetimes and the Environment, Espoo, Finland.

Park, M. (2021). *Closed for repair: Design affordances for product disassembly*. https://depositonce.tu-berlin.de/handle/11303/17440

Pit, L. (2020). *An explorative research on the reasons why people repair their product at the Repair Café* [MSc Thesis Management, Economics and Consumer Studies, Wageningen University]. https://repaircafe.org/wp-content/uploads/2020/05/Thesis_Lianne_Pit_februari_2020.pdf

Rosner, D. K., & Ames, M. (2014). Designing for repair?: Infrastructures and materialities of breakdown. *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 319–331. https://doi.org/10.1145/2531602.2531692

Statistics Denmark. (2024, September 2). *BEBRIT21: Use of internet for private purposes—Per cent of the population(16-74 years) by type, equipment and behaviour when replacing*. https://www.statistikbanken.dk/bebrit21

Terzioğlu, N. (2021). Repair motivation and barriers model: Investigating user perspectives related to product repair towards a circular economy. *Journal of Cleaner Production*, *289*, 125644. https://doi.org/10.1016/j.jclepro.2020.125644

Terzioğlu, N., Lockton, D., & Brass, C. (2015, November 10). Understanding User Motivations and Drawbacks Related to Product Repair. *Sustainable Innovation 2015: 'State of the Art' Sustainable Innovation & Design*. Towards Sustainable Product Design: 20th international conference, University of the creative arts, Epsom, Surrey, UK.

United Nations. (1987). *Report of the World Comission on Environment and Development: Our common future*. United Nations. https://www.are.admin.ch/are/en/home/media/publications/sustainable-development/brundtland-report.html

van den Berge, R., Magnier, L., & Mugge, R. (2023). Until death do us part? In-depth insights into Dutch consumers' considerations about product lifetimes and lifetime extension. *Journal of Industrial Ecology*, *27*(3), 908–922. https://doi.org/10.1111/jiec.13372

Van Der Velden, M. (2021). 'Fixing the World One Thing at a Time': Community repair and a sustainable circular economy. *Journal of Cleaner Production*, *304*, 127151. https://doi.org/10.1016/j.jclepro.2021.127151

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E-Waste Management Trend in Ethiopia: Strategies for Extending Electronics Lifecycles

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Keywords: E-Waste; Sustainability; Lifespan; Repair Network; Circular Economy.

Abstract:

The rapid e-waste generation poses a significant environmental challenge, necessitating sustainable approaches to managing electronic product lifecycles. This paper investigates how repair practices in Ethiopia affect the lifespan of electronic devices. It has been observed that, compared to several reference countries, electronics in Ethiopia tend to have slightly longer lifespans, primarily due to extensive repair and reuse practices. In this study, we conducted a lifespan analysis by collecting lifespan data from various maintenance shops. The Weibull distribution method was used to analyze the lifespan of different categories of devices. The data revealed that the average lifespans of LCD TVs, LCD monitors, laptops, and smartphones are 12.0, 11.0, 10.7, and 6.4 years, respectively. The findings highlight the significant role of repair and refurbishment in extending device longevity while also revealing a growing trend in e-waste generation. This study explores the impact of repair practices on extending electronic device lifespans in Ethiopia, considering policy approaches that support repair and reuse. It also shows the need for collaboration among repair practitioners, policymakers, and consumers to strengthen sustainable e-waste management efforts. This research aims to contribute to environmental preservation and sustainable development in the country by fostering a circular economy.

Introduction

The short lifespan of electronic devices significantly contributes to the global e-waste stream driven by rapid technological advancements and consumer demand for newer technology. With most electronics lasting only three to five years, the volume of e-waste is projected to rise from 57.4 million tons in 2021 to 74.7 million tons by 2030, posing severe environmental and health risks due to the hazardous materials it contains (Forti et al., 2020). This rapid and extensive consumption of short-lived electronic products generates not only e-waste but also significant amounts of waste during their production.

The product lifetime, defined as the duration from when a product is first used after manufacturing to when it becomes obsolete (Bakker & Schuit, 2017), plays a crucial role in this issue. The rapidly growing accumulated waste volume highlights the urgent need to extend the lifespan of electronic devices. Strategies such as improved product design, refurbishment, and reuse can help optimize the longevity of electronics, reducing e-waste and promoting sustainability.

Technological advances have contributed to a shorter product lifespan (Khan et al., 2018). Increasing demand for e-products with reduced product lifespan leads to more frequent replacement/renewal of them, resulting in a growing e-waste stream. The urge to protect the planet against this escalating waste generation fits in the 17 Sustainable Development Goals adopted by the United Nations in 2015 (United Nations, n.d.). The extension of a product's lifespan can be regarded as a tool under the goal of

"Responsible Consumption and Production" (Bakker & Schuit, 2017). Extending the lifetime and delaying the obsolescence of e-products can significantly reduce the environmental impacts and contribute to meeting environmental, climate, and sustainability goals.

Various strategies have been proposed to enhance the longevity of electronic products, focusing on design, refurbishment, and media migration. Designing products that can adapt to technological advancements is a key approach to prolonging usability. This includes creating products intended for multiple uses, enabling them to stay relevant even as technology evolves (Park, 2009). Refurbishment and reuse also play a significant role in extending the lifespan of electronic products. Research indicates that refurbished smartphones are becoming increasingly popular, with sales in secondary markets often surpassing those of new devices (Hazelwood & Pecht, 2021). Establishing industry standards for refurbishment can further enhance the reliability and safety of refurbished products, address common consumer concerns, and promote their acceptance.

In Ethiopia, repairing and reusing electronic devices have been common practice for many years (Ali & Akalu, 2022; Getachew et al., 2019). This repair and reuse culture largely stems from economic challenges, as many people cannot afford the latest technological devices. This practice tends to increase life span, reducing e-waste generation and their environmental impact. Repair practices in Ethiopia, while not extensively documented, reflect broader trends observed in similar developing contexts, where repair and refurbishment significantly extend the lifespan of electronic devices. According to Odeyingbo & Baldé (2022), in Nigeria, repair practices extend the lifespan of televisions by an additional 11 years and refrigerators by 9 years (Odeyingbo & Baldé, 2022). These practices are influenced by cultural, economic, and infrastructural factors that shape consumer behavior and repair capabilities (Marikyan & Papagiannidis, 2024; Odeyingbo & Baldé, 2022; Parajuly et al., 2024).

Despite these positive observations, challenges remain, such as limited access to reliable repair services and a lack of consumer confidence in local repair networks. Addressing these barriers is essential for enhancing repair practices and extending the lifespan of electronic materials in Ethiopia. In this study, we present electronic device lifespan extension practices observed in Ethiopia, along with strategies to improve and formalize lifecycle extension approaches.

Data collection for Ethiopia: Methodological aspects

A large-scale data collection exercise conducted across four Ethiopian cities- Addis Ababa, the capital city of Ethiopia, Jimma, Adama, and Asela- revealed key observations about repair and maintenance practices. These cities were chosen as representatives due to the relatively uniform maintenance behavior observed across Ethiopia. Addis Ababa, specifically the Merkato sub-city, was selected as it serves as Ethiopia's central market hub, where many maintenance shops are concentrated, making it an essential location for studying repair trends.

Both quantitative and qualitative data were collected from different sources to calculate the lifespan of the products and the time spent on the market for various device categories. Questionnaires and surveys were used to obtain lifespan data, which included the brand name and manufacturing date of the devices. The electronic maintenance shops considered in this study are mobile phone maintenance shops, television maintenance shops, and computer and laptop maintenance shops. For each equipment category, the brand name and production year of non-repairable devices were registered using a questionnaire as a data collection tool. Using the Weibull equation (Equation 1), an R-script in the R-Studio software was used to calculate the average lifespan, shape, and scale parameters based on collected data concerning end-of-life product ages.

$$P(t) = 1 - exp\left(-\left(\frac{t}{\alpha}\right)^{\beta}\right) \quad \text{.....(1)}$$

where P(t) is the cumulative distribution function, α is the scale parameter (or characteristic Weibull lifespan), t is time in years, and β is the shape parameter. The lifespan profile is defined by an appropriate choice of shape and scale parameters, α and β, respectively. The R script used in estimating the life span uses Maximum Likelihood Estimation (MLE) as the primary method to minimize errors when fitting a Weibull distribution to lifetime data. Specifically, the fitdist function from the fitdistrplus package is employed to estimate the Weibull parameters (shape and scale) by maximizing the likelihood of the observed data under the assumed

distribution. The error minimization process focuses on reducing the negative log-likelihood (NLL), which measures how well the Weibull model fits the data. A lower NLL indicates a better fit (Lastras, 2019). The Weibull distribution has been used since it was experimentally demonstrated that it provides a good fit for the life span of many different types of electronic products (Polák & Drápalová, 2012; Kalmykova et al., 2017). It is a commonly used method for determining the lifespan of products that can help to estimate the amount of WEEE generated (Parajuly et al., 2017).

Data analysis and interpretation

Many maintenance and repair shops face challenges such as limited storage space, which prevents them from keeping old electronic devices for extended periods. These shops typically retain obsolete electronics only when they anticipate an immediate need for spare parts. However, other shops adopt a different approach by storing such devices for longer periods, viewing them as a repository of potential resources that can be harvested in the future. This includes harvesting working components, such as functional screens, circuit boards, or power supplies, which can be used to repair or refurbish other electronic products. This practice not only supports the repair of existing products but also plays a crucial role in extending the lifespan of electronics by reusing valuable parts. This is particularly important in the Ethiopian context, where new spare parts are often unavailable on the market or, when they are, tend to be expensive. Harvesting components from obsolete electronics helps mitigate the impact of these challenges and supports sustainable repair and maintenance practices. Figure 1 shows laptop and mobile phone maintenance shops storing various obsolete devices for spare parts harvesting.

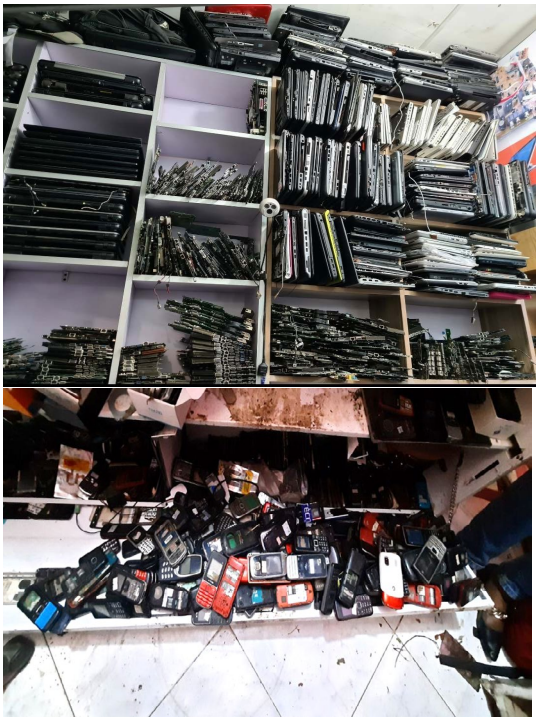


Figure 1. Stored obsolete electronic devices in electronic maintenance shops in Jimma City of Ethiopia. (a) obsolete laptops and (b) obsolete mobile phones.

Table 1: Locations and number of shops where data were collected.

Site	# of shops reached	LCD TVs	Monitors		Laptops	Mobile Phones	
			LCD	CRT		Smartphone	Feature Phone
Addis Ababa	9	32	-	-	7	101	96
Jimma	32	26	363	287	70	326	475
Adama	3	12	-	-	40	44	65
Arsi Asella	3	-	-	-	40	30	71
Total	**47**	**70**	**363**	**287**	**157**	**501**	**707**

Data for 70 LCD TVs, 363 LCD monitors, 287 CRT monitors, 157 laptops, and 501 smartphones, with their brand and production year, were collected and analyzed for lifespan estimation(see Table 1).

Table 2: Weibull life span distribution, shape, and scale parameters for different categories of ICT equipment in an Ethiopian context.

Type of equipment	Mean value	Shape parameter	Scale parameter
Smartphone	6.4	2.9	7.2
Laptop	10.7	3.6	11.9
LCD TV	12.0	3.2	10.0
CRT TV	17.0	4.8	18,3
CRT monitor	18.3	5.0	19.7
LCD monitor	11.0	3.9	12.0

As shown in Table 2 model parameters, such as shape and scale parameters were analysed. In addition, the average lifespan of each category of equipment is calculated, which shows that in Ethiopia, ICT equipment has a relatively long service life compared to different countries for which data are available in the literature. For example, CRT monitors have an average lifespan of 18.3 years, primarily because this figure considers the total lifecycle of the product from production to final abandonment, including storage time. For this category of equipment, the extended lifespan is not attributed to repair or refurbishment but rather to the replacement of CRT monitors with LCD monitors, resulting in their prolonged storage for future disposal or repurposing (see Table 2).

During our survey, we found that CRT monitors were commonly stored in the facilities of major government organizations and NGOs, such as universities and banks. Some of these monitors were still functional and were planned to be donated to educational centers. For other categories of devices, data from maintenance shops indicate that storage times typically range from three to six months, as these devices are either repaired and returned to customers or repurposed to repair other devices.

Another key factor influencing the extended lifespan of electronic devices in Ethiopia is the strong culture of reuse, which plays a crucial role in the continued functionality of mobile phones, televisions, and laptop computers.

Figure 2 compares the lifespan distribution of ICT equipment determined in this study with lifespan data from three different European countries to assess how Ethiopian electronic devices perform in comparison. The graph compares the lifespan of Ethiopian devices to those from France, the Netherlands, and Belgium combined. The European lifespan data are based on research conducted by the International Telecommunication Union (ITU) in 2015 (C.P. Balde et al., 2015). In their study, the lifespan of various electronic waste categories was estimated based on data from the Netherlands and extrapolated to other EU countries. The comparison reveals that the lifespan of ICT equipment in Ethiopia is longer than what is observed in the European countries analyzed. For instance, the estimated average lifespan of a laptop in these countries is estimated to be 4.7 years, while in Ethiopia, based on the collected data, it is estimated to be 10.7 years. In another study, the lifespan of a new desktop computer in Uganda is around 9.0 years (Wasswa & Schluep, 2008), while in Ethiopia this is estimated to be around 10.7 years. Private households tend to hold on to their laptops longer than any other sector by replacing faulty hardware components with new or recovered ones. The lifespan of electronic equipment in Ethiopia largely depends on the availability of spare parts for maintenance: if spare parts are readily available, the lifespan of the device tends to be extended. However, if the device is not maintained properly or the cost of maintenance is not affordable, the device may be considered as a source of spare parts for other devices. From interviews conducted in repair shops, it could be apprehended that for some devices, technicians are trained with as vision that if spare parts are available, there is no end-of-life for any dysfunctional electronic device. They have a saying that goes "No device is ever beyond being repairable". Depending on the willingness to pay of the owner, they either fix a faulty device or use its parts for repairing other similar devices. Another issue we observed is the lack of new spare parts availability; new spare parts are difficult to find in Ethiopia. This is due to the large variety of brands available on the Ethiopian market, which makes it difficult to find the correct spare parts. Also, the high cost of those parts then forms a major hurdle. Mobile phones in Ethiopia have a shorter average lifespan compared to those used for

comparison in Figure 2. This can be attributed to the lack of new spare parts in the

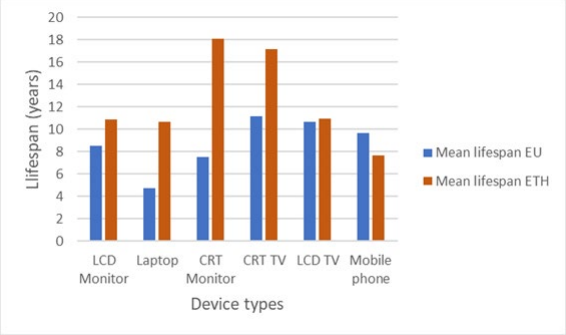


Figure 2. Comparison of life spans from 3 EU countries and Ethiopia.

market, leading to a reliance on components harvested from obsolete devices, which often fail more quickly. Additionally, smartphones' small size, sensitivity to environmental conditions, precise physical tolerances, and fragile electronic components make them difficult to repair or refurbish. The lack of enhanced knowledge through education or training, as well as the absence of appropriate tools to detect failure points further complicate the process (Getachew et al., 2019). Design choices, such as case adhesives, bonded glass displays, non-removable batteries, and soldered components, also contribute to complex refurbishment processes requiring specialized tools and knowledge (N. Proctor, 2020). Building on the earlier comparison of device lifespans in Ethiopia and European countries, another analysis provides additional insights. Ethiopian devices again demonstrate an improved lifespan compared to those in other countries, as shown in Table 2. For example, mobile phones in the Czech Republic are reported to have the longest lifespan at approximately 7.99 years. However, 4.5 years of this period is attributed to storage time after the device has failed (Polák & Drápalová, 2012), resulting in a functional lifespan of 3.5 years. Interestingly, a study by the European Environmental Bureau (EEB) reports a mobile phone lifespan of 3 years in Europe, which contradicts the earlier findings (Francisco et al., 2019). In addition, the lifespan of devices in India is reported to be shorter than in Ethiopia (see Table 3). Limited access to tools and replacement parts poses a significant challenge to maintaining and extending the lifespan of electronic products. Another factor that makes repair difficult and less efficient is the lack of advanced knowledge and tools required for modern electronic devices (John Alake, 2014). As technology becomes more complex, technicians struggle to keep up.

Table 3: Comparison of life spans observed in different countries and Ethiopia.

TV		Computer monitor		Laptops	Mobile phone		Reference	Public. year	Country
LCD	CRT	LCD	CRT		Cellular	Smartphone			
10.0	-	5.0	-	4.0	6.0	-	(Ahmed et al., 2014)	2014	India
6.0	15.0	8.0	12.0	-	-	-	(Kalmykova et al., 2015)	2015	Sweden
-	-	-	-	3.5-5.2	-	-	(Jianxin Yang, 2008)	2008	China
-	-	-	-	-	-	7.9	(Polák & Drápalová, 2012)	2012	Czech Rep.
10.0	15.0	7.0	9.0	-	-	-	(Chancerel et al., 2012)	2012	Germany
5.0	-	5.0		4.0	-	2.0	(Moyen Massa & Archodoulaki, 2023)	2023	Developed countries
-	-	-	-	4.5	-	3.0	(Francisco et al., 2019)	2019	EU
12.0	17.0	11.0	18.3	10.7	7.6	6.4	This work		Ethiopia

Providing training to enhance the skills of repair shop workers can help support a more sustainable repair culture. Additionally, introducing policies that promote and encourage sustainable repair practices is essential for reducing e-waste. One of the limitations of this study is the lack of precise data on the storage (hibernation) phase of electronic devices. While the active lifetime (in-use phase) was determined through repair shop records, obtaining information on how long devices remain unused before final disposal proved challenging. Local shops primarily track functional repairs rather than storage periods, making it difficult to quantify the exact duration of the obsolescence phase. Future research could explore alternative methods, such as household surveys or second-hand market assessments, to better capture this aspect.

Observations and Conclusions

This study allows to conclude that there seems to be potential in the repair culture in Ethiopia for extending the lifespans of electronic devices. However, repairers face several challenges when dealing with more complex devices. Another issue is the lack of spare parts, especially for older or less common devices, which makes it difficult to find the components needed for repairs. Another area of concern is the evolution towards devices that are virtually impossible to take apart without destroying them. Devices such as smartphones and high-tech electronics are often designed with glued parts or non-removable batteries, making disassembly challenging and increasing the risk of inflicting further damage during repair. There is also another issue with the unavailability of important software and firmware, especially on phones where proper working can greatly be based on updates or proper operating system installations. Furthermore, the lack of technical documentation is common, as many repair shops do not have access to manuals or schematics that would allow for efficient troubleshooting and repairs. Lastly, the absence of adequate tooling as well as lack of formal training respectively limit repair capabilities. Many modern electronics require specialized tools, such as precision soldering irons or heat guns for glued components, which may not be available in local shops, hindering the repair process. These challenges make repairing complex devices much more difficult compared to simpler devices, where parts are more accessible, and designs allow for easier disassembly and repair. Generally, the efforts of stakeholders, including the government and maintenance shop owners, to modernize the repair culture could positively impact the emerging e-waste stream.

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References

Ahmed, S., Panwar, R. M., & Sharma, A. (2014). *Forecasting e-waste amounts in India*. *2*(6).

Ali, A. S., & Akalu, Z. K. (2022). E-waste Awareness and Management Among People Engaged in E-waste Selling, Collecting, Dismantling, Repairing, and Storing Activities in Addis Ababa, Ethiopia. *Environmental Health Insights*, *16*, 11786302221119145. https://doi.org/10.1177/11786302221119145

Bakker, & Schuit. (2017). *The_Long_View_2017.pdf*. https://pure.tudelft.nl/ws/portalfiles/portal/32862068/The_Long_View_2017.pdf

Chancerel, P., Deubzer, O., Nissen, N. F., & Lang, K.-D. (2012). From CRT to flat displays-consequences for collection and recycling. *2012 Electronics Goes Green 2012+*, 1–6.

C.P. Balde, R. Kuehr, K. Blumenthal, & S. Fondeur Gill. (2015). *E-waste statistics Guidelines on classification, reporting and indicators 2015*. https://www.itu.int/en/ITU-D/Statistics/Documents/partnership/E-waste_Guidelines_Partnership_2015.pdf

Forti, V., Balde, C. P., Kuehr, R., & Bel, G. (2020). *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential*. United Nations University/United Nations Institute for Training and Research, International Telecommunication Union, and International Solid Waste Association. https://collections.unu.edu/view/UNU:7737

Francisco, Z., Jean-pierre, S., Mauro, A., & Stephane, A. (2019). *EEB (2019). Coolproducts don't cost the earth—Full report.* https://eeb.org/library/coolproducts-briefing/

Getachew, B., Amde, M., & Danno, B. L. (2019). Level of selected heavy metals in surface dust collected from electronic and electrical material maintenance shops in selected Western Oromia towns, Ethiopia. *Environmental Science and Pollution Research*, *26*(18), 18593–18603. https://doi.org/10.1007/s11356-019-05018-z

Hazelwood, D. A., & Pecht, M. G. (2021). Life Extension of Electronic Products: A Case Study of Smartphones. *IEEE Access*, *9*, 144726–144739. https://doi.org/10.1109/ACCESS.2021.3121733

Jianxin Yang, C. X. (2008). *WEEE flow and mitigating measures in China*. https://doi.org/10.1016/j.wasman.2007.08.019

John Alake, T. (2014). The Challenges of Maintaining Consumer Electronic Goods in the Era of Digital Divide by Repair Technicians in Ekiti State of Nigeria. *International Journal of Engineering Trends and Technology*, *15*(3), 136–140. https://doi.org/10.14445/22315381/IJETT-V15P227

Kalmykova, Y., Berg, P. E.-O., Patrício, J., & Lisovskaja, V. (2017). Portable battery lifespans and new estimation method for battery collection rate based on a lifespan modeling approach. *Resources, Conservation and Recycling*, *120*, 65–74. https://doi.org/10.1016/j.resconrec.2017.01.006

Kalmykova, Y., Patrício, J., Rosado, L., & Berg, P. E. (2015). Out with the old, out with the new – The effect of transitions in TVs and monitors technology on consumption and WEEE generation in Sweden 1996–2014. *Waste Management*, *46*, 511–522. https://doi.org/10.1016/j.wasman.2015.08.034

Khan, M. A., Mittal, S., West, S., & Wuest, T. (2018). Review on upgradability – A product lifetime extension strategy in the context of product service systems. *Journal of Cleaner Production*, *204*, 1154–1168. https://doi.org/10.1016/j.jclepro.2018.08.329

Lastras, L. A. (2019). *Information Theoretic Lower Bounds on Negative Log Likelihood* (arXiv:1904.06395). arXiv. http://arxiv.org/abs/1904.06395

Marikyan, D., & Papagiannidis, S. (2024). Exercising the "Right to Repair": A Customer's Perspective. *Journal of Business Ethics*, *193*(1), 35–61. https://doi.org/10.1007/s10551-023-05569-9

Moyen Massa, G., & Archodoulaki, V.-M. (2023). Electrical and Electronic Waste Management Problems in Africa: Deficits and Solution Approach. *Environments*, *10*(3), 44. https://doi.org/10.3390/environments10030044

N. Proctor. (2020). *The Fix is in: How Our Smartphones Get Fixed, Why it's Harder Than it Should be, and Why That Matters*. https://pirg.org/wp-content/uploads/2022/07/The_Fix_Is_In_March2020_USPEF-9.pdf

Odeyingbo, O. A., & Baldé, C. P. (2022). The Role of Repair and Refurbishment in Extending Lifetime of Electrical Electronic Equipment in Nigeria. *The Journal of Solid Waste Technology and Management*, *48*(1), 55–64. https://doi.org/10.5276/JSWTM/2022.55

Parajuly, K., Green, J., Richter, J., Johnson, M., Rückschloss, J., Peeters, J., Kuehr, R., & Fitzpatrick, C. (2024). Product repair in a circular economy: Exploring public repair behavior from a systems perspective. *Journal of Industrial Ecology*, *28*(1), 74–86. https://doi.org/10.1111/jiec.13451

Parajuly, K., Habib, K., & Liu, G. (2017). Waste electrical and electronic equipment (WEEE) in Denmark: Flows, quantities and management. *Resources, Conservation and Recycling*, *123*, 85–92. https://doi.org/10.1016/j.resconrec.2016.08.004

Park, S. Y. (2009). *An Analysis of the Technology Acceptance Model in Understanding University Students Behavioral Intention to Use E-Learning. Educational Technology and Society*. https://www.researchgate.net/publication/220374248_An_Analysis_of_the_Technology_Acceptance_Model_in_Understanding_University_Students%27_Behavioral_Intention_to_Use_e-Learning

Polák, M., & Drápalová, L. (2012). Estimation of end of life mobile phones generation: The case study of the Czech Republic. *Waste Management*, *32*(8), 1583–1591. https://doi.org/10.1016/j.wasman.2012.03.028

United Nations. (n.d.). *Sustainable Development Goal 15: Life on Land. United Nations.* https://sdgs.un.org/goals/goal15

Wasswa, J., & Schluep, M. (2008). *e-Waste Assessment in Uganda: A situational analysis of e-waste management and generation with special emphasis on personal computers*.

Research paper
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The Care and Repair Guide: Reducing Environmental Impact and Addressing Skills Gaps in Responsible Wardrobe Management

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Keywords: garment care; garment repair; product longevity, responsible wardrobe management

Abstract: This research explores the critical relationship between consumers, brands and the charity retail sector regarding garment care, repair and second-life ownership to encourage responsible wardrobe management. It acknowledges the importance of considered and active garment maintenance practices to ensure the longevity of a garment and retain value to prevent the purchasing of new, replacement garments. A qualitative methodology was informed by an extensive literature review, highlighting the identified problem space and creating a focus on critical gaps in knowledge. The core concepts of care and repair were explored through participatory workshops with charity retail sector volunteers and consumers to gain vital knowledge and skills in sustainable use behaviors. Collaborating with North-East based St. Oswald's Hospice within the charity retail sector, the project empowers stakeholders to facilitate sustainable clothing behaviors intended to extend the lifetime of clothing. Key insights generated include the critical requirements of resource, skills and knowledge, and motivation to ensure holistic engagement with garment maintenance and care. Moreover, these factors need to be underpinned by an individual's attachment of value to a garment, to rationalize the investment of time and effort in care and repair practices.

Introduction

Clothing has increasingly become a disposable commodity aligned with the extractive, linear 'take, make and dispose' mentality, exacerbated by excess production from the fast fashion sector. In Europe, clothing has the fourth highest impact on the environment, is the third highest area of consumption for water and land use and the fifth highest for use of primary raw materials and greenhouse gas emissions (EU, 2022). UK consumers wear an item less than twice on average, with £30 billion of unused clothing residing in wardrobes, and an estimated £140 million of clothing annually ending up in landfill, with only 1% of clothing being recycled into new products (WRAP, 2020). Of the 11.5 thousand UK charity shops between ten and 30 per cent of second-hand donations are resold in store, with many garments entering this waste stream or being diverted to landfill simply because they need repairing, typically because of stains, tears, pilling, broken seams and missing buttons. Increased garment care and repair practices will increasingly become a major requirement for brands, charities and consumers, yet current initiatives are uncoordinated or inaccessible for many stakeholders.

A coordinated response is needed to change how clothing is managed and consumed to extend product lifetimes and minimize waste by supporting enhanced clothing care and mindful wardrobe management. Resource reduction relating to production and consumption is dependent on restricting acquisition rates and extending garment longevity through careful post-consumption clothing management, repair, renovation, renewal and upcycling. The direct correlation between responsible garment care and resulting environmental impact of carbon emissions was reported to have been reduced in the UK by 700,000 tons from 2012-2016 due to minimizing ironing, tumble drying and washing temperatures, for example (WRAP, 2021). The worn life of clothing can be significantly extended via repair, with the Ellen MacArthur Foundation recently estimating that garment repairs can

increase usage by 75% and reduce associated emissions by 30%.

This research aims to i) gain insight into current understanding of garment care (washing, use and maintenance) and repair and, ii) to empower stakeholders with skills and knowledge to action responsible wardrobe management practices. The aims will be addressed by working in collaboration with North-East based charity St. Oswald's Hospice through the implementation following objectives:

- To analyse the relationship between consumer understanding of environmental impact and care practices by engaging with consumer groups;
- To enable St. Oswald's Hospice to divert damaged donations from rag/landfill by upskilling staff to repair damaged donations;
- To prevent damaged clothing being donated to the charity retail sector by engaging citizens in clothing repair practices.

Literature Review

Care and Circularity

The influence of consumer behavior is acknowledged within current sustainability discourse as an important driver in transitioning towards a circular economy for the fashion and textiles industries (Ellen Macarthur Foundation, 2019; Patwary et al., 2022). However, compared to other product lifecycle stages like production, there is relatively less robust data about the consumer use phase (Daystar et al., 2019; Mutambo et al., 2024). In particular, the role played by post-purchase 'care, maintenance and repair has been under-explored in wider narratives on fashion and sustainability' (Dubé, 2023, p.4). This dearth in research is also acknowledged by Tölg & Fuentes (2024) and Laitala et al. (2018). Implementing and achieving ambitious aims such as those set by the British Fashion Council (Hetherington et al., 2021), by WRAP in their Textiles 2030 plan (WRAP, 2021) or the EU under their Green Deal (European Commission, 2023), closing the loop, optimizing product lifetimes and reducing waste in the fashion systems will require major shifts in consumer behavior. Responding to the relatively low levels of action towards this end requires interventions grounded by a deeper understanding of how consumers care for their clothing (Laitala & Klepp, 2020).

Within the context of wardrobe management, the term care commonly encompasses a range of processes and activities undertaken by consumers to maintain clothing. These include storage, laundering (washing, ironing, drying), repair and use. In addition to adverse impacts on the environment through resource, energy and water use, consumer care practices have the potential to influence product longevity and the second life potential of clothing which ultimately impacts the amount of clothing entering waste streams (Klepp et al., 2020; Laitala et al., 2018; Laitala & Klepp, 2020). Similarly to ecologically driven acquisition (Lundblad & Davies, 2016; Niinimäki, 2010), the factors which influence care practices and decisions are varied, including values, education and knowledge, social economic factors, culture, geography and beliefs (Kant Hvass, 2014; Patwary et al., 2022).

Framing care as a part of 'mindful clothing consumption' Patwary et al. (2022) recommends measures like reduced washing, using a full load at lower temperatures, and the use of liquid detergent as a means of engaging in responsible care. Additionally, some theorists have framed notion of care beyond literal garment maintenance, extending it to care for the environment and future generations (Tölg & Fuentes, 2024). Drawing from feminist theory espousing ethics of care, Tölg & Fuentes propose the notion of 'care-in-practice' (2024, p.2) contending that 'most forms of circular consumption involve and are enabled and shaped by enactments of care' (2024, p.3). This theorization of care helpfully posits the need for an awareness of a deficit of care and a sense of responsibility as requisite to acts of caring. Moreover, the authors contend that *care problems* arise when there is lack of resources and when multiple care needs are in competition. In essence this speaks to the affective and practical barriers and enablers of care. Focusing on the role of repair within the second-hand retail sector, our research

examines how responsible care practices can be supported.

Repair for longevity and second life

Damage has been noted as a leading reason why garments are disposed of by consumers (Laitala et al., 2014). A study by Degenstein et al. (2020) revealed that in addition to factors like perceived garment quality (luxury vs. fast fashion), garment type and damage level influence care and disposal decisions. Furthermore, consumers are more likely to repair lightly damaged garments.

While repair is a care strategy that has potential to extend product lifetimes and reduce waste (McQueen et al., 2023; Niinimäki, 2018), there are a number of common barriers, which include a lack of recourses such as time, finances, equipment and skills (De Castro, 2021; McLaren & McLauchlan, 2015). Notably the skills gap has been attributed in part to changes of curricula within early education (Allsop & Cassidy, 2019). Additionally, the relatively lower price of clothing has disincentivized engagement by consumers in repair (Twigger-Holroyd, 2016). Palmer (2024) points to the need to educate consumer about garment quality and repair, while Niinimäki and Durrani (2020) advocate repair events and pop-up cafes as avenues for consumers to acquire skills from their peers while fostering a sense of community and social cohesion (Treggiden, 2023). As such, greater effort is needed to support the development of repair skills among consumers and other stakeholders.

In addition to its impact within the domain of responsible consumer use, repair has the potential to impact the charity retail sector. Donating garments to a second-hand retailer is categorized as an 'eco-conscious disposal' option (Patwary et al., 2022, p.2) as there is value in diverting clothing from landfill, however this paper argues that such action can only be considered as responsible if garments are in an adequate condition for re-use. in addition to maximizing product lifetimes during use, repair skills are essential to mitigating post-consumer waste by maximizing potential re-use of garments. For instance, a study exploring common reasons for garment failure examined over 1000 garments donated to UK second-hand retailers to reveal that at least 29% of clothing had accidental damage including rips and stains, while 14% had holes in seams and 8% had a trim (i.e. buttons, zips, beads etc.) failure (Cooper & Claxton, 2022). While the authors suggested solutions to address these issues during the design phase, acknowledging the potential of mitigation during and after consumer use, this research builds on these findings to explore how repair can be deployed by consumers and second-hand retailers to reduce that share of garments that end up in landfill.

Garment lifetimes are determined by a combination of inherent physical and functional properties of products and the care they receive during use (Cox et al., 2013; Laitala et al., 2020). Moreover, caring for the environment, others and products requires resources as well emotional and cognitive capacities (Tölg & Fuentes, 2024). Consequently, in addition to measures to improve garment quality (Piippo et al., 2022), there is a need to support and promote longevity during and after consumer use. This research aims to add to this area of inquiry and action by exploring the critical relationship between consumers, brands and the charity retail sector regarding garment care, repair and second-life ownership.

Methodology

This externally funded project explored the concepts of care and repair through an understanding, action and communication lens. These two distinct, but closely interrelated concepts are studied through the implementation of a qualitative methodology in collaboration with St. Oswald's Hospice Charity in Newcastle upon Tyne to understand consumer care practices and enable skills exchange in garment repair practices. This series of stakeholder interactions focused on the sharing and up-skilling of individuals to facilitate their engagement with repair practices and encourage positive repeat behaviors.

An extensive literature has informed the design of the methodology, identifying gaps in knowledge and critical areas which have been previously under-researched. This secondary scoping resulted in the framing of a unique problem space which directed stakeholder

engagement and insights into potential intervention points.

Working collaboratively with St. Oswald's Hospice, four 3-hour repair workshops were conducted between January and March 2025. Key skills taught during these sessions included visible and invisible mending, in particular darning and Sashiko (Japanese decorative embroidery technique). Workshops one and two focused on upskilling individuals in the skills and knowledge required for the repair and maintenance of garments. These sessions worked with staff and volunteers within the donation sorting depot in St. Oswald's Hospice to determine the role repair practices could play in diverting damaged donations from landfill and rag. Workshops three and four were open to members of the public and facilitated an opportunity for participants from the first two workshops to share their newly developed skills with a larger group. Participants across the workshops were aged between 18 to 65+, with a steady attendance of 8-10 staff and volunteers in workshops one and two, and 25 – 30 members of the public in workshops three and four. Participants were recruited through internal and external advertisement at the charity retail premises of the charity, alongside social media promotion. Data collected included a short questionnaire at the start and end of the event, observational notes and audio recorded, facilitated group discussions.

All data was analysed using the general inductive method (Thomas, 2006), which involves a close reading and rereading of data to synthesise key themes.

Findings & Discussion

The data generated during the four repair workshops provided a breadth of insights to address the aims of the study. The qualitative findings were categorised into four thematic areas: value, skills and knowledge, resources and caring.

Value

The concept of value emerged across all workshops as a key theme, with participants expressing varied perceptions of how it shaped their care practices. It was detailed that increased access to cheap clothing had contributed to lower engagement in care, with participants also discussing how an expectation of lower garment quality (in the case of fast fashion) made people less likely to value their clothes. In essence, some participants did not see the point of investing time and resource in a cheap garment. A lack of awareness about the labour and skill involved in making garments was referenced with some participants saying that engaging in repair during the workshops had helped them to gain a greater value for clothing in general.

Discussions with staff and volunteers also revealed differing views on the commercial value of repaired donated items, with some doubtful of the commercial viability of visibly repaired garments, especially with new cheaper garments being readily available. There was a generational divide evidenced as some older participants pointed to the associations to poverty, while younger participants argued that visible repairs could be viewed and marketed as unique. Interestingly, negatives views of visible repair did shift for a few as they continued to attend workshop sessions. The generational divide also extended to experiences of valuing as some participants noted how clothing used to be valued (and consequently cared for) more because it was too expensive to replace them. In contrast, others pointed to their experience of following ever-changing trends.

Skills and Knowledge

A key theme, identified as an enabler of care, was skills and knowledge. Conversations with staff and volunteers highlighted the lack of specialised skills required to embed care and repair within the charity retail sector. Aside from the basic knowledge of things like embroidery, stain removal or darning, participants pointed to a need for greater knowledge and skill in differentiating fabric types and determining whether an item was even worth the effort of care. This relates back to the notion of value, with the sorting of donations being a subjective process that relies on individuals to be able to recognise the commercial potential of a garment. Similarly, participants in workshops three and four referenced a perceived lack of care and repair skills. This, some argued, was compounded by the diminishing value of clothing as well has a lack of opportunities to learn in formal educational and communal

contexts. Therefore, the workshops were viewed by many as a valuable opportunity and safe space to learn new skills from the research team and other community members who had varying levels of knowledge and experience. Finally, while skills and knowledge of care practices were identified as key to supporting garment longevity, it was acknowledged that resources and motivation also played significant roles in the engagement with responsible wardrobe management.

Resources

An additional emerging theme from the data was the role that resources played in shaping care and repair practices. The limited amount of time available in the charity retail sector was repeated referenced in workshop one and two. Although there was a high-level of enthusiasm expressed by the staff and volunteers about repairing and caring for (laundering, removing stains, etc.) donated items, they also acknowledged how time constraints circumscribed their ability to action these desires. While a few volunteers involved in sorting donations shared experiences of taking the initiative to repair or clean a few garments at home, many deemed it unfeasible to add that level of work to their current sortation workflow. Citing the sheer volume and variety of donations they received; staffing capacity was also recognised as a limiting factor making it difficult for consistent garment care work to take place within the charity. Creating a specialised garment care role was suggested as solution to this, however the realities of funding constraints across the charity sector made this option unlikely.

The resource of physical space at the sorting location was also discussed, as some pointed to the lack of dedicated space for care activities to take place. The consumer perspective on resources, similarly, referenced limits of time as shaping care practice. Furthermore, ownership or access to care tools like a dryer, pilling comb, airing racks for example, influenced how and if consumers enacted garment care. Lastly the resource of information emerged in discussions. Access to care information in the form of physical garment labels and online guides/ tutorials was referenced with participants expressing varied engagement. From those claiming to always use such information, to those that never consulted them, relying instead on tacit know-how, there was a spectrum of reasons cited. These included the desire to extend garment lifetimes, maintain fit or save time. Moreover, many expressed a lack of awareness about online care information from brands, pointing to a need for further engagement from brands through effective communication channels. Interestingly, care information was also referenced as a driver of acquisition decisions, with some participants detailing that they limited their purchase of clothes to items which could be laundered at a specific temperature.

Motivation

The last theme from the data was regarding motivational behaviour for engaging in care and repair practices. While environmental and broader sustainable and ethical concerns were referenced by many during the workshops (especially in relation to fast fashion and over consumption), discussions centred specifically on garment care revealed the nuanced and sometimes competing motivations driving actual care practice. For instance, for some, care (for the planet and others) was and important yet secondary concern to factors such cost saving, convenience, or the desire to maintain the functionality of a technical garment like a waterproof jacket. Therefore, furthering our understanding of the breadth of concerns and motives shaping care and how it is enacted, is essential. Moreover, limited engagement with care communication reported by consumers emphasises the need for key stakeholders like brands to consider the most effective approaches of disseminating care information to consumers. Aside from insights regarding the drivers and enablers of care, this study highlights general lack of awareness that consumers have about the fate of the garments they donate into the second-hand supply chain. Better education about this may encourage greater care to optimise product second lifetimes.

Conclusions

All four workshops provided insights into the appetite and potential for wide-scale uptake of garment maintenance and repair to be implemented to divert damaged clothing

donations going directly to landfill or rag. Discussions both with the charity retail workers and the public featured enthusiasm for learning about and engaging in care practices in communal and personal contexts. Indeed, many participants saw the potential of care and repair practices to reduce waste and support longevity. However, from both a charity retail and consumer perspective, motivations to engage were largely dependent on the knowledge, skills and resources. In summary, responsible wardrobe management relies on the perceived value, both in terms of time as a resource, but also the investment of this time into garments.

References

Allsop, D., & Cassidy, T. (2019). Revitalising and enhancing sewing skills and expertise. International Journal of Fashion Design, Technology and Education, 12(1), 65-75. https://doi.org/10.1080/17543266.2018.1477997

Allwood, J. M., Laursen, S. E., de Rodriguez, C. M., & Bocken, N. M. P. (2015). Well dressed?: The present and future sustainability of clothing and textiles in the United Kingdom [Journal Article]. Journal of the Home Economics Institute of Australia, 22(1), 42. https://search.informit.org/doi/10.3316/ielapa.377098202739183

Cooper, T., & Claxton, S. (2022). Garment failure causes and solutions: Slowing the cycles for circular fashion. Journal of Cleaner Production, 351, 131394. https://doi.org/10.1016/j.jclepro.2022.131394

Cooper, T., Claxton, S., Hill, H., Holbrook, K., Hughes, M., Knox, A., & Oxborrow, L. (2014). Development of an Industry Protocol on Clothing Longevity.

Cox, J., Griffith, S., Giorgi, S., & King, G. (2013). Consumer understanding of product lifetimes. Resources, Conservation and Recycling, 79, 21-29. DOI: 10.1016/j.resconrec.2013.05.003

Daystar, J., Chapman, L. L., Moore, M. M., Pires, S. T., & Golden, J. (2019). Quantifying apparel consumer use behavior in six countries: addressing a data need in life cycle assessment modeling. Journal of Textile and Apparel, Technology and Management, 11(1).

De Castro, O. (2021). Loved clothes last: How the joy of rewearing and repairing your clothes can be a revolutionary act. Penguin UK.

Degenstein, L. M., McQueen, R. H., McNeill, L. S., Hamlin, R. P., Wakes, S. J., & Dunn, L. A. (2020). Impact of physical condition on disposal and end-of-life extension of clothing. International Journal of Consumer Studies, 44(6), 586-596. DOI: 10.1111/ijcs.12590

Dubé, S. F., Mary; Bailey-Cooper, Naomi (2023). Empowering Citizens for Garment Longevity. https://instituteofpositivefashion.com/uploads/files/1/BFC-Empowering-Citizens-for-Garment-Longevity_VX.pdf

Ellen Macarthur Foundation. (2019). Fashion and the circular economy – deep dive. https://www.ellenmacarthurfoundation.org/fashion-and-the-circular-economy-deep-dive

European Commission. (2023). Circular economy for textiles: taking responsibility to reduce, reuse and recycle textile waste and boosting markets for used textiles https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3635

Hetherington, A., Malmberg, J., Mariam, S., Munkedal, C., Kilgour, R., Diment, M., Miller, S., Decker, J., Bull, K., & Fisher, G. (2021). The circular fashion ecosystem: a blueprint for the future. doi:10.20935/AcadEng7611.

Kant Hvass, K. (2014). Post-retail responsibility of garments – a fashion industry perspective. Journal of Fashion Marketing and Management, 18(4), 413-430. https://doi.org/10.1108/jfmm-01-2013-0005 DOI: 10.1108/JFMM-01-2013-0005

Klepp, I. G., Laitala, K., & Wiedemann, S. (2020). Clothing Lifespans: What Should Be Measured and How. Sustainability, 12(15), 6219. https://www.mdpi.com/2071-1050/12/15/6219

Laitala, K., Austgulen, M. H., & Klepp, I. G. (2014). Responsibility Without Means. In S. S. Muthu (Ed.), Roadmap to Sustainable Textiles and Clothing: Environmental and Social Aspects of Textiles and Clothing Supply Chain (pp. 125-151). Springer Singapore. https://doi.org/10.1007/978-981-287-110-7_5

Laitala, K., Klepp, I., & Henry, B. (2018). Does Use Matter? Comparison of Environmental Impacts of Clothing Based on Fiber Type. Sustainability, 10(7), 2524. https://doi.org/10.3390/su10072524

Laitala, K., & Klepp, I. G. (2020). What affects garment lifespans? International clothing practices based on a wardrobe survey in China, Germany, Japan, the UK, and the USA. Sustainability, 12(21), 9151. https://doi.org/10.3390/su12219151

Laitala, K., Klepp, I. G., Kettlewell, R., & Wiedemann, S. (2020). Laundry Care Regimes: Do the Practices of Keeping Clothes Clean Have

Different Environmental Impacts Based on the Fibre Content? Sustainability, 12(18), 7537. https://www.mdpi.com/2071-1050/12/18/7537 DOI: 10.3390/su12187537

Lundblad, L., & Davies, I. A. (2016). The values and motivations behind sustainable fashion consumption. Journal of Consumer Behaviour, 15(2), 149-162. https://doi.org/10.1002/cb.1559

McLaren, A., & McLauchlan, S. (2015). Crafting sustainable repairs: practice-based approaches to extending the life of clothes.

McQueen, R. H., Jain, A., McNeill, L. S., & Kozlowski, A. (2023). The role of resources in repair practice: Engagement with self, paid and unpaid clothing repair by young consumers. Textile Research Journal, 93(3-4), 576-591. DOI: 10.1177/00405175221123067

Mutambo, N., Peirson-Smith, A., Kechi-Okafor, C., Irving-Munro, A., Sheridan, K. J., Prendergast-Miller, M. T., Namdeo, A., Stanton, T., Gallidabino, M. D., & James, A. (2024). Mapping the Environmental Impact Assessment Landscape in the Fashion and Textile Industries: Critical Gaps and Challenges. Sustainability, 16(19), 8377. https://doi.org/10.3390/su16198377

Niinimäki, K. (2010). Eco-clothing, consumer identity and ideology. Sustainable Development, 18(3), 150-162. https://doi.org/10.1002/sd.455

Niinimäki, K. (2018). Sustainable fashion in a circular economy. Aalto University.

Patwary, S., Haque, M. A., Kharraz, J. A., Khanzada, N. K., Farid, M. U., & Kumar, N. M. (2022). Apparel Consumer Behavior and Circular Economy: Towards a Decision-Tree Framework for Mindful Clothing Consumption. Sustainability, 15(1), 656. https://doi.org/10.3390/su15010656

Piippo, R., Niinimäki, K., & Aakko, M. (2022). Fit for the Future: Garment Quality and Product Lifetimes in a CE Context. Sustainability, 14(2), 726. https://www.mdpi.com/2071-1050/14/2/726

Primark. (2024). Primark Durability Framework. https://primark.a.bigcontent.io/v1/static/Primark-Durability-Framework-2024

Thomas, D. R. (2006). A general inductiveapproach for analyzing qualitative evaluation data. *American journal of evaluation*, *27*(2), 237-246. DOI: 10.1177/1098214005283748

Tölg, R., & Fuentes, C. (2024). Care and circularity: how the enactment of care enables and shapes the circular consumption of clothing. Consumption and Society, 1-19. https://doi.org/10.1332/27528499Y2024D000000032

Treggiden, K. (2023). Broken: Mending and repair in a throwaway world. Ludion.

Twigger Holroyd, A. (2016). Perceptions and practices of dress-related leisure: shopping, sorting, making and mending. Annals of Leisure Research, 19(3), 275-293. https://doi.org/10.1080/11745398.2015.1111148

Weft. (2024). EPR variable fee white paper. https://unbxd.ams3.digitaloceanspaces.com/ukft.org/wp-content/uploads/2024/09/25162307/WEFT-EPR-variable-fee-white-paper.pdf

WRAP. (2017a). COS: Extended wash test. https://www.wrap.ngo/resources/guide/sustainable-clothing-guide/cos-extended-wash-test

WRAP. (2017b). How to use the Clothing Longevity Protocol. https://www.wrap.ngo/resources/guide/extending-clothing-life-protocol

WRAP. (2021). Textiles 2030 Circularity Pathway. https://www.wrap.ngo/sites/default/files/2021-04Textiles%202030%20Circularity%20Pathway.pdf

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Repair as a driver of community-led behavioural change

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Keywords: Social resilience; Repair-led design; Commons; Social impact; Co-design.

Abstract: Repair has been at the epicentre of place-based approaches led by communities/commons in order to sustain resources and address socio-environmental challenges. This paper presents the initiative Creative Industries, Social Enterprise, Repair and Restoration (CISERR) situated in regional Queensland, which is providing practical and social skilling to at-risk young men by employing creative repair practices. CISERR adopts repair as a wholistic approach targeting not only material restoration but also self and community renewal. To capture its social impact, all phases of the initiative were evaluated through an evolving Monitoring Evaluation and Learning (MEL) framework. The paper focuses on the third round of CISERR for which, the methodological approach and findings were divided in two parts. The participatory Narrative Inquiry (PNI) methodology was used for the first part while the Participatory Scenario Planning (PSP) method and a facilitators' workshop were employed for the second part. Interviews and visual data collection were conducted for both parts. The findings combined demonstrated how CISERR facilitated the development of adaptation skills related to possibilities of employment by exposing at-risk young men to creatively repairing and reusing local resources. They additionally made evident how CISERR's wholistic repair approach created the circumstances for a community to use its lived experience and place-based resources to support at-risk youth. The paper concludes with CISERR as an example of repair driving community-led behavioural change; the latter being a response to the growing need for social resilience and an antidote to the failed efforts by governments to activate individual behavioural change.

Introduction

In the past few decades repair has been gaining ground in the sustainability discourse as a response to built-in obsolescence (Salvia and Cooper, 2016; Dewberry et al., 2016) and the brokenness of ecosystems (Jones et al., 2018). Within these ecosystems, communities/commons and grassroots movements have been advocating for repair to contest the growing exhaustion of natural resources but also the social injustices stemming from a lack of access to repair (Bartram, 2023). In this context, communities/commons' initiatives have created circumstances of repair varying from repair cafés (Ozanne, 2024) to cities (Bianchi, 2023) that demonstrate its all-encompassing nature. These efforts have manifested the importance of making visible fragility (Denis & Pontille, 2015) and the unnoticed work of maintenance along with the innovation lying in repair (Jackson, 2014). Furthermore, these initiatives have put forward repair-led design, described as socio-material manifestations of care that derive from the place-based, lived experience of collectives (Kalantidou et al., 2024).

Against this backdrop, repair becomes an instigator of community-led behavioural change triggered by community-driven action and grounded in place-based capacity, human and material. In conditions of environmental and social crises, individual behavioural change is failing to make a difference. Nudging, which has been employed by governments to promote individual behavioural change, has been questioned in relation to its effectiveness and its ethical (Kuyer & Gordijn, 2023), legal (Lepenies & Małecka, 2015) and human rights (Zeilstra, 2024) implications. Climate change cannot be alleviated by nudging alone, especially when its impact on reducing greenhouse gas emissions is not really measurable (Siipi and Koi, 2022). By comparison, community-led behavioural change's social impact is usually manifested in the locality where it is situated and it can also spread through trans-local connectivity (Vélez-Torres & Agergaard, 2014). As a case in point,

the Right to Repair movement, which started in Massachusetts, has gained momentum as a driver for legislation change around the world and forced technological companies to revise their Intellectual Policy practices (Perzanowski, 2022).

In addition to the growing need for resource maintenance, community-led behavioural change catalysed by repair, answers to the need for social resilience. Communities/commons have been employing their place-based, lived experience in order to determine the resources that need to be repaired and the skills required for maintaining their livelihoods (Villamayor-Tomas & García-López, 2021). Examples involve The Little Mesters, a repair community in Shefield, United Kingdom, which turned into commons to save and repair the building (Portland Works) that housed its businesses. In this case, commoning triggered repair-led design, allowing repairers to reclaim Portland Works in order to continue offering repair services to their local community and earn their bread and butter (Udall, 2019). Another instance is that of the Chilean Streets (*estallido social*) commons that became a vehicle to mend the collective wounds of a nation by using public infrastructure as a protest site. They showcased an ecological practice of reparation (Bonelli and la Cadena, 2024), entailing the "recognition that harm and recovery of environments and human societies are intrinsically linked" (Papadopoulos, Puig de la Bellacasa and Tacchetti 2024, p. 2). In view of this, repair receives a wider connotation than just being 'a practice of fixing stuff'. It becomes an ontological position for adaptation including not only materials but also the self through cognitive challenging and re-skilling; the community via skills exchange and interdependence; and habitus by re-engaging humans with (their) nature (Kalantidou and Brennan, 2024).

This paper presents an initiative consistent with the aforementioned rationale, titled the Creative Industries, Social Enterprise, Repair and Restoration (CISERR), which is placed in regional Queensland. Since 2021, CISERR has been exposing at-risk youth, and specifically young men between the ages of 15-19, to a wholistic approach of repair. These have been disengaged from mainstream education, had an interaction or have been identified as in danger of being involved with the Youth Justice System. While designing the initiative, repair was intentionally chosen as a manifestation of "caring for things within webs of material, social, economic, and political interactions" (Corwin and Gitwani 2021, p. 3). It was selected to broker community and transgenerational bonds, prompt skills exchange and enable circular economy practices via preservation and reuse.

Through creative repair and art workshops, literacy and numeracy, life and cultural skills together with collectively setting up a social enterprise, CISERR has facilitated a transgenerational exchange of skills, material knowledge and adaptation awareness. This paper focuses on the third iteration of CISERR[1], which was divided into two parts. Their respective findings are discussed below as well as their connection to repair and community-led behavioural change.

The Creative Industries, Social Enterprise, Repair and Restoration (CISERR) initiative

Repair as a concept of restoration and renewal is needed more than ever not only in relation to material resources but whole areas that have been depleted over the years of opportunities, services and means for young people to thrive (Hickey et al., 2024). Maryborough is a regional town situated in the Fraser Coast local government authority in Queensland, Australia, where a significant number of young people residing there has been impacted by systemic injustices such as higher than state average unemployment, homelessness, educational exclusion and intergenerational cycles of poverty. According to the Hervey Bay Neighbourhood Centre (2023), 89 per cent of Australian regions have higher levels of socioeconomic advantage in comparison with the greater Fraser Coast population. In 2021, 17 per cent of 15–24-year-old young people on the Fraser Coast were disengaged from

[1] CISERR was based on a pilot study under the name Transformative Repair for Social Change (TRSC). A more detailed description of the MEL and findings from the pilot and two rounds are provided in other publications (Kalantidou and Brennan, 2024a; Kalantidou and Brennan,2024b).

employment and education, compared to 10.6 per cent in Regional Queensland (Hervey Bay Neighbourhood Centre, 2023). This reality led to the emergence of the Creative Industries, Social Enterprise, Repair and Restoration (CISERR) initiative, which was created by Testimony Arts, a for purpose company, and co-designed with the local community. The initiative provides alternative education through creative repair and life skills support in order to activate employability and community re-engagement pathways for at-risk youth. To evaluate CISERR's impact, a Monitoring, Evaluation and Learning (MEL) framework [2] was designed anchored in systems thinking, by employing a soft (interpretive) approach, involving a creative process of problem analysis (Jackson, 2001). From this perspective, emphasis was placed on gaining knowledge by using exploratory models of enquiry including predominately qualitative data and stakeholder participation. An Impact Map (Burkett et al., 2020), was adopted instead of a Theory of Change, as a more accurate representation of the perceptions, assumptions and expectations stemming from the initiative. This paper presents the MEL methodological framework and findings of the third round, which was divided into two parts, before and after the Christmas period of 2023-2024.

CISERR, Third round – part I: MEL methodological framework and findings

Methodologies and methods

The first part of the third round emphasised the need to further support the well-being of the youth participants as well as connecting their skilling in creative repair practices to employability pathways and the development of a social enterprise. The Impact Map (figure 1) from the previous round was updated to capture the shift to a scaffolding approach in terms of providing creative specialisations (visual arts, arts communication and creation, repair and restoration) to the youth participants. It was also amended to reflect an emphasis on well-being, through the implementation of the Rage program, in order to explore communicating emotions and traumatic experiences in a safe environment among peers, delivered by a qualified youth worker. To evaluate the impact of these changes participatory evaluation was adopted in order to spark a co-production of knowledge with a shared responsibility of gathering and interpreting data. Hence, the Participatory Narrative Inquiry (PNI) methodology (Kurtz, 2014) was employed, which is a type of action research. PNI emphasizes participatory decision making through the sharing of lived experience stories and their interpretation by the participants. This methodology overcomes the interpretation of lived experience by the researcher by bringing it to the forefront through the person who holds it, the story-teller. In this respect, the story-tellers co-produce knowledge with the researchers (narrators) (Colla and Kurtz, 2024). Story-sharing, a method grounded in narrative research (Lee et al., 2013) was used to collect stories from the participants. Two story-sharing sessions were realised in Maryborough between the 13th and 15th of December, 2023, with the participation of 10 youth participants and 11 facilitators, respectively.

The participatory evaluations that took place with the employment of the PNI methodology were complemented by at-risk youth and facilitators' interviews and triangulated with visual data and quantitative data such as 500 workshop hours, production of more than 100 creative repair artefacts (figures 2 & 3) and 90 per cent attendance rate.

[2] This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Research Ethics and Integrity Office for Research, Griffith University (variation approved 27/02/2023—GU Ref No: 2021/734). Informed consent (to participate and/or to publish) was obtained from individual participants and parents/guardians.



Figure 2. Repaired artefact. ©TammyBrennan.



Figure 3. Repurposing materials. ©TammyBrennan.

Findings

The analysis of the stories was realized by employing sense-making, a method that allows for connecting the stories back to the locality, the participants and the research enquiry (Kurtz, 2014). From the sense-making of the youth participants' PNI emerged the following themes: Self-empowerment; future thinking for professional development; alternative educative options; and community engagement. In detail, creative repair and art practices with the addition of the Rage program helped them get self-empowered by being skilled and active, socialise and process emotions. Concerning their employability, the youth participants confirmed that the exposure to making a trailer (figure 4) and the skills they acquired from restoration and repair got them thinking about professional development, apprenticeships and future skilling ("I'd probably want to come back next year…I enjoy the skills"). Most importantly, they recognised the program being an alternative to not going to school. What also came forth was their enjoyment of learning creative repair skills whilst they also expressed the need to further their skillset. In terms of community engagement, all young men spoke favourably towards facilitators, mentors and youth workers ("The mentors, they're really nice and respectful").

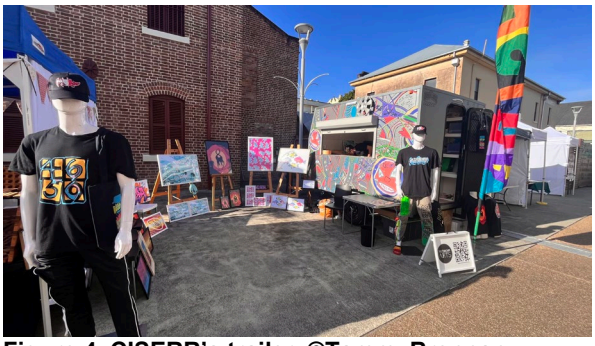


Figure 4. CISERR's trailer. ©TammyBrennan.

The facilitators' PNI stories focused on themes revolving around: mental health; skills' enhancement; entrepreneurialism; a three-year version of CISERR; and CISERR responding to the pain points of conventional education. Regarding the youth participants' mental health, the facilitators positively connected it to creative repair practices. They promoted the idea of a permanent home for CISERR and an at least three-year engagement with the initiative for the youth participants to build their resilience and grow their independence (the latter related to generational interdependence and examples of dependency and unemployment coming from their families). The facilitators also stressed the necessity of skills' enhancement through small groups, more exposure to making, as well as trial and error. What was highlighted through many stories was the effectiveness of individual mentorship and small groups where skills can be practiced ("I think that at the end, most of them felt like they were a little more stable than they were when they started and some of them found that they had skills they didn't really know they had"). There were also success stories regarding youth participants showcasing skills to their peers. Other aspects that were underlined by the facilitators were opening up to creativity with an entrepreneurial understanding of the creative repair products (saleable/scalable) and

connecting these activities back to strengthening skills, engagement time and attention span. Finally, a recurrent theme appearing in the story-telling was conventional education failing young people, manifested through youth participants coming to CISERR because of their disengagement from conventional education.

The youth participants' interviews reinforced the PNI findings by demonstrating how their experience of being exposed to creative repair and art practices contrasted conventional schooling. They additionally shared their conviction that the parallel behavioural support they received, helped them deal with difficult emotions and traumatic experiences. Likewise, the interview themes that emerged from the facilitators' responses were similar to the PNI themes. The facilitators' interviews revealed their belief that CISERR supports the youth participants building on creative repair skills and resilience so as to prepare them for employment.

The PIN findings combined with the interviews from both cohorts responded to the Impact Map in terms of the workshops altering the at-risk youth perception of what constitutes education and helping them establish bonds with their community by creative repair skilling. The at-risk youth and facilitators' assertion that creative repair skilling has sparked self-confidence, interconnection and material knowledge for the youth participants could render them as factors affirming employability and community re-engagement readiness. This, in conjunction with high participation rates and the production of numerous repurposed material artefacts by the youth participants. Creative repair's lasting effect on mental health and the potential of employability is additionally indicated by the return of over 50 per cent of the youth participants to the program and the growing number of apprenticeships (two to three) acquired after every round.

CISERR, Third round – part II: MEL methodologies and findings

Methodologies and methods

The second part of the third round was rooted in the MEL findings from the first part. The goals that were set were to continue scaffolding pathways to employment and future thinking, establish a social enterprise through the use of the trailer and the production of creative repair artwork/artefacts, as well as reinforcing positive behaviours.

For this part, the MEL was designed to evaluate the readiness for the creation of a social enterprise centred on creative repair practices; CISERR's sustainability as an initiative; and the development of future thinking by the youth participants. As a component of this process, the Participatory Scenario Planning (PSP) method was selected, due to being a multi-stakeholder approach designed to enable an understanding and collective interpretation of place-based conditions with associated uncertainty. This method involves a collaborative process guided by the researcher in order to imagine future scenarios related to specific aspects of a condition, problem or initiative (Oteros-Rozas et al. 2015). The PSP process was realised between the 9th and 10th of April, 2024, in Maryborough Queensland.

Two PSP actualisations occurred. The first, with the participation of seven facilitators (youth workers, artists and tutors) who were given some guiding questions related to CISERR's sustainability-future planning; building community involvement; and securing a permanent home for CISERR. These questions emerged from ongoing MEL findings together with the organic co-designing of CISERR.

Similarly to the facilitators' PSP, six youth participants contributed to the PSP that was organised for them. To actuate PSP discussions, the questions/issues that were put forward were: the creation of a creative repair social enterprise; opportunities for apprenticeships; what happens after finishing the program; what should change in CISERR; how a youth-led social enterprise should work; what are the barriers for being employed in a preferred job in Maryborough; and the youth participants' vision for their future.

In addition to the PSP process, 14 facilitators, five parents/guardians and seven youth participants were interviewed in respect to their experience of the program and their expectations moving forward.

Findings

The findings from the facilitators' PSP revealed themes such as: the necessity for a more active involvement of the local schools in supporting CISERR; recognition of the value of creative repair practices as alternative learning; the acknowledgement of CISERR as an expression of local culture through the establishment of a local festival; more support from local businesses; and engaging the community via initiatives such as a repair café and a physical/online marketplace. Regarding community involvement, it was stressed that the youth participants need to interact more with their community via the markets, and CISERR opening up to the community for repairing, exchanging and sharing artefacts. Finally, the necessity of a permanent home was addressed in order to pursue goals such as running workshops, a repair café, establishing cooking classes and having permanent storage space for artefacts and materials.

The youth participants' PSP demonstrated how CISERR has animated their future thinking by making them proactive about their future employment. Being part of a social enterprise or doing an apprenticeship were expressed as desirable in contrast to going back to school and poorly paid, precarious jobs, which are the predominant working option for young people in Maryborough.

Concerning the interview findings, the facilitators talked about unearthing the youth participants' ability to "see something that's needs restoring and then seeing a product". The parents reinforced the sentiment that CISERR has a positive effect on the youth participants via a wholistic framework of support (transportation, food, emotional and practical skilling, communication with parents) and that it is a rewarding alternative in relation to conventional schooling. In their interviews, the youth participants responded positively to how CISERR has contributed to their future aspirations by being willing to continue their skills development. They acknowledged the role CISERR played in them feeling as a part of a community, improving their socialisation and communication skills, and gaining self-confidence. The youth participants also found useful learning how to use tools, building the trailer, upcycling and budgeting.

The findings of this round exhibited how CISERR gradually 'repaired' predispositions by preparing the at-risk youth, mentally and practically, to engage with the community and potentially become self-employed through the market trailer. The multifaceted preparation for this step was evidenced through the parents confirming the positive influence the support systems in place had on their children. Likewise, CISERR's emphasis on circular economy practices by working with reclaimed materials, incorporating creative repair skills and embedding education on resource preservation, made possible for youth participants to see discarded items as valuable resources. Further, it established repair as a means to create employability pathways by selling repurposed goods or providing repair services to the community.

Repair as a driver of community-led behavioural change

The brief presentation of the third round of CISERR evidences the potential of creative repair practices to address a number of environmental and social challenges. By combining repair with place-based knowledge and lived experience and embedding them in the design of the initiative, CISERR showed how at-risk youth re-engagement can be rooted in circular economy principles and activation of skills via the local community. The big learnings that came out of the third round were grounded in how repair can become a vehicle of transgenerational and cultural exchange, shape material awareness and instigate employability potential. To illustrate, volunteers from the Men's shed shared their repair skills and mentorship with young men, tutors and artists showed them their strengths and capabilities and public spaces opened up to house these efforts. Furthermore, culturally diverse young men got connected to Country with the cultural support of artists and youth workers and developed their adaptation skills by valuing resources through restoration and repair. By building a trailer to sale their creative repair and art artefacts at the local markets, the at-risk youth got a direct interface with the community to showcase their newly acquired skillset and get the community involved with CISERR, in some capacity.

Despite its long-term positive impact being hard to measure, there are strong indicators of how it has altered the prospects of the at-risk youth. Young people coming back to the program, expressing the need to continue learning repair skills, their behavioural change exhibited through attendance and hard work as well as their engagement with the community through the trailer and apprenticeships could be interpreted as steps toward employability and 'staying out of trouble'. Furthermore, CISERR, while being a small initiative, has demonstrated how regional communities can rely on their own resources to respond to social disadvantage and lack of services. Entrenched in place-based, lived experience rather than a top-down prescription of sustainable behaviour, it has created a framework that can be implemented in other regional areas experiencing the same problems. In this light, it can also propagate the potency of repair to spark community-led behavioural change by enacting trans-local connectivity (Vélez-Torres & Agergaard, 2014). As a final note, the ongoing documentation and evaluation of CISERR's outcomes and impact could lead to policy makers acknowledging repair as a driver of community-led behavioural change. This, by bringing together people through collectively maintaining resources, inciting knowledge and skills exchange, and instilling a new understanding of local agency within communities.

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References

Bianchi, I. (2023). The commonification of the public under new municipalism: Commons–state institutions in Naples and Barcelona. *Urban Studies*, *60*(11), 2116-2132. https://doi.org/10.1177/00420980221101460

Bartram, R. (2023). Routine dilapidation: How homeownership creates environmental injustice. *City & Community*, *22*(4), 266-285. https://doi.org/10.1177/15356841231172524

Bonelli, C., & de la Cadena, M. (2023). Chilean Streets: An Archive against the Grain of History. In D. Papadopoulos, M. P. de la Bellacasa, & M. Tacchetti (Eds.) (2023), *Ecological reparation: Repair, remediation and resurgence in social and environmental conflict* (pp. 301-326). Bristol University Press. https://doi.org/10.51952/9781529239560.ch020

Burkett, I., McNeill, J., & Allen, M. (2020). *Substation 33 Impact Report 2020*. The Yunus Centre, Griffith University.

Colla, R. H., & Kurtz, C. F. (2024). Storying Research: Exploring the Benefits of Participatory Narrative Inquiry as a Methodology for Wellbeing Research. *International Journal of Applied Positive Psychology*, 1-20. https://doi.org/10.1007/s41042-024-00147-4

Corwin, J. E., & Gidwani, V. (2021). Repair work as care: On maintaining the planet in the Capitalocene. *Antipode,* 1-20. https://doi.org/10.1111/anti.12791

Denis, J., & Pontille, D. (2015). Material Ordering and the Care of Things. Science, Technology, & Human Values, *40*(3), 338-367. https://doi.org/10.1177/0162243914553129

Dewberry, E., Saca, L., Moreno, M., Sheldrick, L., Sinclair, M., Makatsoris, C. and Charter, M. (2016). A landscape of repair. In: *Proceedings of the Sustainable Innovation 2016. Circular Economy Innovation and Design.*, Towards Sustainable Product Design, The Centre for Sustainable Design, University of the Creative Arts, Epsom, Surrey, UK, pp. 76–85.

Estalella, A., & Criado, T. S. (Eds.). (2018). *Experimental collaborations: Ethnography through fieldwork devices*. Berghahn Books. https://doi.org/10.3167/9781785338533

Fawcett, S. B., Boothroyd, R., Schultz, J. A., Francisco, V. T., Carson, V., & Bremby, R. (2014). Building capacity for participatory evaluation within community initiatives. In

Y. Suarez-Balcazar & G. Harper (Eds.), *Empowerment and participatory evaluation of community interventions* (pp. 21-36). Routledge.

Hervey Bay Neighbourhood Centre (2023). *State of the Youth Report 2023*. Hervey Bay Neighbourhood Centre.

Hickey, A., Riddle, S., McKee, A., Skye, D., Wallis, R., & Pocock, C. (2024). Youth Community Futures: Enhancing Opportunities for Young People in Regional Queensland. University of Southern Queensland.

Jackson, M. C. (2001). Critical systems thinking and practice. *European Journal of operational research*, *128*(2), 233-244. https://doi.org/10.1016/S0377-2217(00)00067-9

Jackson, S. J. (2014). Rethinking Repair. In T. Gillespie, P. J. Boczkowski, & K. A. Foot (Eds.), *Media Technologies: Essays on Communication, Materiality, and Society* (pp. 221–239). MIT Press. https://doi.org/10.7551/mitpress/9780262525374.003.0011

Jones, H. P., Jones, P. C., Barbier, E. B., Blackburn, R. C., Rey Benayas, J. M., Holl, K. D., ... & Mateos, D. M. (2018). Restoration and repair of Earth's damaged ecosystems. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1873), 20172577. 10.1098/rspb.2017.2577

Kalantidou, E., & Brennan, T. (2024a). Community Resilience by Repair: Skilling At-Risk Youth for Social Impact and Environmental Sustainability. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis (Eds.), *Design/Repair: Place, Practice & Community* (pp. 213-240). Springer Nature. https://doi.org/10.1007/978-3-031-46862-9_9

Kalantidou, E., & Brennan, T. (2024b). Co-designing Resilience: Practical and Social Skilling through Place-based Repair. *Diseña*, (24), 5-5. https://doi.org/10.7764/disena.24.Article.5

Kalantidou, E., Keulemans, G., Mellick Lopes, A. M., Rubenis, N., & Gill, A. (Eds.). (2023). *Design/Repair: Place, Practice & Community*. Springer Nature. https://doi.org/10.1007/978-3-031-46862-9

Kurtz, C. (2014). Working with stories in your community or organization: Participatory narrative inquiry. Kurtz-Fernhout Publishing.

Kuyer, P., & Gordijn, B. (2023). Nudge in perspective: A systematic literature review on the ethical issues with nudging. *Rationality and Society*, *35*(2), 191-230. https://doi.org/10.1177/104346312311550

Lee, J., Hunter, J., & Franken, M. (2013). Story sharing in narrative research. *Reo, Te*, *56*, 145-159.

Lepenies, R., & Małecka, M. (2015). The institutional consequences of nudging–nudges, politics, and the law. *Review of Philosophy and Psychology*, *6*(3), 427-437. https://doi.org/10.1007/s13164-015-0243-6

Oteros-Rozas, E., Martín-López, B., Daw, T. M., Bohensky, E. L., Butler, J. R., Hill, R., ... & Vilardy, S. P. (2015). Participatory scenario planning in place-based social-ecological research: insights and experiences from 23 case studies. *Ecology and Society*, *20*(4). http://dx.doi.org/10.5751/es-07379-200161

Ozanne, L. K. (2024). Repair cafés: exploring collaborative repair. In *Understanding Collaborative Consumption* (pp. 68-81). Edward Elgar Publishing. https://doi.org/10.4337/9781035307531.00014

Papadopoulos, D., de la Bellacasa, M. P., & Tacchetti, M. (2023). Introduction: No justice, no ecological peace: The groundings of ecological reparation. In *Ecological Reparation: Repair, remediation and resurgence in social and environmental conflict* (pp. 1-16). Bristol University Press. https://doi.org/10.51952/9781529239560.int001

Perzanowski, A. (2022). *The right to repair: Reclaiming the things we own*. Cambridge University Press. https://doi.org/10.1017/9781108946926

Salvia, G., & Cooper, T. (2016). The role of design as a catalyst for sustainable DIY. *Sustainable consumption: Design, innovation and practice*, 15-34.

Siipi, H., & Polaris, K. O. I. (2022). The ethics of climate nudges: Central issues for applying choice architecture interventions to climate policy. *European Journal of Risk Regulation*, *13*(2), 218-235. https://doi.org/10.1017/err.2021.49

Vélez-Torres, I., & Agergaard, J. (2014). Political remittances, connectivity, and the trans-local politics of place: An alternative approach to the dominant narratives on 'displacement' in Colombia. *Geoforum*, *53*, 116-125. https://doi.org/10.1016/j.geoforum.2014.03.001

Villamayor-Tomas, S., & García-López, G. A. (2021). Commons movements: Old and new trends in rural and urban contexts. *Annual Review of Environment and Resources*, *46*(1), 511-543. https://doi.org/10.1146/annurev-environ-012220-102307

Udall, J. (2019). Mending the commons with the 'Little Mesters'. *Ephemera: Theory and Politics in Organization*, *19*(2).

Zeilstra, R. (2024). Nudging and the Safeguards of the Rule of Law. *German Law Journal*, 1-22. https://doi.org/10.1017/glj.2024.30

IF WE:	BY:	THIS WILL RESULT IN:	AND EVENTUALLY WILL LEAD TO:
If we expose at-risk-youth to alternative education models, they will engage with their communities.	**1. Engagement in Education** • Conduct 16 face to face workshops (Rage Program) over 10 weeks with max 13 participants. Over a period of 12 months (x2) to build skills in: • Interpersonal skills • Developing a work pathway • Construction skills • Gaining certification in Manual Arts skills.	• Re-engage through soft skills, mentor-led education, scaffolded commercial training/activities. • Opportunities to acquire interpersonal and professional skills • Individual identified learning/training that supports a work experience pathway, or return to education.	• Engaged with skills development/learning opportunities in community e.g. apprenticeships/ traineeships/ meaningful employment.
If we provide creative manual and repair skills training, at-risk-youth can get access to employability pathways.	**2. Creative Industries Program** • Conduct 3 face to face workshops over 8 weeks with max 14 participants. Over a period of 12 months (x2) to build skills in 3 streams: 1. Visual Arts 2. Arts, Communication and Curation 3. Repair and Restoration • Build relationship skills • Develop communication skills • Build connections to the wider community • Build confidence in communication skills, which will assist with interview skills.	• Re-engage through soft skills, mentor-led education, scaffolded commercial training/activities. • Opportunities to acquire interpersonal and professional skills • Individual identified learning/training that supports a work experience pathway, or return to education • Social enterprise readiness.	• Engaged with skills development/learning opportunities in community e.g. apprenticeships/ traineeships/ meaningful employment.
If we provide customised numeracy and literacy training to at-risk-youth, they will gain confidence in their ability to learn.	**3. Literacy and Numeracy Workshop** • Conduct 3 face to face workshops over 8 weeks with max 14 participants. Over a period of 12 months (x2) to build skills in: • Connections to the wider community • Confidence in communication skills, which will assist with interview skills • Literacy skills • Numeracy skills.	• Work with Education specialists to understand and improve the social-educational barriers and learning factors of the disengaged learners, • Deliver a program specific literacy and numeracy support program • Improve literacy and numeracy results • Regularly engage with education • Positive relationships with educators • Successful educational outcomes.	• Have a literacy/numeracy level to be able to undertake Cert II /above courses • Independently complete MYGOV and other government administrative tasks • Positive self-view as a capable learner with the ability to improve.

Figure 1. Impact Map round 3, parts I & II. ©EleniKalantidou & TammyBrennan.

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Treat and Clean: A pilot study in stain removal and mending of substandard thrift store donations

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Keywords: Second-hand textiles; sorting; stain removal; repair; sustainability.

Abstract: The growing prevalence of textile waste, largely driven by the fast-fashion model, necessitates a shift towards a circular economy that prioritises the reuse of materials. In Canada, the textile donation landscape is primarily managed by charities and for-profit organisations, which often rely on public donations to generate revenue. Despite high donation rates, many items received by thrift stores are unsuitable for resale, creating challenges for organisations dependent on volunteer labour. This paper discusses the *Treat & Clean* pilot study, part of a larger investigation into the quality and type of clothing donations received in Canadian thrift stores. The project aimed to assess the feasibility of rejuvenating so-called "substandard" clothing through cleaning and repair techniques, allowing these items to be resold. In total 4946 textile items donated to two large non-profit thrift organisations at nine separate store locations within Alberta and Saskatchewan were sorted. A significant portion of the donations were deemed unfit for immediate resale. A subset of sorted items (N=2271) was analysed off-site and considered for the *Treat & Clean* pilot. The effectiveness of the pilot was evaluated by analysing the success of treatments (e.g., stain removal) and tracking the resale of treated items. Results indicate that enhancing the quality of donations through simple cleaning and repair methods can increase the likelihood of their sale, thereby promoting sustainability in local communities. This study highlights the importance of increasing consumer awareness regarding donation quality.

Introduction

Textile waste has become increasingly prevalent due to the dramatic rise in clothing production and consumption associated with the fast-fashion business model (Casey & Johnston, 2021; Roos et al., 2015). It is evident that we must shift from the linear “take-make-use-waste” model to a circular economy, where materials are valued, products are retained for as long as possible, and waste is viewed as a resource. Following in the footsteps of the EU's circular economy action plan, Canada is setting in motion to create a sustainable and resilient economy (Government of Canada, n.d.). Within any circular economy framework, prioritising the reuse of items is essential. Among various methods for reusing clothing, thrift stores play a critical role by collecting, sorting, and selling clothing, relying on donations from the public.

In Canada, the collection of used clothing and textiles is primarily conducted by charities that generate funds to support their charitable activities, as well as for-profit organisations that often depend on charities for textile collection (e.g., Diabetes Canada). Clothing, including footwear and accessories, comprises approximately 36% of revenue generated by used goods stores, more than any other product segment (Koronios, 2021). Surveys on clothing disposal methods have shown that donating clothing is one of the most common ways people dispose of their unwanted garments (Han et al., 2024; Degenstein et al., 2021; Weber et al., 2017), although this may be more prevalent in urban areas due to the greater accessibility of donations bins and collectors.

Thrift stores and charitable collectors request that clothing donations be clean and in good condition (e.g., MCC Thrift, n.d.; Goodwill Industries Alberta, n.d.). However, the reality is that many items received from the public do not meet these standards. Reportedly, only 30% of donations received by local thrift stores are deemed suitable for resale within the local store where it was donated (Degenstein et al., 2021). This situation burdens charities that depend on volunteers for labour, as managing unsaleable items requires additional action and strategies,

such as downcycling, meticulous repricing, and internal distribution (Genge & Schouten, 2021; Larsen, 2023). Additionally, this can create an emotional strain on thrift store volunteers and staff who have to decide to bin items that may still be otherwise usable (Berry, 2022).

Maintaining a certain quality of donations is crucial for ensuring customer satisfaction and reducing negative perceptions regarding the cleanliness and hygiene of used clothing (Oscario, 2023). However, cleaning and repairing donated items is often not feasible for many thrift organisations due to resources, labour costs, limited volunteer capacity, and the uncertainty of whether items will sell (McQueen et al., 2023). Nevertheless, if donations arrive in good condition, the likelihood that they will be placed on the sales floor—and subsequently sold—greatly increases, promoting reuse within local communities.

Increasing consumer awareness regarding the quality of donations could help extend the longevity of these items. Consumers have access to commercial products for cleaning and stain removal, and skills for repair can be easily acquired through online tutorials. This paper presents the *Treat & Clean* pilot study, which evolved from a broader investigation into the quantity and quality of clothing and textile donations at selected Canadian non-profit thrift stores. The *Treat & Clean* pilot project aimed to assess whether clothing donations deemed unsuitable for the retail floor could be rejuvenated through repair, stain removal, de-pilling and de-hairing, and standard cleaning procedures, ultimately allowing them to be sold in a local thrift store. This paper will cover three key aspects of the project: an overview of the condition of clothing donations from the larger study; a report on the clothing categorised as being in "substandard" condition for inclusion in the Treat & Clean pilot; and finally, an evaluation of the pilot project's success in terms of the proportion of clothing sold following the treating and cleaning process.

Methodology

Collection and sorting of C&T donations

From September 2023 to October 2024, clothing and textile donations donated at selected thrift stores in two Canadian provinces were characterised. Bags of unsorted donations were randomly chosen from bins received by two large non-profit thrift organisations at nine separate store locations within Alberta and Saskatchewan. Sorting occurred either on-site or off-site, where bags were collected and sorted in facilities at the University of Alberta. In total, 4946 textile items (1191 kg) were sorted. Of these, 2271 textile items (558.2 kg) were collected and analysed off-site. The donations sorted off-site were included in the *Treat & Clean* pilot project.

Condition of clothing and textiles (C&T)

The evaluation of the condition of the donated C&T items was informed by textile waste audit literature (Weber et al., 2023) and insights from thrift store managers collected by the research team during earlier site visits. The assessment relied on subjective criteria to determine if items were suitable for sale based solely on their condition, without considering brand or vintage status. Six categories for the condition were used: A) **brand new** and in excellent condition with original hang-tags still on; B) **excellent** condition with none or minimal signs of wear; C) **good** condition - shows some sign of wear but at an acceptable level for C&T type and does not hinder resale; D) **substandard** - the item could still be used for its original purpose but condition when donated would prevent resale, as the item may require cleaning, stain-removal or repair; E) **recycling** - the item would not be reusable in its original form, but there is still value in the fabric; F) **end-of-life** - the item is contaminated or degraded to the point there is no remaining value in the fabric/fibres. For the *Treat & Clean* pilot project only category D, “substandard,” items were included.

The issues that were present in the D category C&T were further categorised into five groups according to their repairability and the severity of the defect (see Table 1) (Brasch & Ulasewicz, 2023).

Measurement of fibre content

All items were assessed for fibre content following the fibre content label and/or scanned using near-infrared (NIR) spectroscopy (FabriTell, Matoha). When fibre content labels were missing, and the NIR scanner could not identify fibre content for various reasons, such as a lustrous surface, excessive pilling, black-and-white compact patterns, etc. (Cura & Mäkelä, 2024), then the fibre content was marked as ‘unknown’.

Category	Description
Wash/Clean	Wash or dry clean
Minor	Spot clean, repair needed on seams/hems, buttons, soaking, bleaching, light pilling that can be removed by pill remover easily, light hair attached
Major	Special stains (grease), require multiple steps for stain removal, difficult placement of damage, special fabric type, skills needed for repair (e.g., snagging, noticeable hole)
Innovative	Not repairable as is, recognisable/high-value brand, special or unique fabric, vintage
Rejection	Stain will not come out, severe pilling, damaged/hole not repairable, no value, moderate/ severe hair

Table 1. Description of the substandard textile items by treatment method. Modified from Brasch and Ulasewicz (2023)

Treat & Clean Pilot

In the *Treat & Clean* project determining the most effective treatment while balancing time and resources was required. Finding commercially available products that would be easily accessible for consumers and thrift stores for the project was necessary. The list of tools and cleaning products that were required for certain applications is provided in the Appendix (see Table A1).

Items included in the *Treat & Clean* project were returned to one of two MCC thrift stores following treatment. The first batch to the Edmonton store in October 2024 which comprised of 44 items, and the second batch (95 items) to the Saskatoon store in Saskatchewan in early January, 2025.

Every item that was treated and cleaned within the *Treat & Clean* pilot study was given a hang-tag label with a brief description of the issues that had been resolved, and any issues remaining. Figure 1 shows the front (a) and back (b) of the label. An additional smaller label (not shown) was attached which included the item code number and was to be removed at the point of sale by the cashier. These tags were then saved and collected by the research team later. Once *Treat & Clean* items were returned to the thrift store the items were priced and tagged by the stores' pricer and put out with all the regular clothing items organised by size/gender/type.



a. b.

Figure 1. Hang-tag for treated and cleaned items a. front, and b. back

Results and Discussion

Table 2 shows the 2271 textile items analysed off-site at the University of Alberta, categorised by condition. Of these, 52.9% were in excellent to good condition (i.e., A, B or C) and were returned as soon as possible to the thrift store for resale. Substandard textiles (Category D) accounted for 42.7% (N=970) of the total. These D items were further assessed for their suitability in the *Treat & Clean* pilot study.

Categories	Count	% of total
A	46	2.0
B	406	17.9
C	750	33.0
D	970	42.7
E	93	4.1
F	6	0.3
Total	**2271**	**100.0**

Table 2. Items and categories analysed off-site

Categories of substandard textiles and their defects

The dominant fibre content (i.e., greater than 50%) of the D items is shown in Figure 2. Cotton and cotton-dominant blends accounted for 49.9% of the total fibre content, followed by polyester and polyester-dominant blends at 25.4%. Regenerated cellulosic dominant fibres (mostly viscose but also including lyocell and acetate) comprised 9.0% of the fibre types. Protein-based natural fibres, including wool (N=5) and silk (N=3), only accounted for 1% of the total fibre types. In approximately 7% of the D items, the fibre content was unknown. Despite this, it was clear that alkaline cleaning solutions would be used as the primary

treatment for the majority of the cleaning processes.

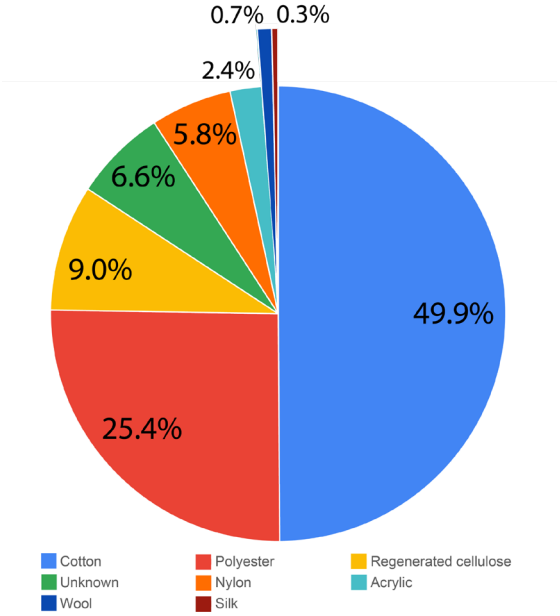


Figure 2. Major fibre components (accounted for ≥50% of the fibre content) of the inspected substandard items.

Table 3 shows the assignment of substandard but potentially reusable items categorised by the level of treatment they may require to become saleable. Those identified in the "wash/clean" category or only requiring "minor" treatment were easily treatable with a single process, such as soaking or spot cleaning, before laundering. Following this, these items would be returned in a good enough condition for sale on the retail floor. However, 29% of the items required "major" treatment. Those considered "major" had a lower repairability or required more steps in the treatment process than the "wash/clean" and "minor" categories. Rejected items constituted the largest group, and many included defects that could not be solved or had little value in resale. Table 4 describes the main reasons for rejection.

The type of textile item per treatment category is shown in Figure 3. The most common (N=379) were everyday tops, which included t-shirts, button-up shirts and women's tops. The next most common (N=218) were everyday bottoms, which included jeans, trousers, capris, shorts, etc. Activewear, socks, and underwear represented the next most common items, at N=53, N=50, and N=50, respectively. Among the everyday tops and bottoms, the proportion of items categorised as minor, major, or to be rejected were approximately the same. However, there were far higher rejection rates among underwear and socks, at 84% and 74%, respectively. The primary issues were damage, significant wear and a lack of value (i.e., used panties and single socks).

Category	Total count	% of total
Wash/Clean	49	5.1
Minor	276	28.5
Major	281	29.0
Innovative	11	1.1
Rejection	353	36.4
Total	970	100.0

Table 3. Frequency and categories of the substandard textile items sorted

Reasons for Rejection	Total count	% of total
Stain that will not come out	50	14.2
Severe pilling	120	34.0
Damaged/ Hole not repairable	137	38.8
No value	29	8.2
Moderate/ Severe Hair	17	4.8
Total	**353**	**100.0**

Table 4. Reasons for rejection of the substandard textile items sorted

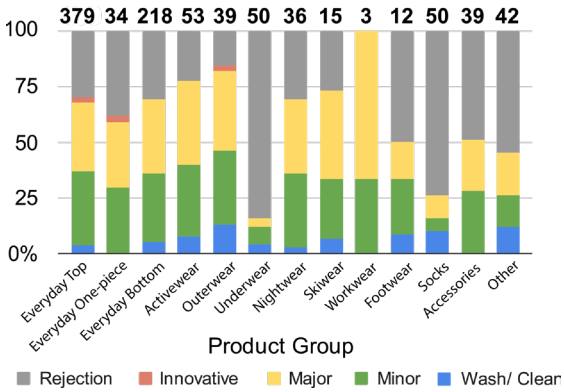


Figure 3. The count and ratio of each category of substandard textile items according to the product group

Holes, tears, and wear were the most common types of damage in substandard D items (Figure 4). Most holes could be mended, yet 42.4% of repaired holes would be noticeable or require advanced mending skills. About 52% of the "wear and tear" damage was categorised as rejection as the torn area could be time-consuming to mend, or the fabrics were more severely abraded and thinning through. Snagging, another type of repairable damage, was a complex issue requiring advanced mending skills and time. This led to 39.7% of snagged items being classified as major, and 46.6% were rejected due to long snags or numerous noticeable snags on a single item. Items with undone stitching and parts missing could be repaired in most cases. However, 26.1% of items with undone stitches and 16.7% with lost parts were rejected because the parts to replace them were unavailable, including lost buckles and buttons.

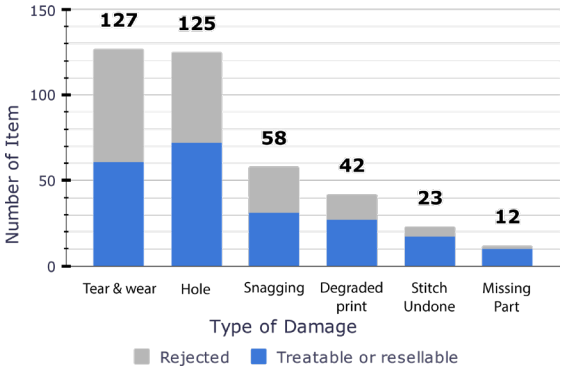


Figure 4. Overview of the repairable damage on inspected items, in which one item could contain multiple damages

Degraded prints could not be fixed, and this was another issue leading to a rejection (35.71%, N=15). Most of them were presented with cracks, peeling, or brittleness.

Figure 5 presents the types of stains found. It was not possible to identify the majority of stains through the purely sensory assessment undertaken in this project. However, some stains could be identified based on their colour, smell, texture and location on the garment. Approximately 71% (93/129) of the unidentified stains were considered treatable (i.e., wash/clean, minor, major). Perspiration and/or deodorant, as well as dirt, were the major types of identifiable stains. For these stains, about 75% of perspiration/deodorant stains and 61% of dirt stains were considered treatable. Unfortunately, the stains mentioned above were not the only reason for considering if the item was treatable. Multiple issues were found to occur on the same item, such as excessive hair and other damage. These other issues may have led to the rejection of the item despite the stain being removable.

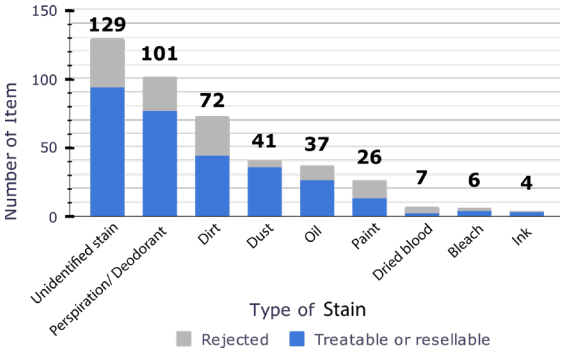


Figure 5. Overview of the potential stains on inspected items, which one item could contain multiple stains

The average processing time for the stain removal treatments was either relatively short or could be reduced by treating the garments in batches (i.e., 3-5 items soaked together). Table 5 illustrates the average treatment time for these common stains. Dirt stains could be easily removed by spot-cleaning with diluted dish soap, with a high success rate of 87.5% (Appendix Table A2). Unidentified stains, perspiration and deodorant stains were tested with multiple methods for stain removal, and soaking the stains with OxiClean™ Versatile Stain Remover was the safest and the most effective way to remove the stains. Dried blood stains accounted for only 1.5% of the total stains. Still, they could also be easily removed with hydrogen peroxide (Howard et al., 2019) with a 100% success rate (see Table A2).

Nevertheless, some stains could not be removed entirely during this study. For example, in Figure 6 a residual paint stain on a cotton dominant top is shown. While the paint on the top layer could be removed by scraping with tools after soaking them in an ammonia and vinegar mixture overnight (8 hours) (see Table 5), paint residue attached intimately to the fabric surface could not be removed, and marks remained (Figure 6). Ink was another stain that could not be removed during this project, as the ink had been absorbed within the fibres. Neither rubbing alcohol nor ammonia/detergent mixtures could eradicate

ink stains. Some ink stains faded yet were still noticeable. Since bleach removed the colour from the affected fabric/fibres, bleach marks were untreatable and not included in Table 5.

Stain	Avg. processing times (min)
Oil	53.6
Dust	5
Perspiration/ Deodorant	190
Paint	480
Dirt	10
Dried Blood	60
Ink	7.5
Unidentified stains	75

Table 5. Average treating time of each type of stain, excluding bleach stain.



Figure 6. Paint stain remaining after treatment

Treated items and samples of the treating process

As of 29 November 2024, 200 individual items had been treated for the *Treat & Clean* pilot study. Table 6 provides an overview of the success of treatments. There were 170 successful treatments, which meant that the stain(s) had been removed to the point they were no longer visible, or where repaired, the visibility of the repair was negligible. Thirty items resulted in unsuccessful outcomes, where the severity of the stain(s) may have been improved to some degree, they could not be removed completely and were still visible, or the repair was more obvious.

Total treated items	**200**
Success	170
Not Success	30

Table 6. Count of successful and unsuccessful treated items

Figure 7 illustrates the overall result by treatment category. Where treatments were successful 4.7% were wash/clean, 61.2% minor, and 34.1% major. In the instances where stains/damage were not found to have been successfully removed/repaired 40% were in the minor category and 60% major.

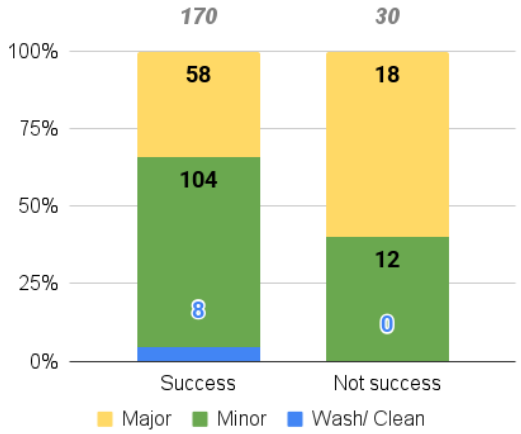


Figure 7. Count and ratio of the categories of successful and unsuccessful treatment

Examples of treated substandard items

Motor oil – One item considered to be major were a pair of shorts composed of 100% polyester. They had a dark stain that appeared to be some type of motor oil (see Figures 8a & b). Baking soda paste was applied to the stain directly and set on the stain for 30 minutes before washing. Through this treatment the motor oil stain was removed successfully (see Figure 8c).

a.


b.


c.


Figure 8. Cleaning process of item with motor oil stain

Perspiration and deodorant – Another item considered in the major category was a 100% cotton shirt (Figure 9a) that had yellowish perspiration and deodorant stains on both armpits (Figure 9b). The item was soaked with 2-3 other garments requiring similar treatment. They were soaked in 3.8 L of tap water with 113 g of OxiClean™ Versatile Stain Remover for 2 h, as per the product instructions. Following this treatment the stains disappeared (Figure 9c).

a.


b.


c.


Figure 9. Cleaning process of item with perspiration and deodorant stain.

Soaking for Textile Cleaning Before Donation

Items from the substandard D category were randomly selected for the *Treat & Clean* pilot. There were 8 items in the wash/clean category, 116 in the minor category and 76 as major. The results indicated that all three groups showed relatively high success rates for treatment: 100% for wash/clean, 89.7% for minor, and 76.3% for major, suggesting that even items

with moderate imperfections can be effectively restored with appropriate care.

OxiClean™ Versatile Stain Remover was the most commonly used tool in this study, which had a high success rate in removing oil (100%), perspiration and deodorant (100%), and unidentified stains (72.5%) (see Table A2 in the Appendix). The ingredients include sodium carbonate, which gives negative charges to the soil, especially oily ones containing fatty acid, and sodium percarbonate, which decolourises and breaks the soil, providing a high success rate in removing oil and perspiration stains (Bajpai, 2007; Nagarajan et al., 1984). With such compelling results, OxiClean™ Versatile Stain Remover and other products with similar active ingredients could assist in cleaning the majority of stains in donated clothing.

Soaking of garments can take an overall longer time, but as shown here, there is a good chance of success in removing the stains following soaking. Multiple garments with similar issues could be soaked together, allowing operators to leave the textiles to soak, followed by laundering. However, monitoring the items in the first thirty minutes is crucial to observing any colour bleeding, which could lead to pigment migration. During the study, a few items experienced pigment migration issues; some required more steps to remove pigment, and some were rejected because of these additional colourations. Given the high number of textiles with these types of stains that would be received in thrift stores than those included in the *Treat & Clean* pilot, then cleaning textiles before donation by the consumer would be optimal to avoid the extensive time and resources for cleaning in thrift stores.

Reselling Treated Textiles: Results from the Pilot Project

As of 5 March 2025, 139 items in the *Treat & Clean* project had been returned to the local thrift store. Of these, 81 items (58.3%) were confirmed as having sold (see Table 7).

	Total	**Wash/ Clean**	**Minor**	**Major**
Sent to MCC	**139**	5	87	46
Confirmed sold	**81**	3	47	31

Table 7. Count of *Treat & Clean* items sent and confirmed sold

It is possible that a few more items may have sold because some tags might not have been removed and collected by the cashier at the point of sale. If this happened, it would have occurred with the first batch of *Treat & Clean* items. In late 2024, a total of 44 items were sent back to the Edmonton store, and 17 items were confirmed to have sold. However, unsold items were not collected after the rotation period, which means it could not be confirmed what had not sold. In January 2025, 95 items were sent to the Saskatoon store, and unsold items were returned to the research team at the end of the store's five-week rotation period. From this second batch of *Treat & Clean* items, 64 items had sold, resulting in a success rate of 67.4%.

To date, the success of the *Treat & Clean* project's resale has room for growth. There is still evidence that substandard items can continue to have value after cleaning and mending, especially those requiring only a single and/or simple treatment, as 58% of sold items were soaked, sprayed, or simply mended, and 3.7% were only washed (Table 7).

In this project, 56% (N=95) of the restored textiles were cotton and cotton-dominant blends, while 22.4% (N=38) were polyester and polyester-dominant blends. Additionally, 58% (N=47) of the sold items were cotton dominant and 25.9% (N=21) were polyester dominant. With the high successful textile restoration rate in the treated items, especially in cotton and polyester dominate items, energy could be saved in their second life: only 2.6% and 1.8% the energy was consumed in the reused cotton and polyester during the process like sorting and selling, comparing to their initial status (Woolridge et al., 2006). Other research also indicates that reusing textiles could significantly extend the longevity of the textiles, and the active use length of second-hand tops could achieve 74.9% of that of the original (Laitala et al., 2024). With 51.9% of the sold items in this pilot project were tops, the result of extending the textile's longevity in this project could be promising.

Conclusions

This study highlights the potential for reusing substandard items in thrift stores. Substandard items in thrift stores still held substantial potential for reuse with appropriate treatment, even though there were shortcomings. Many items in the wash/clean and minor categories could be restored with simple processes like washing, soaking, or spot-cleaning. The result demonstrates that even lightly damaged or

soiled garments can have a second life, minimising waste and contributing to a circular economy. Furthermore, understanding common repairs and laundering issues can contribute to additional apparel design criteria considerations to address these common problems at the forefront. Attending to these problems at the design phase can enable design for easier repairs and/or associated laundering issues (e.g., design for modularity and design for disassembly).

Fibre analysis revealed that cotton and polyester were the most common materials in donated textiles, with alkaline cleaning solutions being the most effective treatment for these fibres. Although some items with severe damage, such as deep stains or irreparable fabric issues, were ultimately rejected, a considerable portion of the textiles could be successfully treated. Perspiration, oil, and dirt, were the most common stains found in this study, and many could be removed with targeted cleaning methods, yielding high success rates in the treatment process.

The results of this pilot project presented the significant potential for reusing and extending the lifespan of substandard textiles. Cleaned and treated items were shown to have the potential for resale in the market, even though they were initially considered damaged or stained. This study emphasises the impact of restoring substandard donated textiles, extending their lifespan, and reducing the environmental impact of textile disposal.

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References

Bajpai, D. (2007). Laundry detergents: An overview. *Journal of Oleo Science, 56*(7), 327-340. https://doi.org/10.5650/jos.56.327

Berry, B. (2022). Glut: Affective labor and the burden of abundance in secondhand economies. *Anthropology of Work Review*, *43*(1), 26–37. https://doi.org/10.1111/awr.12233

Brasch, J., & Ulasewicz, C. (2023). San Francisco textile repair pilot. California Product Stewardship Council.

Casey, B., & Johnston, B. (2021). Recommendations to the New Zealand Government from the Clothing & Textile Industry. Usedfully. https://www.textilereuse.com/wp-content/uploads/2021/05/Usedfully_Government-Recommendations-Report-Final-May2021.pdf

Cura, K., & Mäkelä, M. (2024). Sorting and Composition Analyses of Discarded Textiles. In K. Niinimäki (Ed) *Recycling and Lifetime Management in the Textile and Fashion Sector* (pp. 144-160). CRC Press.

Degenstein, L. M., McQueen, R. H., & Krogman, N. T. (2021). 'What goes where'? Characterizing Edmonton's municipal clothing waste stream and consumer clothing disposal. *Journal of Cleaner Production*, 296, 126516. https://doi.org/10.1016/j.jclepro.2021.126516

Genge, C., & Schouten, J. (2021). Assessment of the Economic, Environmental, and Social Impacts of the Clothing Reuse Industry in Atlantic Canada. https://nactr.ca/wp-content/uploads/2022/02/AFTeR-Impact-Report_2021.pdf

Goodwill Industries Alberta (n.d.). What to Donate: Goodwill's Donation Guide. Retrieved November 26, 2024 from https://www.goodwill.ab.ca/what-to-donate/

Government of Canada. (n.d.). Explore circular economy initiative. Service Canada. Retrieved December 4, 2024 from: https://www.canada.ca/en/services/environment/conservation/sustainability/circular-economy/circular-economy-initiatives.html

Han, S. L. C., Blanco-Velo, J., Boiten, V. J., & Tyler, D. (2024). European Circular Economy Perspectives on Fashion and Textile Consumer Behaviour. In K. Niinimäki (Ed) *Recycling and Lifetime Management in the Textile and Fashion Sector* (pp. 69-91). CRC Press.

Howard, D., Chaseling, J., & Wright, K. (2019). Detection of blood on clothing laundered with sodium percarbonate. *Forensic Science International,* 302, 109885. https://doi.org/10.1016/j.forsciint.2019.109885

Koronios, E. (2021). *Used Good Stores in Canada* (Report 45331 CA). Canada Industry (NAICS) Report. https://my.ibisworld.com/ca/en/industry/45331ca

Laitala, K., Klepp, I. G., & Berg, L. L. (2024). The impact of modes of acquisition on clothing lifetimes. In K. Niinimäki (Ed) *Recycling and Lifetime Management in the Textile and Fashion Sector* (pp. 92-112). CRC Press.

Larsen, F. (2023). Selling Thrift: Work Practices in an American Thrift Store. *Journal of Business Anthropology, 12*(1).

MCC Thrift. (n.d.). *Donate.* Retrieved November 26, 2024, from https://mccthrift.com/donate

McQueen, R.H., Kozlowski, A., McNeill, L.S., & Ehrenholz, J. (2023, July). *The recirculation of textiles: Why volunteers matter* [Paper presentation]. Joint sessions of the 5th SCORAI & 21st ERSCP Conference 2023, Wageningen, Netherlands.

Nagarajan, M. K., & Paine, H. L. (1984). Water hardness control by detergent builders. *Journal of the American Oil Chemists Society, 61*(9), 1475–1478. https://doi.org/10.1007/BF02663615

Oscario, A. (2023). The transformation of second-hand clothes shopping as a popular sustainable lifestyle in the social media era. E3S Web of Conferences, 388, 04020. https://doi.org/10.1051/e3sconf/202338804020

Roos, S., Sandin, G., Zamani, B., & Peters, G. (2015). Environmental assessment of Swedish fashion consumption: Five garments–sustainable futures. Mistra Future Fashion.

Weber, S., Lynes, J., & Young, S. B. (2017) Fashion interest as a driver for consumer textile waste management: Reuse, recycle or disposal. *International Journal of Consumer Studies, 41(2), 207-215.* https://doi.org/10.1111/ijcs.12328

Weber, S., Weber, O., Habib, K., & Dias, G. M. (2023). Textile waste in Ontario, Canada: Opportunities for reuse and recycling. *Resources, Conservation and Recycling*, 190, 106835. https://doi.org/10.1016/j.resconrec.2022.106835

Woolridge, A. C., Ward, G. D., Phillips, P. S., Collins, M., & Gandy, S. (2006). Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: An UK energy saving perspective. *Resources, Conservation and Recycling*, 46(1), 94-103. https://doi.org/10.1016/j.resconrec.2005.02.005

Appendix

	Cleaning tools and materials	**Applied on**
Alkaline	OxiClean™ Versatile Stain Remover	Oil stains, perspiration/ deodorant stains, pigment, and unidentified stains
	OxiClean™ Max Force™ Laundry Stain Remover Spray	Oil stains and unidentified stains
	Baking Soda Paste	Oil stains, perspiration/ deodorant stains, and unidentified stains
	Diluted dishwashing Detergent	Dirt, dust, and oil stains
	Diluted Bleach	Stains on white garments
pH Neutral	OdoBan® Pet Oxy Stain Remover	Dried blood stains
	White Vinegar mix Ammonia	Paint stains
	Rubbing alcohol	Ink stains
Acidic	Diluted White Vinegar	Stains on protein fibres

Table A1. Cleaning tools and materials that were required for certain applications

Stain	**Method**	**Cleaning tools/materials used**	**Success Rate (%)**
Oil	Spot Cleaning	OxiClean™ Max Force™ Laundry Stain Remover Spray	100.0
	Soaking	OxiClean™ Versatile Stain Remover (powder) 2-4 scoops	100.0
	Paste	Baking soda paste	54.6
Dust	Washing	Diluted dish soap	100.0
Perspiration/ Deodorant	Rubbing	Diluted ammonia	100.0
	Soaking	OxiClean™ Versatile Stain Remover (powder) 2-4 scoops	100.0
	Paste	Baking soda paste	66.7
Paint	Soaking	Ammonia, white vinegar, and table salt mix	0.0
Dirt	Washing	Diluted dish soap	87.5
Dried Blood	Spot Cleaning	OdoBan® Pet Oxy Stain Remover	100.0
Ink	Soaking	Diluted ammonia and detergent mix	0.0
	Rubbing	Rubbing alcohol	0.0
Unidentified stains	Paste	Baking soda paste	27.3
	Spot Cleaning	OxiClean™ Max Force™ Laundry Stain Remover Spray	58.8
	Soaking	OxiClean™ Versatile Stain Remover (powder) 2-4 scoops	72.5
	Soaking	Diluted Bleach (for white garments)	100.0

	Washing	Diluted dish soap/ diluted white vinegar for protein fibres	50.0

Table A2. The success rate of removing each type of stain with different methods and tools

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Repair Cafés as Circular Economy Enablers: Exploring Participants Practices through Social Practice Theory

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Keywords: Repair Cafés; Volunteering; Social Practice Theory; Community Repair; Sustainability, Circular economy.

Abstract: In this paper, we study the repair practices in Danish repair cafés, to understand how repair activities initiated by civil society are organized and sustained within broader social and material contexts. By applying Social Practice Theory, the analysis dissects the interconnected elements of materials, competencies, and meanings that constitute and shape the ongoing practice of repair in Danish Repair cafés. The repair practices form part of "bundles" of interconnected practices within the repair cafes. The study demonstrates that repair cafés are more than spaces for fixing broken items; they hold broader societal and cultural aspects. Through the interconnectedness of repair, learning, and community-building practices, these cafés challenge the "throwaway culture" and foster a collective commitment to sustainability that potentially could have implications far beyond their immediate settings.

Introduction

In recent years, repair cafés have become key components of the circular economy, addressing environmental sustainability and community cohesion (Moalem & Mosgaard, 2021; Madon, 2022). These community spaces, where volunteers help individuals repair various items, serve not only to reduce waste but also to foster connections and skills-sharing among participants. Originating in Amsterdam in 2009, they have rapidly expanded globally, countering the prevailing "throwaway culture" (Moalem & Mosgaard, 2021). Denmark alone has seen repair cafés grow from zero to 127 since 2013 (Repair Café Danmark, 2022, October 3).

Embedded in the circular economy, repair cafés counter high-income societies' "throwaway mindset," shaped by economic growth, planned obsolescence, and consumer convenience, leading to a preference for newness over durability (McCollough, 2020). This mindset discourages repair through high costs, time constraints, and limited access to repairable designs (Forti et al., 2020; Hennies & Stamminger, 2016).

By providing accessible repair services, repair cafés aim to overcome these barriers, offering community hubs where people from various backgrounds can develop skills, share knowledge, and access tools. By addressing common socioeconomic barriers these spaces aim to make repair a viable option for all consumers (Hennies & Stamminger, 2016; Meißner, 2021). This accessibility is vital for overcoming some of the entrenched socioeconomic challenges associated with repair (McQueen et al., 2022a).
Repair cafés also promote stronger attachment to personal belongings through hands-on involvement, challenging dominant consumer norms around disposability (Lee & Wakefield-Rann, 2021).

Despite the benefits, repair cafés face obstacles in countering design trends. Planned obsolescence, where products are manufactured with limited lifespans, remains a significant barrier to repairability and favors replacement over repair (Jaeger-Erben et al., 2021). Additionally, consumer preferences for low-cost replacements, coupled with time constraints, make repair seem impractical or inconvenient (McCollough, 2020; Forti et al.,

2020). Repair cafés address these barriers by providing resources, skills, and a supportive environment dedicated to sustaining consumer goods (McQueen et al., 2022b).

Participants' motivations in repair cafés are diverse, ranging from environmental concerns to the appeal of community and learning. Studies show that while a minority of individuals join to reduce waste, others find value in social interactions and the sense of achievement that comes from repairing items themselves or are motivated by cost savings (Madon, 2022; Jaeger-Erben et al., 2021).

As repair cafés continue to expand, their significance lies less in the volume of waste they prevent and more in their potential to reshape consumer practices. While their direct contribution to waste reduction is limited, they play a crucial role in fostering repair skills, increasing awareness of product longevity, and challenging throwaway habits. By examining the social practices and motivations of participants in Danish repair cafés, this study aims to deepen our understanding of the elements that sustain and drive these initiatives and how they contribute to a broader cultural shift toward repair-minded consumption within a circular economy in Denmark.

Theoretical Framework

Social Practice Theory (SPT) offers a framework for understanding how practices are shaped and sustained through the interactions between social norms, cultural meanings, and material infrastructures (Shove et al., 2012). Drawing on earlier philosophies, SPT shifts the focus of analysis from individual actions to collective practices, viewing them as dynamic constellations of organized activities embedded within broader social contexts.

Shove et al., (2012) breaks down practices into three key elements: **materials**, **competencies**, and **meanings** (figure 1). *Materials* include the physical objects, tools, and infrastructures required to perform a practice. *Competencies* refers to the knowledge, skills, and techniques that practitioners need, while *meanings* encompass the socially shared conventions, expectations, and values that give significance to the practice. These three elements interact continuously, shaping and breaking practices over time.

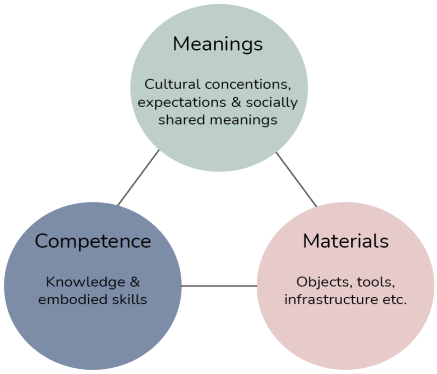


Figure 1: The three core elements of a practice (Markussen et al., 2021 based on Shove et al., 2012).

Within SPT, there is an analytical distinction between **practice-as-performance** and **practice-as-entity** (Shove et al., 2012). Practice-as-performance refers to the observable actions of individuals engaging in a practice while 'practice-as-entity' describes the norms and structures that sustain these actions. This distinction allows us to examine repair practices at two conceptual levels: as discrete, observable activities within the specific café (performance) and as enduring norms and structures that sustain the café's ecosystem (entity).

SPT also recognizes that practices are not isolated; they often interconnect and influence each other, forming what Shove et al. (2012) describe as “bundles” of practices. Shared elements across practices can bridge them, creating relationships that allow practices to evolve together or influence one another. This interconnectedness helps to explain how shifts in one practice can impact others, as shared elements like tools, skills, or cultural values circulate among practices.

SPT thus provides a structured framework to examine how practices emerge, persist, and evolve through the interplay of materials, competencies, and meanings (Shove et al., 2012). This study applies SPT to explore the interconnected practices within the ecosystem of Danish Repair Cafés. Specifically: What are the materials, competencies and meanings of participant practices at repair cafes and how are they interconnected? The aim is to

investigate how these practices and their elements collectively sustain the broader purpose of repair cafés in promoting a Danish circular economy.

Methodology

This study uses a qualitative approach to explore repair practices in Danish repair cafés, drawing on two datasets to uncover the social dynamics of these spaces.

A pilot study involved an ethnographic approach using participatory observations at six different repair cafés across Denmark, with 20 semi-structured interviews with volunteers. The data were transcribed and analyzed using a socio-material lens, focusing on emotional attachment in decision-making.

This study extends the focus to an examination of repair café practices in action, through a further analysis of four repair cafés in Copenhagen, Denmark. New data was collected through on-site participatory observation, focusing on real-time interactions between volunteers and visitors (bringers) to inform *competence* and *material* aspects. In addition, semi-structured interviews were conducted with 11 volunteers and 20 visitors. To ensure further participation, a small survey was distributed to all four cafés, enabling volunteers unable to engage during the field visits to provide further insights. The 10 survey responses complemented the interviews and expanded the dataset. These questions were concerned with understanding participants motivations for repair such as upbringings, political stance and/or economic situation informing the *meaning* and c*ompetence* aspect of their practice.

The data highlights the interactions between volunteers and visitors, the specific nuances of repair processes, and the broader practices within the café environment.

Findings: Repair Cafés as Ecosystems

Within the repair cafés the diversity of participants ensures that new connections are continuously made, with bringers contributing unique items and narratives about the product they bring, while volunteers bring diverse skills and expertise.

As these elements are linked, they coalesce into a **bundle of practices**, characterized by fluid interactions and mutual reinforcement. This bundle is not static; it evolves with every repair session, reflecting the dynamic nature of the café as a site of learning, innovation, and community building. Tools, tables, and items brought for repair create the material foundation of repair activities, while volunteers' skills in diagnostics, crafting, and assembling make repairs possible. It thus encompasses diverse repair elements (see table 1), that flourish within the café as practice-as-performance including:

- **Creative Repair**: Repurposing items using limited resources.
- **Diagnostic Repair**: Troubleshooting technical problems through systematic problem-solving.
- **Sentimental Repair**: Preserving emotional value by fixing cherished items.
- **Functional Repair**: Restoring everyday items to usability.
- **Social Repair**: Building relationships and community connections through shared repair experiences.
- **Educational Repair**: Empowering bringers by teaching them repair techniques and empowering volunteers by sharing experiences among them.
- **Aesthetic Repair**: Enhancing the visual appeal of repaired items.

Repair Type	Material	Competence	Meaning
Creative Repair	Unusual materials and spare parts such as; parts scavenged from old items, duct tape, wooden sticks, repurposed materials, sewing patches etc.	Improvisation, resourcefulness, "making do" with available resources.	Pride in ingenuity, resisting overconsumption, upcycling as creativity.
Diagnostic Repair	Diagnostic tools such as multimeter, torx screwdrivers, test lamps, small screwdrivers, etc. Complex products: often electronics.	Troubleshooting, circuit tracing, disas-sembly knowledge, system logic.	Intellectual satisfaction, solving a "puzzle", Technical mastery.
Sentimental Repair	Heirlooms and nostalgic items such as old sewing machines, childhood toys or items with family stories and delicate components.	Careful handling, empathy, restoration skills with emotional sensitivity.	Preserving memories, emotional attachment, honoring past gene-rations.
Functional Repair	Tools and spare parts such as power cords, glue guns, zippers, plugs, drewdrivers etc. Broken products.	Fixing mechanical/electrical failures, basic soldering, cable replacements.	Reducing waste, cost-saving, practicality, valuing durability.
Social Repair	Tables, shared food/tools and café setup such as chairs for waiting.	Welcoming, conversation, active liste-ning, cooperation, community hosting.	Belonging, shared identity, inter-generational exchange, enjoyment through helping.
Educational Repair	Shared work tables, labeled tools, tutorials on phones and YouTube, whiteboards, instructions.	Teaching others, breaking down tasks, inviting participation, simplifying steps.	Empowerment, democratizing repair, learning-by-doing, creating ripples.
Aesthetic Repair	Products and tools typically related to sewing tasks such as decorative fabrics, buttons, mending kits, thread, textile markers, scissors, clothing.	Craftsmanship, sewing, fitting, mending, color-matching, cosmetic enhancement.	Beauty, pride, self-expression, dignity of wear/use, visual taste.

Table 1: The elements of the 7 types of repairs.

These repair types are deeply interconnected and dynamic during the repair process. For instance, diagnostic repair may evolve into educational repair when volunteers teach bringers troubleshooting techniques, or creative repairs may incorporate aesthetic elements, transforming functional fixes into visually appealing outcomes. This interrelation between elements highlights how volunteer-driven, material-dominant practices often shift to value-oriented interactions, through the interplay between volunteers and bringers. For example, when a bringer describes their heirloom the meanings, such as emotional attachment or sustainability, get a more central role in the repair café practice.

Through the lens of SPT, this evolution reflects the interplay of elements. Materials and volunteers' competences initially drive the individual repairs, but the focus often shifts to the shared values sustaining the broader repair café entity. This dynamic interplay demonstrates how repair cafés not only restore objects but also foster cultural and social learning. Thus, the interconnected elements within the café constitute the practice-as-entity (figure 2).

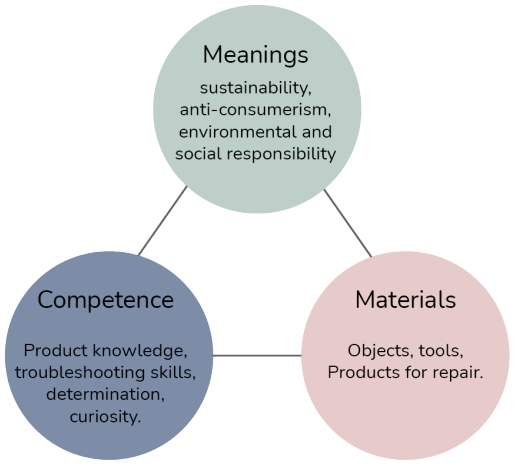


Figure 2: Practice-as-entity.

This entity represents the collective act of restoring broken items. It is shaped by the **materials** at hand, the **competencies** of volunteers, and the **meanings** associated with sustainability and resourcefulness.

Materials: The Backbone of Repair

At the conceptual level of *practice-as-performance*, materials in repair cafés, such as tools and the objects brought in for repair, play a crucial role in shaping repair practices. Volunteers interact directly with tools and items, often adapting them creatively to overcome specific challenges. One repairer noted, "I just cut a chord that I have at home; I could use the spare parts of it" demonstrating the improvisation and resourcefulness inherent in the act of repair.

Additionally, the items brought in for repair form a significant part of the material component, because the design, complexity, and condition of these objects influence the techniques required, prompting volunteers to adapt their skills to the specific challenges presented. For example, a complex electronic device might demand advanced troubleshooting, while a simpler item might prioritize precision and care. These interactions highlight how the characteristics of the products guide and shape the repair process in real time.

At the level of *practice-as-entity*, materials reflect the enduring norms and routines of the café. The shared use of tools, organized spaces, and communal resources demonstrates a structural commitment of resourcefulness and accessibility. These material arrangements stabilize repair practices over time, ensuring the availability for future sessions.

Materials thus act as both immediate enablers of repair and as structural components that reinforce the repair café's ongoing operation within a circular economy

Competencies: Skills and Learning in Action

Competencies within repair cafés span a wide and diverse spectrum; from formal technical expertise to informal, experience-based know-how. At the level of practice-as-performance, these skills become visible in the hands-on actions of volunteers. Competences include electrical engineering, such as diagnosing faults in power circuits or soldering broken connections; mechanical skills, like fixing mixers, drills, or vacuum cleaners; and textile and sewing skills, essential for mending clothing, replacing zippers, or altering fits. One volunteer shared, *"I'm trying to run power through several parts of the system to locate which part is not responding"* a typical example of real-time, diagnostic thinking in action. Volunteers also frequently demonstrate digital competencies, such as searching online for manuals, disassembly instructions, or spare parts.

Beyond the execution of repairs, many volunteers take on the role of instructors, teaching visitors how to assess damage, handle tools, or even make simple repairs themselves. This collaborative knowledge exchange is a defining feature of repair café culture and supports a broader goal of enabling repair literacy in the local community.

At the level of practice-as-entity, these competencies are not just individual assets, they are collectively maintained through routine interactions, mentorship, and peer-to-peer learning. Volunteers often rely on one another's expertise to complete complex repairs, drawing on shared diagnostic logic, cross-disciplinary techniques, and accumulated local knowledge. For example, someone with sewing skills may consult a colleague with electrical experience to resolve a hybrid repair (e.g., a heated blanket or a battery-powered toy). In this way, individual competencies are interdependent and reinforced through the group dynamic, creating a shared reservoir of capabilities that transcends any single session or fixer.

This dynamic interplay between personal expertise and collective collaboration ensures that repair cafés remain adaptive learning environments, where technical proficiency, creative problem-solving, and mutual support evolve together to sustain the repair practice.

Meanings: Repair as a Symbolic Act

The meanings associated with repair practices also operate at both immediate and structural levels. At the level of *practice-as-performance*, meanings are expressed through the cultural and emotional value of individual repairs. For

example, one volunteer shared, "I like fixing trinkets; they remind me of my wife - she has a million small quirky things that sometimes need fixing" and another one said “I take pride in making things work" demonstrating how repair can embody personal significance by giving value to objects, revealing how meanings are enacted during repair sessions.

At the level of *practice-as-entity*, meanings are embedded in the collective purpose and values within the café. For instance, a shared commitment to sustainability is reflected in comments like, "We want to create ripples that inspire people to take better care of their things" and “Throwing away my 15-year-old drill felt like such a waste. The [repair] café offers a chance to preserve resources and learn new skills”. These meanings are not confined to individual actions but are institutionalized within the café’s ecosystem, shaping its role as a space that promotes care and reuse. The interplay between performance and entity highlights how meanings are both lived in specific moments of repair and stabilized as part of the café’s identity.

Linking Elements Through Social Interactions

Each repair café thus represents a dynamic ecosystem where diverse elements interact to create a cohesive and functional environment. These spaces transcend the act of repairing objects, making them able to foster a broader network of sustainable consumption, skill-sharing, and community. Through the lens of SPT, the repair cafés emerge as sites where various elements are linked together through the interactions of volunteers and bringers, forming a bundle of interconnected practices that sustain the overarching practice-as-entity.

Repair café practices emerged from a rich historical tradition of mending and maintaining belongings, often driven by practical necessity. Many volunteers bring personal histories of repair that reflect earlier societal norms of resource conservation. One volunteer recalled fixing a sewing machine as a child because their family couldn’t afford a replacement. Another shared memories of growing up in a household where repair was a regular activity, ingraining a lifelong commitment to fixing over discarding and a third mentioned his grandfather as an “inventor type” inspiring him to acquire troubleshooting and functional repair skills.

Over time, these individual practices contributed to what we see as the ecosystem of repair cafés, taking on broader meanings tied to sustainability and resistance to consumerism. As one volunteer mentioned “I’ve always been passionate about sustainability. [Repair Café Denmark] has shifted the focus to something more positive where I can actively make a difference instead of just debating endlessly” showing how the repair cafés have institutionalized these habits, providing tools, spaces, and social support to sustain and expand the entity of the repair café practice.

The repair café ecosystem thus operates as a complex bundle of interconnected practices, sustained by the links between materials, competencies, and meanings. These practices do not exist in isolation but are embedded within broader social contexts. Stemming from practice elements formed before entering the ecosystem, but also from the dynamic development between elements within this space. For example, shared meals and informal gatherings within cafés create a supportive community that sustains repair practices over time. Highlighting how repair practices are strengthened through social bonds, a volunteer said “they bring us all together [around shared goals]”. Another mentioned “I love the ‘ping pong’ of ideas between us volunteers. It’s not just about fixing things. It’s about working together to solve problems”. The repair café thus transcends its immediate function as a space for fixing items. It emerges as a site where environmental stewardship, community building, and sustainable consumption converge, potentially influencing participants' behaviors and values beyond the café itself.

Conclusion

This study explores how cultural and social patterns constitutes practices within the ecosystem of Danish repair cafés. By analyzing their activities through SPT, repair cafés are seen as spaces where materials, competencies, and meanings come together into dynamic, interconnected practices.

The materials central to repair practices actively shape the strategies employed by volunteers, for example how complex items prompt diagnostic and creative problem-solving and simpler objects may lead to functional or aesthetic repairs. The interconnected nature of practices within repair cafés facilitates the circulation of skills and values within and among the cafés. Volunteers emphasize the importance of collaborative problem-solving and mutual learning, which is also where competencies evolve. Meanings associated with repair practices, such as resistance to the throwaway culture and sustainability, are reinforced through the interactions of various participants. One volunteer said: “Repair cafés function as a meeting point across age groups. It’s a place for knowledge-sharing and to help the environment”. Repair practices thus form a "bundle of practices" where elements work together to develop and sustain the repair café ecosystem, meanwhile the interactions between participants help scale repair culture into broader Danish societal contexts.

In this sense, scaling Danish repair cafés is less about increasing the volume of repaired items and more about embedding repair into cultural habits, making these spaces more accessible and thereby contribute to the national discourse about repairable and non-repairable products. Adjustments, such as extended opening hours, could encourage broader participation and support the integration of repair practices into more daily routines. By linking elements across immediate actions and enduring structures, repair cafés promote resource conservation and inspire a shift toward sustainable consumption.

Through the dual lens of practice-as-performance and practice-as-entity, this study reveals how repair cafés operate on multiple levels. Practice-as-performance captures the immediate, tangible acts of repair. Meanwhile, practice-as-entity encompasses the enduring norms, routines, and shared values that stabilize the café's ecosystem over time.

At the level of practice-as-entity, Danish repair cafés embed circular economy principles by institutionalizing norms and routines that prioritize repair over replacement. These practices cultivate a shared commitment to the reduction of waste by creating a space where the value of repair is both celebrated and normalized. This makes Danish repair cafés challenge the prevailing throwaway culture and promote circular economy.

In conclusion, the SPT analysis of repair cafés reveals their significance as cultural hubs. The studied repair cafés enable participants to internalize sustainable values, which they then can carry into their personal and social networks, further enforcing the principles of circular economy and potentially ensuring that these practices persist and spread beyond the café itself. In this way, repair cafés can act as enablers of a circular economy in Denmark by creating the space for the repair elements to link and evolve.

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References

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). *The Global E-waste Monitor 2020: Quantities, flows, and the circular economy potential*. United Nations University (UNU), United Nations Institute for Training and Research (UNITAR) & International Telecommunication Union (ITU), and International Solid Waste Association (ISWA). https://www.itu.int/en/ITU-D/Climate-Change/Documents/GEM_2020_def.pdf

Hennies, L., & Stamminger, R. (2016). An empirical survey on the obsolescence of appliances in German households. *Resources, Conservation and Recycling, 112*, 73–82. https://doi.org/10.1016/j.resconrec.2016.04.013

Hjorth Nielsen, A. S. A., & Laursen, L. N. (2023). *Love at first sight: Immediate emotional attachment of volunteers in repair cafés.* Paper presented at the 5th PLATE Conference, Espoo, Finland, 31 May–2

June 2023. Retrieved from https://www.researchgate.net/publication/371327675

Jaeger-Erben, M., Rückert-John, J., & Schäfer, M. (2021). Why do users (not) repair their devices? A study of the predictors of repair practices in Germany. *Journal of Cleaner Production, 286*, 125468. https://doi.org/10.1016/j.jclepro.2020.125468

Lee, J., & Wakefield-Rann, R. (2021). Conspicuous and inconspicuous repair: Reconceptualising repair practices in a sustainability context. *Journal of Cleaner Production, 280*, 124291. https://doi.org/10.1016/j.jclepro.2020.124291

Madon, J. (2022). Free repair against the consumer society: How repair cafés socialize people to a new relationship to objects. *Journal of Consumer Culture, 22*(2), 534–550. https://doi.org/10.1177/14695405219908 71

Markussen, T., Petersen, S. B., & Kronby, H. society: (2021). Moving Towards Individualized Work Models. Aalborg Universitet.

McCollough, J. (2020). The impact of consumers' time constraint and conspicuous consumption behaviour on the throwaway society. *International Journal of Consumer Studies, 44*, 33–43. https://doi.org/10.1111/ijcs.12545

McQueen, R. H., Jain, A., McNeill, L. S., & Kozlowski, A. (2022a). The role of resources in repair practice: Engagement with self, paid, and unpaid clothing repair by young consumers. *Textile Research Journal*. https://doi.org/10.1177/00405175221123067

McQueen, R. H., McNeill, L. S., Huang, Q., & Potdar, B. (2022b). Unpicking the gender gap: Examining socio-demographic factors and repair resources in clothing repair practice. *Recycling, 7*(4), 53. https://doi.org/10.3390/recycling7040053

Meißner, M. (2021). Repair is care? Dimensions of care within collaborative practices in repair cafés. *Journal of Cleaner Production, 299*, 126913. https://doi.org/10.1016/j.jclepro.2021.126913

Moalem, R. M., & Mosgaard, M. A. (2021). A critical review of the role of repair cafés in a sustainable circular transition. *Sustainability, 13*(22), 12351. https://doi.org/10.3390/su132212351

Repair Cafe Danmark. (2022, October 3). *Historie – Repair Cafe Danmark*. https://repaircafedanmark.dk/om/historie/

Shove, E., Pantzar, M., & Watson, M. (2012). *The dynamics of social practice: Everyday life and how it changes*. SAGE Publications. https://doi.org/10.4135/9781446250655

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Repairing the upbringing: Socialization and product repair behavior

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Keywords: Repairability; barriers; motivations; behavior; socialization.

Abstract: With growing concerns over sustainability and waste generation both globally and in Denmark, understanding consumer behavior in product repair is crucial. This study investigates in-house product repair behavior in Danish households, focusing on the motivations, and barriers of repairs related to social upbringing. Data was collected as a mixed-methods approach, using 9 qualitative semi-structured interviews as primary data based on secondary picture data collection of self-repaired products from 30 Danes. The study confirms prior studies that show: lack of emotional value, economic feasibility, tools and knowledge as barriers for consumer repairs. Moreover, it contributes by adding multi-socialization during upbringing and types of knowledge, particularly informal repair knowledge from family members, as a crucial determinant in shaping repair behavior specifically related to the knowledge barrier and motivation. This research sheds light on the nuances of Danish household repair behavior, suggesting the integration of repair education in schools and the utilization of repair cafés to foster a sustainable repair culture.

Introduction

Every year the world throws out over two billion tons of household waste globally (The World Counts, 2023). Denmark is one of the countries, that consumes the most per capita, and if every country in the world consumed the same, it would require four times as many resources as the Earth currently provides (Faartoft, 2023). To ensure more sustainable consumption and production patterns, one of the goals of the 12th Sustainable Development Goals (SDG) is to substantially reduce waste generation through prevention, reduction, recycling, and reuse (The Global Goals, n.d.). Prevention, such as repairing, is one of the key strategies to prolong the lifespan of products by reducing the environmental impact of consumer goods thus counteracting the use-and-throw-away culture (Hernandez, 2020; Laitala, 2020).

Most Danes associate repairs with sustainability. Nevertheless, every second Dane has chosen not to repair something they considered, where 60% of the respondents would like to repair more if it was cheaper, and 49.5% would choose to repair more if they could do it themselves (Make It Good Again, 2020). Scholars find, the most significant repair barriers are lack of economic incentives, knowledge, missing spare parts, emotional and economic attachment or no need for the specific product etc. (Hernandez, 2020; Make It Good Again, 2020). A recurring repair barrier or motivation in most of the current studies is the lack or presence of knowledge (Hernandez, 2020; Laitala, 2020; Nielsen, 2023; Make It Good Again, 2020; Ackermann, 2018a). This repair knowledge is crucial in determining whether consumers even attempt to repair or not. However, there are very limited research on where consumers' repair knowledge stems from and how it can be positively influenced. An area in which knowledge is affected is through socialization which is closely related to one's upbringing (Dencik, 1995; Pérez, 2008; Brøndum, 2020). Therefore, the paper investigates this gap with the following question: How do knowledge barriers and motivations, related to social upbringing, influence repairs at home?

Literature review and theory

Product repair has various definitions, with Ackermann combining maintenance and repair, under the umbrella term "product care" (Ackermann, 2018b). Denis and Pontille argues for understanding repair as a part of an ongoing maintenance process, not just as a reaction to breakdowns (Denis, 2023). In this paper, the overall definition of product repair is; Product functionality is restored to working condition or

partially working condition, product refurbishment, and maintenance of products. In relation to repair behavior, various motivational factors and barriers influence people's repair behavior, impacting the success of home repairs. A study from the Netherlands explores consumers' motivation, ability, and triggers related to product care. They found that the consumers are generally motivated to do product care due to the importance of the product's functionality or it being more sustainable consumption-wise. While they often possess the necessary knowledge and tools, they often lack the triggers to prompt action. Triggers such as giving necessary tools or offering a helpful service can increase consumers' motivation or ability. (Ackermann, 2018a)

Another paper categorizes barriers discouraging consumers from repairing products by reviewing academic articles across various fields, including perspectives from consumer, design, production, and sustainability studies (Hernandez, 2020). The five identified barriers are: 1) Lack of knowledge, 2) Lack of spare parts, information, and open contracts, 3) Lack of economic incentives, 4) Lack of emotional and economic attachment, 5) Lack of design for repair. These barriers are substantiated by a Norwegian study. It found that better product quality is the primary incentive for repairs, alongside improved consumer rights, access to spare parts, tools, manuals, and greater knowledge of repair processes (Laitala, 2020). A survey of 2000 Danish respondents, revealed that price is the main reason for not repairing, followed by a lack of knowledge about repair services (Make It Good Again, 2020). This supports the barrier: 'Lack of economic incentives', and 'Lack of knowledge'. Thus, the barrier 'lack of knowledge' recurs in most studies, emphasizing that knowledge is crucial for whether consumers even attempt to repair or not.

Knowledge can be divided into three types: **1) Formal learning** situations, where knowledge is the goal, it is organized and has formal credits e.g. when learning professional skills in educational programs. **2) Informal learning** situations, where knowledge is not the direct purpose but a byproduct of activities with another goal e.g. participating in everyday life with the family. **3) Non-formal learning** situations, where knowledge is the goal, it is organized but without formal credits e.g. actively searching for information through the internet. (Ainsworth, 2010). However, there are very limited research on where consumers' repair knowledge stems from and how it can be positively influenced. An area in which knowledge is affected is through socialization which is closely related to one's upbringing. Specifically informal learning takes place all the time spontaneously throughout life guided by family and other caregivers (Ainsworth, 2010).

This gap can be analyzed using Lars Dencik's 'dual socialization' theory and Pierre Bourdieu's 'theory of practice' to understand how upbringing can influence repair behavior. The Swedish social psychologist Lars Dencik developed the butterfly model of dual socialization to describe how a child's behavior is shaped in post-modern society through primary and secondary socialization (Dencik, 1995). Brøndum later expanded this model to the multi-socialization model (Figure 1), adding a third arena called tertiary socialization (Brøndum, 2020).

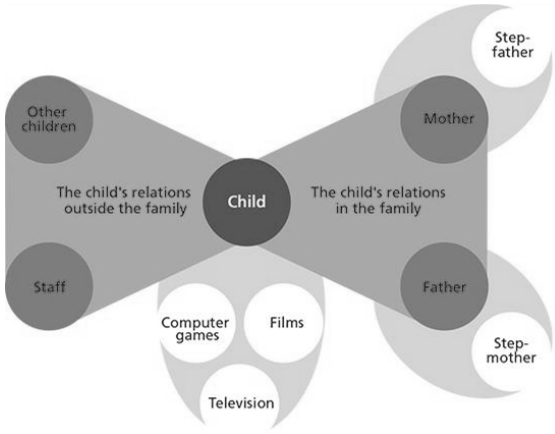


Figure 1. Multi-socialization model. (Brøndum, 2020, building on Dencik, 1995).

Brøndum defined: **1) Primary socialization** as the socialization that takes place at home with the family, e.g. through the upbringing of one's parents and grandparents**. 2) Secondary socialization** as the socialization that takes place in institutions, e.g. through school and one's friends. **3) Tertiary socialization** as the socialization that takes place over medias, e.g. through YouTube, Television and Instagram. Similarly French sociologist Pierre Bourdieu argues that identity is shaped by relationships, particularly in early life. He introduces the concept of habitus, which is the values, norms, and cultural habits that guide individuals. These 'learned codes' form identity and behavior,

leading individuals to maintain consistent patterns of action and perceptions of why they should or should not act in certain situations (Pérez, 2008). These socialization theories and types of knowledge will be applied to analyze and better understand Danish repair behavior related to knowledge.

Methodology

A mixed-methods study was conducted, with the goal of gaining insights into the product repair behavior in Danish households to understand why Dane's repair or do not repair products at home. This includes quantitative and qualitative data collection.

Firstly, an explorative approach was used to narrow down the scope of the paper by gathering pictures and small descriptions of home-repaired products from 30 Danes in ages between 24 and 85 both men and women. Three descriptions of home-repaired products were formulated and sent in the native language: 1) Picture(s) of a product, you have repaired yourself at home, 2) Picture(s) of a product, you have considered to repair yourself, but for some reason did not, 3) Picture(s) of a product, you have tried to repair yourself but failed to.

The pictures were then categorized using the method clustering to find patterns, which the following interviews were based on. The clustering gave insights into: 1) Which products, Danish households repair and do not repair, 2) Which products the different genders repair, 3) Which products Danes repair and do not repair in relation to how established the participants are.

To gain further insights into why the repairs failed or succeeded related to barriers and motivations, 9 qualitative semi-structured interviews were conducted with a total of 11 interviewees. The interviews were based on Danes with an equal distribution of different ages, genders, jobs, occupations, and housing conditions to get the most nuanced outcomes. They were selected based on having sent pictures from all three picture descriptions. The qualitative data focus on Danes between the age of 24 to 65, that where either living in apartments or being homeowners. The insights and quotes from the semi-structured interviews were clustered to find behavior and decision-making patterns. Surprisingly it revealed that upbringing, particularly parental influence, emerges as a crucial determinant in shaping repair behaviors specifically related to the knowledge barrier and motivation. This gap became the scope of the paper and was then analyzed using the multi-socialization model and the three types of knowledge. Quotes regarding knowledge barriers and motivations were divided into, which of the three social arenas, they stem from, and what type of knowledge it is, resulting in three themes.

Lastly, the repair knowledge barrier and motivation regarding upbringing was discussed, and suggestions were made on how to increase repairs performed in Danish homes followed by a conclusion with future research propositions.

Analysis

This study investigates how socialization during upbringing affects the repair behavior related to the knowledge barrier and motivation. The analysis shows that the consumers are exposed to informal, formal and non-formal repair knowledge (Ainsworth, 2010) depending on the social arena (Brøndum, 2020, building on Dencik, 1995), which constitutes the following three themes. The data suggest a connection between the repair success or failure and social upbringing, which shapes the individuals repair behavior throughout life. It highlights a hierarchical division, where informal repair knowledge is the foundation for acquiring both formal and non-formal repair knowledge in the secondary and tertiary arena respectively (Figure 2).

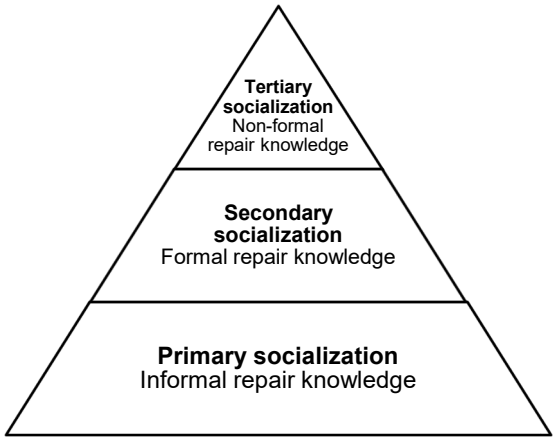


Figure 2. Hierarchy of types of repair knowledge

Informal repair knowledge from primary socialization

In the primary socialization (Dencik, 1995) the consumer is introduced to informal repair knowledge (Ainsworth, 2010), where norms and values from the family (Pérez, 2008) becomes the foundation for whether consumers choose to repair or not. This is substantiated by 11 out of 11 interviewees mentioning that their repair knowledge stems from their upbringing either from a parent or relative. The data further suggests that consumers primarily learn that repair is acceptable rather than embarrassing, when seeing or taking part in repairing products with members of the family. Here the goal is not to learn repair, but a byproduct of doing something together, thus obtaining informal repair knowledge (Ainsworth, 2010): "*It is fun! […] I learned how to repair from my dad […] I helped him […] I watched my father-in-law (repair products) […]* (Interview 3, 10:46). Thus, the informal repair knowledge plays a crucial role in creating a positive repair culture, which is essential for the desire to repair products throughout life.

Additionally, the consumers' fondness for specific product categories, thus interest in repairing these, stems from the primary socialization: *"I learned some basic stuff about sewing from my parents, which sparked my interest (in clothes)"* (Interview 5, 10:4-14:49). The data suggest that the consumers primarily learn very specific and simple repairs as a byproduct of the informal repair knowledge, such as changing a tire on a bike or patch holes in a sweater, and basic tools, such as using a screwdriver or a needle, from their parents or grandparents.

However, the parents or grandparents need to know how to repair, before they can teach their kids this informal repair knowledge at home, which is a barrier: *"[…] (repair knowledge originated from) my education as a carpenter […] my parents did not teach me anything about tools or how to repair"* (Interview 2, 19:24).

Formal repair knowledge from secondary socialization

Repair behavior can also be significantly influenced by secondary socialization (Dencik, 1995) e.g. through educational institutions or related to a job, as noted by 2 out of 11 interviewees. It differs from the learning situation in the primary socialization, by adding formal repair knowledge, thus extending one's basic repair knowledge with more expertise within a professional field. Consumers improve their skills by learning which special tools to use, the correct terms, how to use them correctly, different repair methods etc.: *"[…] I have improved my (sewing) skills most through my education (Fashion Design)"* (Interview 5, 10:4-14:49).

Surprisingly, no interviewees mentioned learning about repair during their earlier education, such as primary and secondary school. Here norms and values can be shaped just as much as in the primary socialization at home, especially in early childhood (Dencik, 1995; Pérez, 2008). Thus, introducing formal repair knowledge in the early education could minimize the knowledge barrier, that some consumers face in the primary socialization, due to the parents' lack of repair knowledge.

This formal repair knowledge from secondary socialization adds a level of expertise to the informal repair knowledge, which can be translated directly into a higher level of repair skills, thus decreasing barriers and increasing chances of successful repairs.

Non-formal repair knowledge from tertiary socialization

In the tertiary socialization (Brøndum, 2020) medias, such as YouTube, act as a tool in the repair moment to expand the consumers existing repair knowledge from the primary and secondary socialization. The learning situation is characterized by the consumer having an on demand need to fix a broken product, thus gain a very specific non-formal repair knowledge (Ainsworth, 2010). This is substantiated by 8 out of 11 interviewees stating that: *"If I can't figure it out myself […] I will find it via the internet or YouTube."* (Interview 8, 09:04).

YouTube videos provide guidance on the repair process, thus are great at communicating how to e.g. locate the problem regarding broken product, how to fix the product, which tools to use etc.

This non-formal repair knowledge is easily accessible only if the consumer has a desire to fix the product and some basic knowledge to search for the right terms, which is a barrier.

Discussion and implications

Based on the results of the interview analysis a few interesting topics can be discussed further. Interestingly all interviewees mentioned that the repair interest and the foundation of the repair knowledge were established by either parents, grandparents, friends, or educational influences during their upbringing. While it seems obvious that social upbringing impacts consumer product repairs, research in this area is very limited. The analysis suggests that especially dual-socialization (Dencik, 1995) and habitus (Pérez, 2008) influence repair behavior.

The concept of habitus suggests that the norms and values learned early in life are challenging to change later, emphasizing the need for early integration of repair education (Pérez, 2008).

Primary socialization has the most significant impact, beginning in childhood when bonds with family form (Dencik, 1995). This is where the results show that informal repair knowledge (Ainsworth, 2010) is passed down, highlighting the importance of parental influence. While primary socialization is beneficial, secondary socialization also plays a vital role, especially in modern society where children spend more time in schools and institutions. This double socialization by teachers, pedagogues, and mentors significantly shapes children's behavior (Dencik, 1995), both socially and repair wise.

Although product repair is essential for sustainability, not all parents have the time, knowledge or resources to teach their children these skills. This is where an educational program of product repair in primary and secondary school could be a solution to this problem by introducing formal repair knowledge (Ainsworth, 2010). Especially since very few interviewees obtained or extended their repair knowledge during their education. Thus, there is room for improvement here and a potential for increasing children's repair knowledge. Incorporating repair education into either the subject Technology Understanding or creative courses like Craftsmanship and Design could empower students with the knowledge and confidence to undertake repairs later in life. In addition, excursions to repair cafés could help students learn practical skills and become comfortable with tools and the repair process, potentially reducing repair barriers in the future.

Lastly, home repair habits can also be influenced by the medias, which is the tertiary socialization (Brøndum, 2020). However, this form of influence often requires individuals to seek out content themselves, which can be a barrier. Additionally, this socialization might come too late into people's lives to have a substantial impact. Instead, it could, as data shows, serve as an additional tool, where consumers gain non-formal repair knowledge (Ainsworth, 2010), to build on one's knowledge from the primary and secondary socialization.

In conclusion, while primary socialization and informal repair knowledge might have the biggest impact on repair behavior, it might be unrealistic to expect all parents in Denmark to educate their children, due to their own limited repair knowledge. Therefore, secondary socialization through institutions could be a viable way to educate future consumers with both informal and formal repair knowledge, thus a higher level of repair skills. Future research could explore the influence of primary, secondary, and tertiary socialization in further detail by incorporating larger in-depth quantitative and qualitative studies to gain a better understanding of the socialization aspect of the topic. This could be a foundation for future implementations of educational programs on repairability and the potential of repair cafés as community resources to enhance repair skills and reduce barriers to product repair thereby making Denmark more sustainable.

References

Ackermann, L., Mugge R., & Schoormans J. (2018a). Consumers' perspective on product care: An exploratory study of motivators, ability factors, and triggers. *Journal of Cleaner Production, Vol. 183*, pp. 380-391. https://doi.org/10.1016/j.jclepro.2018.02.099

Ackermann, L., (2018b). Design for Product Care: Enhancing Consumers' Repair and Maintenance Activities. *The Design Journal, Vol. 21*(4), pp. 543-551. https://doi.org/10.1080/14606925.2018.1469331

Ainsworth, H.L & Eaton, S.E. (2010). *Formal, Non-Formal and Informal Learning in the Sciences*, Onate Press, Canada.

Brøndum, P., & Hansen, T.B. (2020). Changing identity, In: Henriksen, P. (Ed.), *Open up Society: social studies in Denmark,* Forlaget Columbus, Denmark. https://openupsociety.ibog.forlagetcolumbus.dk/?id=130

Dencik, L. (1995). Modern Childhood in the Nordic Countries: 'Dual Socialisation' and its Implications, In: Chisholm, L., Büchner. P., Krüger. H. & Bois-Reymond, M. (Eds.), *Growing Up in Europe* (pp. 105-120), Walter de Gruyter, Berlin, https://doi.org/10.1515/9783110879094-010

Denis, J., & Pontille, D. (2023). Before Breakdown, After Repair: The Art of Maintenance, In A. Mica, M. Pawlak, A. Horolets, & P. Kubicki (eds.), *Routledge International Handbook of Failure* (p. 209-222), New York, Routledge. 10.4324/9780429355950-19

Faartoft, M. (2023). Går i overtræk: Danmark har nu opbrugt sin del af verdens naturressourcer for i år. *Via Ritzau* [online]. Available at: Går i overtræk: Danmark har nu opbrugt sin del af verdens naturressourcer for i år | Danmarks Naturfredningsforening (ritzau.dk)

Hernandez, R.J., Miranda, C., & Goñi, J. (2020). Empowering sustainable consumption by giving back to consumers the “right to repair.”, Sustainability, Vol. 12(3), https://doi.org/10.3390/su12030850

Laitala, K., Klepp, I.G., Haugrønning & Throne-Holst, H. (2020). Increasing repair of household appliances, mobile phones and clothing: Experiences from consumers and the repair industry, *Journal of Cleaner Production*, Vol. 282, https://doi.org/10.1016/j.jclepro.2020.125349

Make It Good Again. (2020). Danskernes reparationsvaner 2020. *Make It Good Again IVS*, Denmark.

Nielsen, A.S.A.H., Laursen, L.N. & Tollestrup, C. (2023). Can you fit it? An investigation of critical repair steps and barriers across product types., *Proceedings of the 5th PLATE 2023 Conference, Espoo, Finland*, Aalto University, Aalto University publication series, pp. 409-417.

Pérez, F.P. (2008). Voluntarism and Determinism in Giddens's and Bourdieu's Theories of Human Agency, Voluntarism and determinism human. https://social-science.uq.edu.au/files/11139/Voluntarism%20and%20determinism_human%20agency_Essex%20Graduate%20Journal%20of%20Sociology%202008.pdfv

The Global Goals. (n.d.). 12 - Responsible consumption and production. *The Global Goals* [online]. Available at: https://www.globalgoals.org/goals/12-responsible-consumption-and-production/

The World Counts. (2023). A world of waste. *The World Counts* [online]. Available at: https://www.theworldcounts.com/challenges/planet-earth/state-of-the-planet/world-waste-facts

Verdensmål, Danmarks officielle side. (n.d.). 12 - Ansvarligt forbrug og produktion. *Verdensmål* [online]. Available at: https://www.verdensmaal.org/12-ansvarligt-forbrug-og-produktion

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Designing products that facilitate easy and intuitive repair, an implementation in product design education

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Keywords: repair; product design; design education; industry 5.0

Abstract: When considering circular economy, reuse, refurbish and repair of products is key in many circular business models. Both efficient and intuitive disassembly and assembly are crucial facilitators for these strategies, impacting feasibility, cost and economic viability. Thus, product designers and product design educations should focus on how to design products for easy and intuitive disassembly and reassembly to facilitate repairability. The focus from design educations on these specific processes is however very limited. This paper elaborates on the outcomes of a project-based learning course for design engineering students. The students redesigned an electric device (power tool or household appliance) with special attention to design for repairability strategies. Necessary frameworks and tools were offered to first analyze the disassembly and assembly process of the product and secondly redesign for repair. Unlike many other methods that are about assessing assembly and disassembly processes in terms of the time needed to perform them, here special attention was paid to the interactions, both cognitive and physical, during repair. This premise aligns better with the context of end-user repair where time is less relevant but where interactions need to be easier and more intuitive. Through case studies, it was investigated whether this focus generated valuable results and was feasible to implement. The paper is especially relevant for those concerned with circular product design, the assembly and disassembly of products linked to circular strategies such as repair and the integration within design engineering curricula.

Introduction

Product design plays a crucial role in facilitating circular economy and reducing environmental impact. Designing products for a circular economy is about maintaining product integrity over multiple use cycles (e.g. by facilitating repair), and closing the loop (e.g., through recycling) in combination with economically viable product–service systems (Bocken et al., 2016). This circular approach contrasts with traditional linear models of take-make-use-dispose and selling artifacts to generate profit.

Many design educations consider it fundamental to prepare future designers for a circular economy, resulting in many educational courses and projects aiming to integrate circular economy in product design education (Ramirez, 2006; Lilley & Lofthouse, 2009). However, as highlighted by Terzioğlu & Wever (2021), few courses and projects focus on design for repair or even more specifically on competencies or skills linked to design for disassembly and reassembly. These processes are however crucial facilitators for many R-strategies such as repair. Moreover, when considering research into these processes, researchers focus mostly on time measurements (i.e., from existing products) or on anticipations of time (e.g., calculations based on product features).

Important efforts have been made to anticipate time using predefined reference values, see e.g., the work of Sodhi et al. (2004) on the U-effort (unfastening-effort) for fasteners. A quantitative indication of time by calculating the time needed for disassembly and reassembly is then again given by the ease of Disassembly Metric (eDiM), see Vanegas et al. (2016). The reference times used in eDiM are from MOST (Maynard Operation Sequence Technique) which was developed to have standardized times for different working steps, see Zandin (2002) on MOST. Another method, the Philips

ECC is working with dismantling times defined through time measurements of real disassembly processes (Boks et al., 1996). The database is linked to product categories, which poses limitations to extend the method towards other categories (Ritthoff et al., 2023). Desai & Mital (2003) developed the disassembly design method which uses five factors to calculate disassembly time (i.e., disassembly force, material handling, requirements of disassembly tools, accessibility of joints as well as tool positioning). Kroll & Carver (1999) developed a method which calculates the required disassembly time based on manual disassembly trials on computers, keyboards, monitors and printers. It uses difficulty levels which can be seen as more subjective (Ritthoff et al., 2023).
Many methods, each having limitations to apply them in every repair context (e.g., non-ideal situations in which operators lack experience, have limited tools or instructions available).

Nevertheless, the anticipation of disassembly and assembly time is relevant, especially when considering priority parts. Priority parts are mainly defined by the frequency of becoming defective, functional importance and economic value (Ritthoff et al., 2023). The steps and time needed to reach these parts are impacted by the product architecture (i.e. how the product is arranged in components and subassemblies which is linked to the functions of the product) and by the complexity of the interactions (physically and cognitively). The disassembly map, see De Fazio et al. (2021), is a tool which allows the analysis of disassembly properties of products in relation to these identified priority parts and the product architecture, which is valuable to facilitate repair.

Although time to repair a product is an important element due to the impact on cost (e.g., repair in the factory or by professionals), we could state that in some contexts time has less economic impact (e.g., repair by the consumer, repair in repair cafés, etc.). Here, ease and intuitiveness of both the disassembly and assembly processes are important as the people repairing are potentially not trained and lack instructions. Therefore, product designers should be aware of how people construct meaning during interactions and how product design impacts complexity of both disassembly and assembly in relation to human interaction during repair.

The construction of intuitive interactions during manual assembly is key within the Design For Assembly Meaning framework (DFAM), see the work of Parmentier et al. (2020, 2021). This framework builds upon affordance theory (i.e. action possibilities) [see, Norman (1988, p 9) and You & Chen (2007) on affordances] and on product semantics [see, Krippendorff & Butter (1984)] as the building blocks of interaction during manual assembly. Therefore, DFAM was considered valuable for the interactions during a repair process and to redesign the product accordingly. Following, both the disassembly map by De Fazio et al. (2021) and the DFAM framework from Parmentier et al. (2020) were considered valuable for the course.

However, considering repairability of products, many elements [i.e., on a system level (e.g., business model, logistics, strategies for spare parts, etc.), on a product level (e.g. product architecture, interfaces, connections and on an interaction level (ease and intuitiveness of interactions, tools, manipulations, etc.)] play a role.

In this paper we discuss how frameworks and tools (e.g., to map and visualize interactions during repair) were used by design engineering students and whether the use of these frameworks and tools generated valuable results. In the following sections we explain how students engaged both on a system and product level to design for repair, and we discuss the results of their redesign efforts.

Methodology

Course and student description

The course was planned for the second semester of the academic year 2023 - 2024. The participants were third year students from the Bachelor of Science (BSc) program in Industrial Design Engineering Technology at Ghent University. Twenty-five students (22 male and 3 female) received 20 hours of lectures during a total of 12 weeks. The rest of

the 180 hours were spent on the project to redesign a product focusing on repairability.
The kick-off of the redesign project was given in week 4. The students selected an electric household appliance or power tool and iteratively redesigned it in the following weeks of the project. The students were guided with individual feedback (critiques) which is typical in Project Based Learning (PBL) (Brosens et al., 2022).

Framework

Repairability of products is defined by the design (product and interaction level) and by the repair context (e.g. tools, information, availability of spare parts, cost, etc.). Following, the students were offered insights, methods and tools looking at the system level (strategies for e.g. spare part, logistics, costs, etc.), the product level (i.e., the architecture, function mapping, priority parts, subassemblies) and the interaction level (interactions over the different disassembly and assembly steps), illustrated in Figure 1.

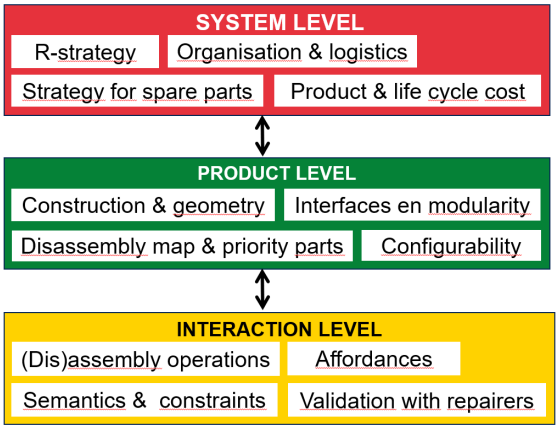


Figure 1: overarching framework offered to the students.

Although insights were given on a system level (red box in Figure 1) and considered during trade-offs (i.e., to weigh design decisions), the focus was mainly on a product level and interaction level (green and yellow boxes in Figure 1).
Students received courses on the DFAM framework [i.e., based on the work of Parmentier et al. (2020, 2021) and papers to read on the disassembly map (De Fazio et al., 2021), product architecture and modularity (K. Ulrich, 1995) and product architecture and platforms (Muffatto & Roveda, 2002). They received information on the French repairability index (French Government, 2021) and suggestions for improving repairability scores based on the work of Rodríguez et al. (2023). They also received the example of Rodriguez & Favi (2024) on a methodology to improve the repairability of mechatronic products.

Constraints and design approach

Functionality, end-user interactions and aesthetics had to remain the same in the redesign. Despite these constraints, they were not bound by the existing architecture, subassemblies or component designs. They could completely redesign the products, focusing on repair while respecting functionality and overall appearance.

Product Autopsy was used to gain understanding of the design decisions made in the original product [see Milton & Rodgers, p. (2013, p. 33) on Product Autopsy]. Priority parts were defined based on available information (e.g., from online forums, or known to be subject to wear) combined with insights from the product autopsy.

During the redesign, the students followed a basic design process, going through the stages of discover (i.e., analysis of the existing product and systems by means of the DFAM framework and the Disassembly Map), define (i.e., problem definition and methods to tackle these problems), develop (i.e., to develop concepts, solutions) and deliver (i.e., to finalize the designs).

During the define stage (mainly the analysis of the existing product), they had to construct a function diagram (Figure 2), an assembly (Figure 3) and disassembly diagram (Figure 4), the disassembly map (Figure 5) and finally analyze the interactions during disassembly and assembly by using the DFAM framework (e.g. by considering whether the action possibility is desired or undesired, possible or obstructed, triggered or not).

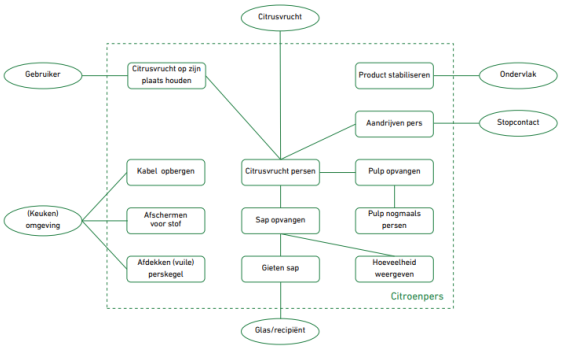


Figure 2. Function diagram made by a student for a citrus juicer

The disassembly and assembly process were then analyzed onto the level of affordances and product semantics. Affordances (i.e., action possibilities) and product semantics (i.e., meanings associated with the product, feature, texture, …which can trigger the action) define the interactions. The students were also registering the time needed to discover and resolve errors.

As pointed out, the interaction level is mainly linked to the DFAM framework in which affordances (desired or undesired), constraints (which limit affordances on a physical level) and semantics (which could trigger the action) are considered. Considering whether the affordance was desired or undesired, triggered or not, obstructed or not, is crucial within the DFAM framework. Focus on ease and intuitive interaction is important when considering non-availability of repair instructions and repair by non-professionals.

The students delivered a final report on the process (documented during the project) and the use of the frameworks and tools, describing the different iterations and the final redesign of the product. The process was weekly observed by researchers during the design critiques.

Results

25 products were redesigned within the categories of household appliances and power tools, see Table 1 for an overview.

Household appliances		**Power tools**	
Coffee grinder	1	Sanding Machine	2
Blender	5	Jigsaw	3
Ice crusher	1	Multitool	2
Slicing machine	1	grinder	1
Coffee maker	2	Glue gun	1
Waffle Iron	1	Electric screwdriver	1
toaster	2	Electric scraper	1
Citrus juicer	1		

Table 1. Products which were redesigned

In this section we explain the results by highlighting one of the redesigns (i.e. a Citrus juicer, see Figure 6) which exemplifies the other cases. We discuss the process of the redesign of the product which was documented by the student.

Process and redesign

Discover phase: The students made an analysis of the product by means of the DFAM framework and the Disassembly Map. The product was disassembled and reassembled by the students to gain understanding of the product (4 times in case of the citrus juicer). Pictures were taken and used to map the product architecture. As reported by the student, several problems on the level of affordances and (product) semantics were discovered when 5 people who had no prior knowledge or technical backgrounds disassembled and reassembled the product. These interactions were filmed and used as a benchmark to validate or compare the redesigns.

After these initial steps, a function analysis of the product was made (see Figure 2) and the components were mapped on these functional elements. Defining how components interact to achieve and maintain functionality is crucial.

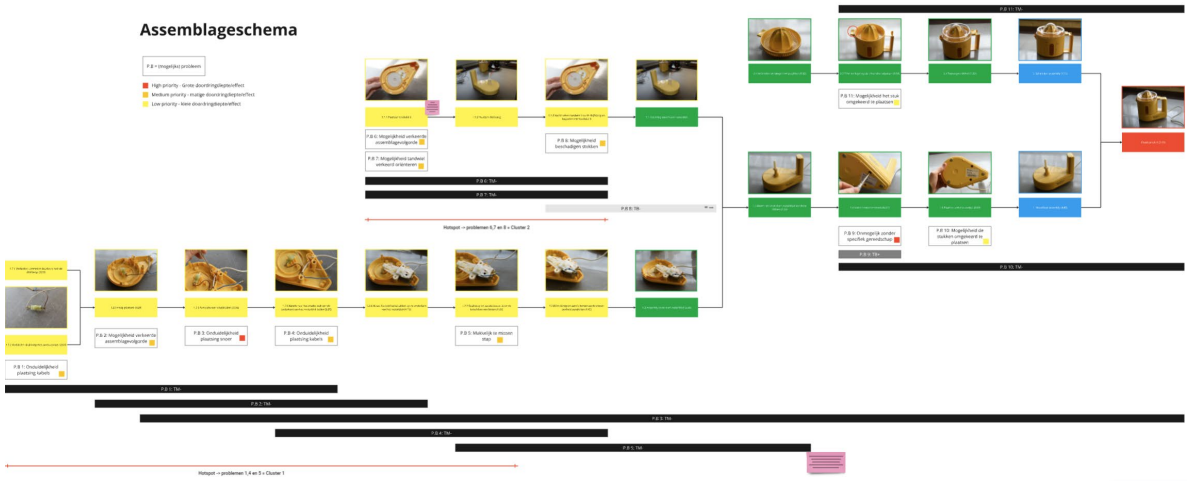


Figure 3. Assembly diagram made by a student (citrus juicer)

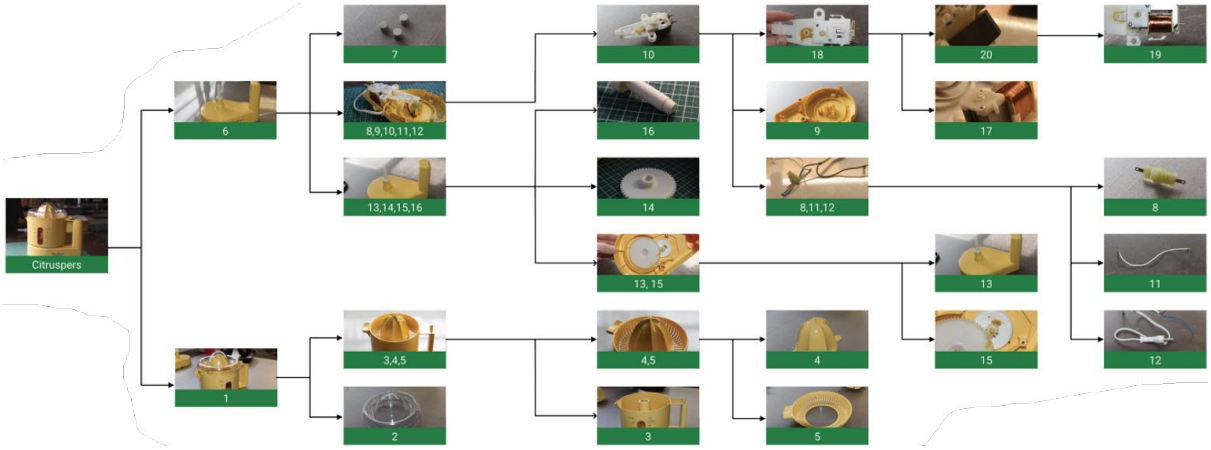


Figure 4. Disassembly diagram made by a student (citrus juicer, numbers are linked to figure 5)

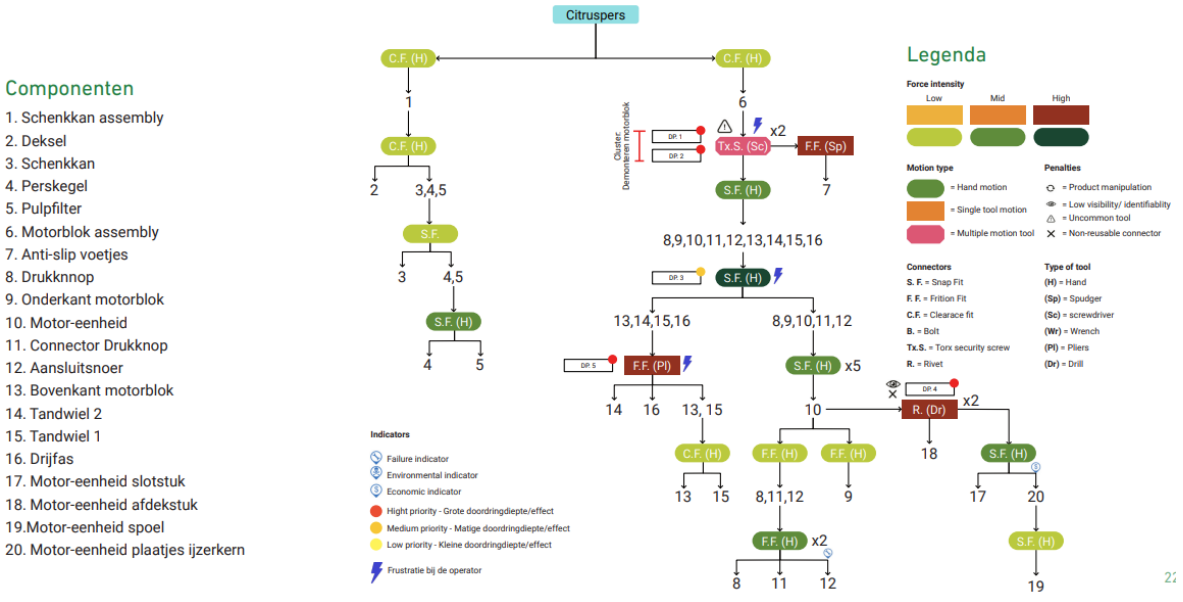


Figure 5. Disassembly map made by a student (citrus juicer), based on De Fazio et al. (2021)



Figure 6. The citrus juicer which was redesigned

Define phase: By conducting a product autopsy, the student was able to construct the assembly diagram (Figure 3), the disassembly diagram (Figure 4) and the disassembly map (Figure 5) for the existing product. The assembly diagram was used to map the problems which were discovered and to identify clusters of problems. The disassembly diagram and the disassembly map from De Fazio et al. (2021) were then used to map the structure and indicate uncommon tools, non-reusable connectors, low visibility, etc. The DFAM framework was used to define the problem on a level of affordances, defining the root cause of a problem (e.g., whether selection of the appropriate tools, and linking it to the different interactions during an assembly step). The combined use of these tools proved especially useful to define and map the problems within the existing product architecture.

Develop phase: Students iteratively developed solutions, build prototypes, and tested different concepts until finding a final solution for the problems found in previous phases.

Different solutions, on different levels, were developed in the citrus press case (i.e., on an interaction level by adding and removing physical constraints or by changing the product semantics). Changing physical constraints and product semantics are inherently part of the DFAM framework. Semantic solutions were, e.g. implemented to trigger correct tool use (Figure 7) or by indicating in color how the cables should be installed (Figure 8).

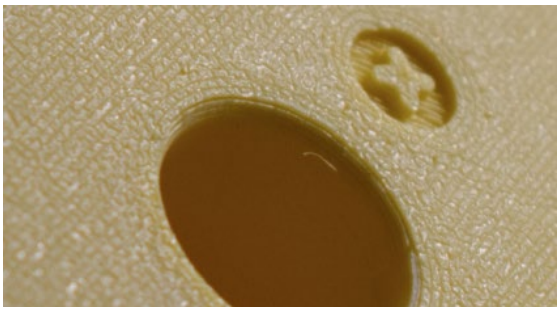


Figure 7. 3D printed part with a semantic addition illustrating the type of screwdriver.

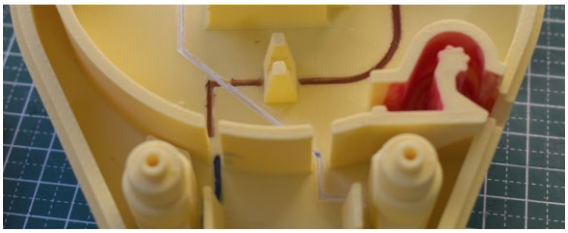


Figure 8. 3D printed part illustrating how the cables should run.

The gears and associated interactions were redesigned by adding numbers, highlighting their correct position and assembly sequence (see Figure 9), or by changing the shape of the axis into a tapered shape which makes the incorrect positioning of the gear impossible (i.e., by adding constraints).

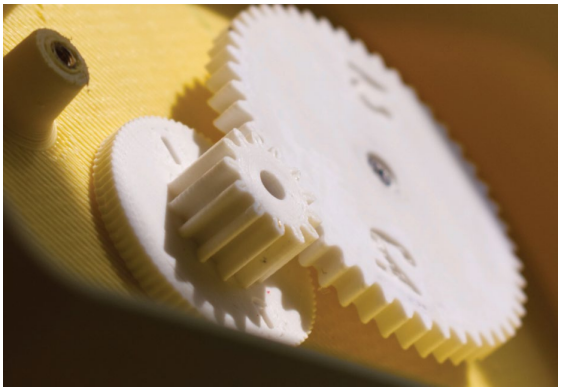


Figure 9. Numbers indicating the correct position and sequence.

Additionally, solutions were explored at a product level. As reported by the student, it was for example impossible to disassemble the drive axis and gear in a non-destructive way (due to a press-connection). By redesigning the connection (Figure 10), physical constraints were removed which prevented disassembly.

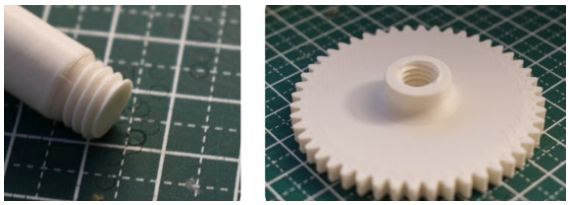


Figure 10. Drive axis and main gear connected by a new integrated thread connection.

Furthermore, the design was reconsidered on a system level (e.g. by. considering the availability of tools in a DIY context). In the original product it was not possible to use a screwdriver with an interchangeable bit. Moreover, a safety-torx was used, which is not very common. Following, the casing was redesigned to facilitate the use of a screwdriver with interchangeable bits and the screw was changed to a commonly found Philips Pan Head Screw. Semantics were added to highlight the type of tool to be used, see Figure 7.

Considering the spare part availability, the student opted to 3D print the replacements. The original product was redesigned to facilitate 3D printed replacements (e.g. the form of 3D printed and injection molded parts might differ, yet both parts need to fit the casing). As reported by the student, insights on the design specifications for these printed parts were gained through iterative testing and prototyping of 3D printed parts.

Deliver phase: During the deliver phase, the designs were finalized (i.e., final iterations on prototypes, detailing, testing) and were validated.

The results in this section were presented by some examples of 1 case study. However, the process, tools and methods used were identical for all case studies and consequently similar results were observed in other case studies.

Discussion and Conclusions

As highlighted by Terzioğlu & Wever (2021), few courses focus on design for repair and on competencies or skills linked to design for disassembly and reassembly. However, in this course this was the very focus.

The case studies' focus was on potential redesigns by manufacturing companies, yet not necessarily for these companies to facilitate the repair service. The case studies focused more on repair in a DIY context where users repair their own product or bring it to a repair café. This differentiation is important to understand the focus on simple and intuitive operations in which time measurement was more considered an indicator for complexity. Therefore, reduction of time was not the primary focus as in different other methods described in the introduction. Following, time anticipation techniques were not offered to the students. Instead, frameworks were offered to make them consider the structure of the product, the use of the tools and the complexity of the interactions (both cognitive and physical) during repair.

Insights were also provided on a system level by offering them insights on e.g. the French repairability index, the availability of spare parts, the availability of instructions etc.

The results (also illustrated by means of the presented case study) illustrate the ability of the students to use the tools and frameworks and to redesign a product focusing on repairability. Conducting a product autopsy, constructing a function diagram, assembly diagram and disassembly diagram clearly helped them to understand the structure of the product, the interactions between the components, the functionality of the components and the sequential nature of both the disassembly and assembly processes. Constructing the disassembly map helped them to consider the priority parts, uncommon tools, non-reusable connectors, low visibility, etc.

The weekly critiques with the students revealed that the offered tools helped students visually map and cluster the difficulties, allowing them to identify the core of the problems. Triggering students to analyze the affordances and product semantics (during disassembly and reassembly processes, (also with non-technical profiles)) proved very valuable. Considering the interactions during repair facilitated easier and more intuitive solutions. Moreover, DFAM helped them to delineate the problem and select appropriate solution strategies.

The presented case study illustrates that students were able to develop and validate

solutions at different levels (interaction, product and system). Moreover, it was observed that the students (familiar with 3D printing), very quickly engaged in printing parts to use them as replacements for a defective component. Consequently, companies could adapt their product designs to facilitate the replacement of parts by 3D printed parts of which the files can be shared online, for example in cases where spare parts are unavailable (as was the case for the citrus press). In a DIY context, repair cafés or makerspaces could facilitate the 3D printing of these spare parts.

The premise of this course was to increase the competencies of design engineering students to redesign a product focusing on the repairability by end users. The results illustrate the use of the frameworks and the value of zooming in on a system, product and interaction level to find appropriate solutions. We therefore hope this can be an inspiration for other design education programs.

Acknowledgments

We would like to thank all the students who participated in this course, especially Ruben Verscheure who worked on the case of the citrus juicer which was presented in this paper.

References

Bocken, N. M. , P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Boks, C. B., Kroll, E., Brouwers, W. C. J., & Stevels, A. L. N. (1996). Disassembly modeling: two applications to a Philips 21″ television set. Proceedings of the 1996 IEEE International Symposium on Electronics & the Environment. ISEE-1996, 224 – 229. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0029717360&partnerID=40&md5=d9d348e2c0ff9571f72e00aca76f102b

Brosens, L., De Vos, E., & Emmanouil, M. (2022). Critique : a workshop to establish shared understanding and clear responsibilities between design students and their lecturers. In E. Bohemia, L. Buck, & H. Grierson (Eds.), DS 117 : proceedings of the 24th International Conference on Engineering and Product Design Education (E&PDE 2022). https://doi.org/10.35199/EPDE.2022.29

De Fazio, F., Bakker, C., Flipsen, B., & Balkenende, R. (2021). The Disassembly Map: A new method to enhance design for product repairability. Journal of Cleaner Production, 320. https://doi.org/10.1016/j.jclepro.2021.128552

Desai, A., & Mital, A. (2003). Evaluation of disassemblability to enable design for disassembly in mass production. International Journal of Industrial Ergonomics, 32(4), 265–281. https://doi.org/10.1016/S0169-8141(03)00067-2

French Government. (2021). Indice de réparabilité. https://www.indicereparabilite.fr/

Krippendorff, K., & Butter, R. (1984). Product Semantics : Exploring the Symbolic Qualities of Form. Innovation, 3(2), 4–9.

Kroll, E., & Carver, B. S. (1999). Disassembly analysis through time estimation and other metrics. Robotics and Computer Integrated Manufacturing, 15(3), 191–200. https://doi.org/10.1016/S0736-5845(99)00026-5

Lilley, D., & Lofthouse, V. (2009). Sustainable design education – considering design for behavioural change. Engineering Education, 4(1), 29–41. https://doi.org/10.11120/ened.2009.04010029

Milton, A., & Rodgers, P. (2013). Research Methods for Product Design (G. Sermon, Ed.). Laurence King Publishing Ltd.

Muffatto, M., & Roveda, M. (2002). Product architecture and platforms: a conceptual framework. International Journal of Technology Management, 24(1), 1–16. https://doi.org/https://doi.org/10.1504/IJTM.2002.003040

Norman, D. (1988). The psychology of everyday things. Basic books New York.

Parmentier, D. D., Van Acker, B. B., Detand, J., & Saldien, J. (2020). Design for assembly meaning : a framework for designers to design products that support operator cognition during the assembly process. Cognition, Technology & Work, 22, 615–632. https://doi.org/10.1007/s10111-019-00588-x

Parmentier, D. D., Van Acker, B. B., Detand, J., & Saldien, J. (2021). Framework to Redesign Products with focus on Design For Assembly Meaning: a PBL Case Study. International Journal of Engineering Education, 37(1), 2–18.

Ramirez, M. (2006). Sustainability in the education of industrial designers: the case for Australia.

International Journal of Sustainability in Higher Education, 7(2), 189–202. https://doi.org/10.1108/14676370610655959

Ritthoff, M., Müller, A., Hopfensack, L., Brüning, R., Wolf, J., & Piehl, F. (2023). Methods and standards for assessing the repairability of electrical and electronic devices.

Rodríguez, N. B., & Favi, C. (2024). Disassembly and Repairability of Mechatronic Products: Insight for Engineering Design. Journal of Mechanical Design, 146(2). https://doi.org/10.1115/1.4064075

Rodríguez, N. B., Gabriel, C., Gaha, R., & Favi, C. (2023). Analysis of disassembly parameters in repairability scores: limitations for engineering design and suggestions for improvement. Procedia CIRP, 116, 738–743. https://doi.org/10.1016/j.procir.2023.02.124

Sodhi, R., Sonnenberg, M., & Das, S. (2004). Evaluating the unfastening effort in design for disassembly and serviceability. Journal of Engineering Design, 15(1), 69–90. https://doi.org/10.1080/09544820310001500152

Terzioğlu, N., & Wever, R. (2021). Integrating Repair into Product Design Education: Insights on Repair, Design and Sustainability. Sustainability, 13(18). https://doi.org/10.3390/su131810067

Ulrich, K. (1995). The role of product architecture in the manufacturing firm. Research Policy, 24(3), 419–440. https://doi.org/10.1016/0048-7333(94)00775-3

Vanegas, P., Peeters, J. R., Cattrysse, D., Duflou, J. R., Tecchio, P., Mathieux, F., & Ardente, F. (2016). Study for a method to assess the ease of disassembly of electrical and electronic equipment - Method development and application in a flat panel display case study. doi:10.2788/130925

You, H., & Chen, K. (2007). Applications of affordance and semantics in product design. Design Studies, 28(1), 23–38. https://doi.org/10.1016/j.destud.2006.07.002

Zandin, K. B. (2002). MOST work measurement systems. CRC press.

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Reviving Bedlinen: User Expectations, Use-Life, and Repair Practices in Australia

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Keywords: Bedlinen; Home Textiles; Product Expectations; Repair; Circularity.

Abstract: This paper considers the relationship between user expectations of domestic bedlinen, product use-life and repair engagement within an Australian context. Bedlinen, in this instance, includes flat and fitted sheets, pillowcases, and quilt covers - also known as duvet covers, or in Australia, doona covers. There is limited data on this specific textile product within sustainability and circularity research. This paper discusses findings from the survey, *Bedlinen and Sustainability* (2023), which includes questions focused upon attitudes and behaviour regarding bedlinen purchase, use, care, repair, reuse and disposal. Key findings are identified and are discussed as factors that directly impact the use-life of bedlinen. These include laundering choices, emotional durability, change of mattress sizes, expectations of comfort, maintaining original condition, and repair challenges.

Introduction

Bedlinen, like all material culture, exists in an interconnected context of production, consumption and entangled systems of historical, social and cultural value (Appadurai, 1988; Rinkinen et al., 2015). Domestic bedlinen in Australia is largely influenced by Western traditions of dressing the bed – expanses of flat woven cloth that protects a mattress, pillows and doona. For the user, bedlinen provides protection, thermal regulation, comfort and hygiene (Ahirwar et al., 2020; Chanda et al., 2020; Dubale et al., 2021; Sundaresan et al., 2016). Like garments and other household textiles, bedlinen is more than a functional item for some users – it is an item of self-expression, identity-creation and home-making (Barnard, 2014; Gram‐Hanssen & Bech‐Danielsen, 2004).

Within sustainable textile literature, bedlinen is most often included within the broader category of 'home' or 'household textiles' which also includes products such as bathroom towels, napery, curtaining and upholstery. To date, there is limited research specific to domestic bedlinen and product longevity. Since 2019, there has been one significant piece of research in this field. *'The Citizen Insights: Estimating the longevity of home textiles'* report published by UK non-governmental organisation WRAP (Rao et al., 2023), was the first major report to investigate home textiles in a Western context, and identifies opportunities to encourage consumer strategies such as care, repair and reuse, to extend product longevity for these types of textiles. This paper takes the opportunity to build upon and deepen these understandings to offer more specific insights of bedlinen use in an Australian context.

Bedlinen Longevity and Consumer Impacts

The longevity of products and materials are an increasing concern in a time of high consumption, mounting waste and escalating energy expenditure (Jensen et al., 2021). Supporting product longevity is the responsibility of multiple stakeholders – federal, state and local governments, industry bodies, businesses, and consumers. Understanding barriers and creating strategies to extend product lifetime are an important approach in shifting towards a circular and more sustainable economy (Bakker et al., 2021; Cooper, 2020).

User expectations, comfort and longevity

It is well established that consumers are a contributing factor to product longevity and sustainability (Gnanapragasam et al., 2017). '*The Citizen Insights: Estimating the longevity of home textiles'* report (Rao et al., 2023) states that the primary reasons household textiles become inactive is that they no 'feel as nice', pointing to expectations of comfort. Unwanted physical issues, such as shrinkage, damage,

fading, or staining that occur over time is reported as the second reason for home textiles to fall out of use.

Comfort is a subjective and dynamic experience (Kamalha et al., 2013) influenced by variables such as age, gender, social and cultural influences, deriving from both physiological and psychological human responses to the sensation of touch (Kergoat et al., 2012).

It could be argued that perception of wear and tear are also subjective and dependent on the user's opinion of material aging, (Chapman, 2015) and confidence in being able to return the product to its original state. British sociologist, Elizabeth Shove in her book, *Comfort, cleanliness and convenience: the social organization of normality* (2003) points to the ever-growing expectations of comfort of goods and services and the impact this has on the environment.

Use-life, care and longevity

Product use-life is dependent on user behaviour. The bed, along with associated bedlinen is a site of intimate events – sleeping, eating, bedwetting, menstruation, sex, childbirth, illness, death - all of which have the potential to leave stains and elicit disgust if the origins are unknown (Ayling-Smith, 2018). The trace of such personal experiences is often perceived to be undesirable and unhygienic. Users apply laundering practices to remove these traces of contact, which simultaneously result in the deterioration of the fabric (McLaren et al., 2015).

There are numerous opportunities for consumers to improve their care and laundering practices for product longevity and sustainability (Godin et al., 2020; Laitala et al., 2011; Shove, 2004). Yet, there are deeply embedded cultural and social belief systems that need to be understood to move towards a more effective care of textiles. In the book '*Purity and danger: an analysis of concepts of pollution and taboo'* (2003), Douglas establishes a connection between the power of social conventions and perceptions of dirt that continue to impact today's increased need to over-launder. Shove (2004) adds that extending the lifetime of products involves rethinking societal norms and expectations around cleanliness and convenience.

Repair, care and longevity

Repair is a circular strategy aimed at maintaining materials at their highest value and delaying waste creation. The term "repair" originates from two Latin words, meaning "to return to" or "to fix," both implying a return to an original state (Harper, 2023; Merriam-Webster, 2017). This dual meaning underscores the traditional goal of repair and aligns with user expectations for possessions to maintain their original condition. In recent times, repair in the west has undergone a shift to include 'visible mending' where creative noticeable repair adds value to an item (Maycroft, 2024).

Repair is an act of care (Tronto, 2013), where skill and time are given to an item that requires mending, with a connection forged between user and object. Professor of philosophy, Elizabeth Spelman, provides an important understanding of repair as a fundamental aspect of human life and 'the creative destruction of brokenness' (2002). Spelman argues that repair of physical objects, emotional bonds or societal issues, is not only concerned with restoring functionality, but also acknowledges and responds to the fractures in our world as part of the human-experience. Chapman (2015) adds that the act of repair creates a strong emotional connection to objects that are consequently kept for longer periods of time. These perspectives recognise the transformational agency of repair as an act of care that also promotes the functional and emotional durability of products such as bedlinen.

In the past, small tears in bedlinen were mended with a darning technique, and for more extensive tears, a process known as 'sides to the middle' or 'turning' the sheets was applied (Lowry, 2020). This technique involves cutting the sheet in half and flipping the less worn sides of a sheet to the centre and sewn down the middle. This repair technique improves longevity and leaves a raised seam down the middle of a sheet. This method of repair is problematized by user expectations of comfort which will be continued as a discussion later in the paper.

Methods

The *Bedlinen and Sustainability* survey was conducted in Australia across two months in

2023. This quantitative research forms part of a doctoral study investigating the diversion of post-consumer bedlinen waste from landfill towards opportunities for product longevity and transformative renewal. Fourteen questions were asked of participants through an online survey to explore attitudes and behavior regarding bedlinen purchase, use, repair, reuse and disposal within a domestic context.

Table 1
Questions asked in the Bedlinen and Sustainability survey, 2023.

Bedlinen Ownership	How many of each of these bedlinen items are in regular use on your own bed, i.e., used at least once a month?
	How many of these items do you have stored and in irregular use, i.e., used less than every six months? (If you use all your linen regularly, check 'none' for each.)
Bedlinen Purchasing	When buying bed sheets and/or doona covers, which of the following factors is the most important to you? Select as many as you like.
	Thinking about your most recently acquired bed sheets and/or doona cover, how did you acquire it?
Bedlinen Expectations	How long do you expect to use the following items for?
	If you have used the following items for more than ten years, what is the main reason?
Bedlinen Care - Laundering	How often do you wash your bedlinen?
	Which of the following cleaning methods do you regularly use for bedlinen? Please select all that apply.
	At what temperature do you wash your bedlinen?
Bedlinen Repair	Has your bedlinen been repaired, by yourself or a professional service?
	If you answered 'no' to your bedlinen being repaired, what prevents you from repairing your bedlinen?
Bedlinen Disposal	What are the primary reasons you have disposed of the following items?
	When you no longer want the following item, how do you dispose of it?

The survey included multiple-select questions with the opportunity to add a free-response answer to provide more detail and offer rich qualitative data. Analysis techniques employed include descriptive statistics to summarise quantitative data, and thematic and sentiment analysis to identify common themes and overall attitudes of qualitative free-response answers.

The small-scale survey was distributed through social media via personal and professional networks over a one-month period (22 September until 18 October 2023). This mode of distribution has potential recruitment biases given that there is high sustainability and repair literacy amongst this network. While the relatively small sample size of 273 responses is not representative of the broader Australian population, it does offer valuable insights into the expectations, attitudes, and behaviors related to bedlinen longevity, an area that remains relatively under-researched.

Selected Findings

Use-life: Laundering

All survey participants reported using a washing machine to launder, with five participants also occasionally handwashing, soaking or bleaching their bedlinen for stubborn stains. Just under half of the participants (48%) opt for a cold wash, 36% wash their linen between 20-30 degrees, and 16% select a higher temperature setting. A small percentage (6%) reported not paying attention to the temperature setting before washing their linen.

Exactly half of the participants washed their bedlinen every two weeks, with 31% laundering every week, 17% once a month and 3% every 2-3 months. Over half (53%) of the survey participants line dry their bedlinen, 28% use a combination of line drying and tumble drying and 22% only use the tumble dryer. Nine participants reported ironing all or a portion of their bedlinen (such as edges of sheets or just pillowcases).

Expected Lifespan of Bedlinen

Most survey participants expected to have their bedlinen for between 5-10 years with doona covers and flat sheets lasting another five years than fitted sheets or pillowcases. This reflects the high-wear use of sheets and pillowcases in comparison to doona covers.

Participant expectations of bedlinen upon acquirement

The survey revealed that participants prioritised fabric and fibre type, as well as the comfort and quality of the fabric, over factors such as price, style, and durability. 'Natural' fabrics, such as cotton and linen, were mentioned in the survey comments as priorities by five participants (Survey respondents #258, #260, #267, #269, #271). Thread count and weave type were remarked upon as a tool to determine high quality bedlinen (Survey respondents #258 and #272).

Table 2
When buying bed sheets and/or doona covers, which of the following factors are the most important to you? Select as many as you like.

Important factors	%
Type of fabric/fibre	93
Comfort eg. texture, weight	88
Quality of fabric	87
Price	85
Design / style	76
Durability	71
Ease of cleaning and maintenance	64
Keeping cool	62
Staying warm	58
Sustainable materials	58
Ethically made	55
Locally made	47
Brand	43
Ease of repair	40
Reviews and ratings	39
Recommendations	35
The item is on trend/fashionable	35
Potential re-sale value	34
Other	11

The findings indicate a concern for easy-care cleaning and maintenance. Body temperature regulation such as warmth or coolness were of importance, with the 'breathability' of fabric mentioned as an additional comfort factor (Survey respondent #255). Specific circular strategies, such as refraining from buying new bedlinen, secondhand purchasing, and reuse appeared as additional comments. This participant commented how they consider use of the bedlinen beyond the first cycle -
'Knowing if I like the fabric enough to cut it up once "finished" and then remade into something new. For example I've remade a duvet into a dress.'
Survey respondent #265, Female, 21-29.

Participant motivations for bedlinen replacement

Just under half of the survey participants reported never having thrown out their bedlinen (43%). Those that had disposed of their bedlinen listed reasons that can be categorised into several key factors (Table 3). The most common reason, cited by 62% of respondents, is a change in living circumstances. This could include moving to a new home, moving in with a partner or moving overseas, which compels bedlinen to be replaced. A related impact, mentioned by approximately 53% of participants, was a change in mattress size, requiring purchasing new bedlinen that fits the new mattress dimensions.

Table 3
What are the primary reasons you have disposed of sheets, pillowcases and doona covers?

Reasons for disposal	%
Change of living circumstances	62
Change of mattress size	53
Received new bedlinen as a gift	51
Elastic on the fitted sheet is compromised	50
Replaced for higher quality fabric	48
Pilling of fabric	44
Torn or ripped fabric	43
Uncomfortable	42
No longer suited my style	40
Wrinkled easily	40
Not warm or cool enough	38
Faded	34
Stained	32
Lost	10

The survey also highlighted wear and tear, as a primary reason for disposal, expanded upon by this participant -

'When we end up discarding of bed linen it's primarily because they have stains/discolouration. My partner sweats a lot (I know it's gross) so basically turns any pillowcase and sheet yellow over time. White sheets can be bleached but have been struggling to clean anything with a print/non-white.' Survey respondent #90, female, 20-29.

Expectations of comfort also provoked survey participants to replace their bedlinen - 45% survey participants shared that bedlinen replacement occurred because they desired a higher quality fabric, 40% stated they were dissatisfied with scratchy or uncomfortable fabric texture, and 35% expected better thermal comfort in terms of warmth or coolness.

Additionally, aesthetic style was mentioned as a reason for disposal. About 40% of respondents mentioned that their bedlinen no longer suited their style, and 40% also cited that it wrinkled too easily.

Participant Perception and Engagement in Bedlinen Repair Strategies

When asked whether the survey participant's bedlinen had been repaired, by themselves or a professional service, over half responded that they had not repaired their bedlinen (60%). Out of those that had engaged in repair, a portion of respondents (37%), stated they had made repairs themselves, while only 2% had paid someone else to make a bedlinen repair, and another 2% had enlisted an unpaid repair by another person.

The types of repairs that survey participants reported making ranged from replacing missing buttons or ties on doona covers, repairing tears in fabric and replacing elastic on fitted sheets.

The primary reasons cited for not undertaking repair were a lack of repair skills at 44%, a lack of time at 28%, and repair being too expensive to outsource at 27%. Two participants commented that it was cheaper to buy new bedlinen than engage with repair services (#238 & #255). Others remarked they did not know that you could repair bedlinen (#51 & #59). A significant number of participants considered worn and torn sheets 'too far gone' as captured by this participant -

'By the time the fabric is so thin that someone puts a foot through it, it's not structurally sound enough to repair.'
Survey respondent #245, gender not specified, 50-59.

An additional comment spoke to the physical discomfort of repair work when sleeping -

'I don't like the texture of repaired sheets (eg the feeling of the stitches)'
Survey respondent #100, Female, 30-39.

Discussion

Participants are making sustainable laundering choices

The majority of survey participants selected more sustainable and life-extending approaches to washing their bedlinen – selecting cold wash not only saves energy, but also reduces erosion of fibres and microfibre release, and reduces colour loss and fading (Cotton et al., 2020), which are contributing factors to more frequent disposal of bedlinen.

The Australian climate allows for a greater uptake in line-drying, in comparison to colder climate locations such as the UK, as described in the paper *'Dirtying Linen: Re-evaluating the sustainability of domestic laundry'* (Yates & Evans, 2016). A significant number of participants use low-impact, low-energy, and low-cost methods of line-drying bedlinen. Despite the additional labor involved, this method preserves the integrity of the fabric for longer and harnesses the natural bleaching effect of the sun to fade stains. However, it also causes greater fading to dyed and printed fabric. Consumers must frequently apply different laundering methods to suit the specifications of the fabric, which requires textile laundering knowledge.

Bedlinen requires embedded emotional durability and timeless design

The survey found that a primary reason for bedlinen disposal was due to a change in living circumstance – bedlinen seems not to be a significant item chosen to accompany participants across different stages of their lives, pointing to the lack of connection and emotional durability. The transition between childhood to adulthood also challenges the longevity of bedlinen designed specifically for certain age groups or themes. The design of bedlinen requires a more timeless approach so that the product can transition throughout a lifetime.

A change in mattress size impacts bedlinen longevity

A common reason for bedlinen disposal was due to a change in mattress size. Inevitably, consumers grow and change mattress sizes to suit living circumstances. With the evolution of standardised mattress sizing (Parsons, 1972), bedlinen has also adopted the same standards, creating greater compatibility between these products. However, this has potentially created an unanticipated secondary complication for bedlinen longevity where users need to replace

their bedlinen due to normalised behavior of changing mattress sizes.

Users expect their bedlinen to be comfortable

Consistent with existing literature (Rao et al., 2023), comfort is a primary expectation for bedlinen. Given that bedlinen is in close contact with our bodies for six to ten hours each night, and the recent emphasise on sleep hygiene for our health (*Sleep Hygiene: Good Sleep Habits*, 2024), a comfortable sleep experience is essential for overall well-being and quality rest. However, as Shove (2003) posits, an escalating desire for comfort can be detrimental to sustainability.

The survey reveals that participants dispose of bedlinen in favor of more comfortable, higher quality fabric. Comfort also impacts if and how bedlinen is repaired, as some users no longer readily tolerate discomfort of repair sites and prefer to acquire a replacement.

Users expect their bedlinen to 'stay new'

A frequently mentioned issue regarding bedlinen longevity was fading, discolouration and staining of sheets. From a functional perspective, staining and discolouration do not compromise the utility of bedlinen. Thus, these issues are not a concern of function, but rather an aesthetic expectation of bedlinen to maintain its 'newness'. The desire for bedlinen to remain unchanged and in 'near-new' appearance stems from historic representations of hygiene, status, wealth and morality (Douglas, 2003; Healy, 2009; Shove, 2003) and continues today with the expectation for products to maintain their 'near-new' characteristics (Chapman, 2015; Walker, 1995).

The practice and results of repairing bedlinen include barriers

While some participants reported actively repairing their bedlinen, there was also strong belief amongst survey participants that once bedlinen begins to tear, repair is no longer an option to return the bedlinen to use-life. The survey participants' concern that repair cannot return sheets or worn elastic to a high level of durability may reflect today's diminished repair skills, access to tools and not having time to conduct the required types of repair.

While the act of repair requires technical skills, access to resources, problem-solving abilities and time, it offers a low-energy, low-carbon option that avoids the current drawbacks of other approaches such as recycling via chemical or mechanical recovery. It is also true that a proportion of torn and worn bedlinen cannot be repaired back to the original function and requires other circular strategies such as reuse, upcycling and downcycling.

Conclusion

This paper has introduced expectations, care and repair strategies employed by Australian users towards domestic bedlinen. These practices are interrelated and reveal differing levels of influence on the longevity of bedlinen, encompassing both beneficial and detrimental effects.

Given the unprecedented and interconnected environmental challenges we face, it is crucial to understand the impact of user behavior upon product longevity, which can then inform the development of impactful circular strategies to extend product use-life for bedlinen.

Encouragingly, bedlinen has great potential for extended longevity. This paper outlines some of the specific areas that have opportunity for further research. Nevertheless, efforts to address these opportunities must be supported by systems beyond the individual to enable greater longevity and transformational environmental change.

References

Ahirwar, M., Khatkar, V., & Behera, B. K. (2020). An integrated approach to develop performance index of bed linen fabric. Journal of Industrial Textiles, 51(1_suppl), 842S-855S. https://doi.org/10.1177/1528083720942963

Appadurai, A. (1988). The social life of things: Commodities in cultural perspective. Cambridge University Press.

Ayling-Smith, B. (2018). The Bedsheet: From Linen Cupboard to Art Gallery. TEXTILE, 16(3), 287-300. https://doi.org/10.1080/14759756.2018.1432142

Bakker, C. A., Mugge, R., Boks, C., & Oguchi, M. (2021). Understanding and managing product lifetimes in support of a circular economy. Journal of Cleaner Production, 279, 123764. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123764

Barnard, M. (2014). Fashion theory : an introduction. Routledge.

Chanda, T., Ahirwar, M., & Behera, B. K. (2020). Appraisal of bed linen performance with respect to sleep quality. Textile & Leather Review, 3(1), 19-29. DOI: 10.31881/TLR.2020.01

Chapman, J. (2015). Emotionally durable design : objects, experiences and empathy (Second edition. ed.). London New York : Routledge, Taylor & Francis Group.

Cooper, T. (2020). Slower Cycles: An Essential Characteristic of the Circular Economy. In S. Eisenriegler (Ed.), The Circular Economy in the European Union: An Interim Review (pp. 99-116). Springer International Publishing. https://doi.org/10.1007/978-3-030-50239-3_9

Cotton, L., Hayward, A. S., Lant, N. J., & Blackburn, R. S. (2020). Improved garment longevity and reduced microfibre release are important sustainability benefits of laundering in colder and quicker washing machine cycles. Dyes and Pigments, 177, 108120. https://doi.org/https://doi.org/10.1016/j.dyepig.2019.108120

Douglas, M. (2003). Purity and danger: an anaylsis of concepts of pollution and taboo. London : Rougledge.

Dubale, M., Ejegu, H., Mamuye, W., & Addis, S. (2021). Development of Bed Linen Performance Index. Journal of Engineering, 2021, 1220130. https://doi.org/10.1155/2021/1220130

Gnanapragasam, A., Oguchi, M., Cole, C., & Cooper, T. (2017). Consumer expectations of product lifetimes around the world: a review of global research findings and methods. In (pp. 464-469). https://doi.org/10.3233/978-1-61499-820-4-464

Godin, L., Senja, L., & and Sahakian, M. (2020). Doing laundry in consumption corridors: wellbeing and everyday life. Sustainability: Science, Practice and Policy, 16(1), 99-113. https://doi.org/10.1080/15487733.2020.1785095

Gram-Hanssen, K., & Bech-Danielsen, C. (2004). House, home and identity from a consumption perspective. Housing, Theory and Society, 21(1), 17-26. https://doi.org/10.1080/14036090410025816

Harper, D. (2023). Repair. Etymology Online. Retrieved 1 October from https://www.etymonline.com/word/repair

Healy, R. (2009). Striptease: An investigation of curatorial practices for fashion in the museum

Jensen, P. B., Haase, L. M., & Laursen, L. N. (2021). A Practical Approach to Companies' Transformation toward Product Longevity: A Best-Case Study. Sustainability, 13(23). https://mdpi-res.com/d_attachment/sustainability/sustainability-13-13312/article_deploy/sustainability-13-13312.pdf?version=1638357201

Kamalha, E., Zeng, Y., Mwasiagi, J. I., & Kyatuheire, S. (2013). The comfort dimension; a review of perception in clothing. Journal of Sensory Studies, 28(6), 423-444. DOI: 10.1111/joss.12070

Kergoat, M., Giboreau, A., Nicod, H., Faye, P., Diaz, E., Beetschen, M.-A., & Meyer, T. (2012). CONSUMER PREFERENCE FOR TACTILE SOFTNESS: A QUESTION OF AFFECT INTENSITY? [https://doi.org/10.1111/j.1745-459X.2012.00388.x]. Journal of Sensory Studies, 27(4), 232-246. https://doi.org/https://doi.org/10.1111/j.1745-459X.2012.00388.x

Laitala, K., Boks, C., & Klepp, I. G. (2011). Potential for environmental improvements in laundering. International journal of consumer studies, 35(2), 254-264. https://doi.org/https://doi.org/10.1111/j.1470-6431.2010.00968.x

Lowry, E. (2020). Household textiles 1660-1850: hidden items of material culture from the country house. Family & community history, 23(2), 95-118. https://doi.org/10.1080/14631180.2020.1820717

Maycroft, N. (2024). A culture of visible mending: improvisation, or bodging the job? https://repository.lincoln.ac.uk/articles/conference_contribution/A_culture_of_visible_mending_improvisation_or_bodging_the_job_/25167428

McLaren, A., Oxborrow, L., Cooper, T., Hill, H., & Goworek, H. (2015). Clothing longevity perspectives: exploring consumer expectations, consumption and use. In Product Lifetimes and the Environment (PLATE) Conference proceedings, [Nottingham Trent University], Nottingham, 17-19 June 2015. (pp. 229-235). Nottingham Trent University: CADBE.

Merriam-Webster. (2017). A Tale of Two 'Repairs'. Merriam-Webster. Retrieved 1 October from https://www.merriam-webster.com/wordplay/a-tale-of-two-repairs

Parsons, H. M. (1972). The Bedroom. Human Factors, 14(5), 421-450. https://doi.org/10.1177/001872087201400505

Rao, N., Salvidge, C., Doriza, A., & Downing, P. (2023). Citizen Insights: Estimating the longevity of home textiles in the UK. WRAP. https://wrap.org.uk/resources/report/citizen-insights-estimating-longevity-home-textiles-uk#download-file

Rinkinen, J., Jalas, M., & Shove, E. (2015). Object relations in accounts of everyday life. Sociology, 49(5), 870-885. https://doi.org/10.1177/0038038515577910

Shove, E. (2003). Comfort, cleanliness and convenience : the social organization of normality. BERG.

Shove, E. (2004). Sustainability, System Innovation and the Laundry

System Innovation and the Transition to Sustainability. In. Edward Elgar Publishing. https://doi.org/10.4337/9781845423421.00014

Sleep Hygiene: Good Sleep Habits. (2024). Sleep Health Foundation. https://www.sleephealthfoundation.org.au/sleep-topics/sleep-hygiene-good-sleep-habits

Spelman, E. V. (2002). Repair : the impulse to restore in a fragile world. Beacon Press Boston.

Sundaresan, S., Ramesh, M., Sabitha, V., & Ramesh, V. (2016). A detailed analysis on physical and comfort properties of bed linen woven fabrics. International Journal of advance researn and innovative ideas in education, 2, 1649 to 1658.

Tronto, J. C. (2013). Caring Democracy : Markets, Equality, and Justice. New York University Press. http://ebookcentral.proquest.com/lib/unsw/detail.action?docID=1153346

Walker, S. (1995). The Environment, Product Aesthetics and Surface. Design Issues, 11(3), 15-27. https://doi.org/10.2307/1511767

Yates, L., & Evans, D. (2016). Dirtying Linen: Re-evaluating the sustainability of domestic laundry. Environmental Policy and Governance, 26(2), 101-115. https://doi.org/https://doi.org/10.1002/eet.1704

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Existing barriers to consumer repair of small household appliances from a product design approach: A scoping review

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Keywords: product design; household appliance; repair barriers; consumers.

Abstract: Small Household Appliances (SHA) and their associated electric and electronic waste are a major concern for the EU, which is tackling this problem with an emphasis in repair as a key strategy to prolong product lifetime. The field of product design plays a fundamental role in the configuration of products to enable their future repair. Therefore, this study explores the main barriers that consumers face when trying to repair their household appliances through a literature scoping review focused on small household appliances, from the product design and the repair ecosystem aspects. This study proposes a novel classification at product system level and product-service system level barriers. The first level relates to the physical product and its repairability, while the second relates to the entire system surrounding the product and the repair experience. According to the literature, most relevant repair barriers from the product system level were 'Understanding of product operation' (specially 'Product complexity'), 'Product accessibility' (specially 'Difficult disassembly and reassembly'), 'Impossibility to repair', 'Obsolescence' and 'Safety concerns'. From the product-service system level, the most relevant were 'Economic factors', 'Consumer factors' (specially 'Lack of time'), 'Access to information' and 'Lack of support by OEM'. The discussion section points out that some of these barriers may be downplayed by shifting the mindset of the SHA industry, currently focused on cost reduction, towards quality and repairability. Finally, least mentioned barriers in the literature are worth of attention and shouldn't be forgotten, as they point to possible research gaps.

Introduction

A regulatory framework is being developed to enable sustainable consumption and product design in Europe, with programs such as the new Circular Economy Action Plan, and regulations like the EU 2024/1799 'Right to Repair' Directive, the EU 2024/825 empowering consumers Directive and the EU 2024/1781 Ecodesign for Sustainable Products Regulation (ESPR)). Among other aspects, these regulations are promoting product repair.

Repair as a research topic has received more attention in recent years because it can promote sustainability and as a key principle of the Circular Economy, as it enables longer product lifetimes (Bakker et al., 2014; Jaeger-Erben et al., 2021). However, consumers tend to discard products before their technical end-of-life is reached, meaning repairable products aren't necessarily repaired (Sonego et al., 2022). Repair has been explored under the lenses of economic feasibility, consumer attitude and socioeconomic aspects, policy, product design and environmental benefits (Purkiss et al., 2024; Von Gries & Bringezu, 2022). In this regard, SHA are reported to be less repaired than other types of products (Korsunova et al., 2023; Pérez-Belis et al., 2017) and consumers are less likely to learn skills related to their repair (Lundberg et al., 2024). For that SHA is therefore the main focus of this work.

Product design has been recognised as an important factor influencing consumers' repair behaviour (van den Berge et al., 2023). Although other studies have analysed repair barriers from a product design perspective, this study proposes an original classification that brings together all typologies and ranks them in order of relevance in the scientific literature. The proposed classification of barriers of this study makes a differentiation between 'Product system barriers' and 'Product-service system barriers', based on the Multilevel Design Model (Joore & Brezet, 2015). The former are related to the physical product, its characteristics and design features, while the latter is related to the whole system surrounding the product and the

repair experience: repair businesses, product manufacturers, consumer and economic factors. This can support other researchers to identify research gaps.

Method

Systematic search

A literature review was performed in the Web of Science and Scopus databases, as well as in the Design Research Society (DRS) digital library and the 5th PLATE 2023 proceedings.

In the Scopus and WoS iterative searches using keywords “product design”, “repair”, “consumer”, “user”, “barrier”, “appliances”, “EEE”, “household”, “small”, “vacuum cleaner”, “behaviour”, “self repair” and “repair cafe” in title, abstracts, topic and other search fields, narrowing it down to a time interval between 2016 and 2024. Wildcards and special characters were used to improve search results. The main focus was on articles from the engineering or environmental sciences fields. From the DRS library and the PLATE 2023 conference, just the search terms “product design” and “repair” were used. Articles found in these two sources were screened based on title.

For the second round, *171* articles had been obtained after discarding duplicates. These were screened based on abstracts. This article focuses on repair of SHA, so articles related to mending or furniture were not selected. At first, *60* articles were approved, and *30* more after discussion between all authors. Finally, these *90* studies were screened by reading the text to assess their relevance. ***26*** papers were selected.

Study identification and data extraction

Identified barriers were clustered and coded given their thematic similarities, from Product System barriers and from Product-Service System barriers. Barriers were listed in two tables along with the number of sources in which they are mentioned. Some barriers were also grouped in common categories. For those, the quantity refers to the aggregated number of mentions of the barriers contained in them.

Analysis and findings

A list of found barriers can be seen in Tables 1 and 2. A more extensive table can be found in the Supplementary Materials[1] showing the analysed articles and the mentioned barriers.

Both tables show barriers, in white and green colors. White barriers are grouped under a parent barrier or category, in green. Quantity refers to the number of articles mentioning each barrier. For the category barriers, this quantity is the aggregation of the subordinate barriers.

Found barriers apply to SHA, however, some of them also apply to bigger appliances like fridges, washing machines, etc; as the sources weren’t always focusing only on SHA.

Product system barriers

Consumers can be motivated or discouraged to repair given certain product characteristics, mostly decided at the design stage. These barriers are listed in Table 1.

Product System barriers	Qty.
Understanding of product operation	**17**
- Product Complexity	12
- Difficult diagnosis	8
- Technical knowledge needed	2
- Visibility of components	2
Product accessibility	**14**
- Difficult disassembly and reassembly	11
- Irreversible repair process	4
- Component accessibility	2
Impossibility to repair	**13**
- Product can't be opened	6
- Product can't be repaired (generic)	5

[1] https://docs.google.com/spreadsheets/d/1TVAu4BrMciWwWfAReuN7F36HjZbyphQHNdQlW235hYo/edit?usp=sharing, (accessed April, 2025)

- Integral products	5
- Product designed to be discarded	4
- Digital locks	1
Obsolescence	**12**
- Perceived Obsolescence	7
- Technological Obsolescence	6
- Obsolescence (generic)	3
- Physical Obsolescence	3
Tools required	**12**
- Tools required (generic)	7
- Non-commercial tools required	5
- Special tools required	4
Safety concerns	**10**
Perceived quality of the product	**9**
Type of fasteners	**7**
- Use of permanent fasteners	7
- Use of adhesives	7
- Fragile components and fasteners	3

Table 1: Repair related product system barriers found in the literature and number of mentions.

Understanding of product operation

Understanding the product is critical to a successful repair. 'Product complexity' is a major barrier. Consumers would repair simple products but are reluctant to repair electrical appliances (Korsunova et al., 2023). This barrier is also linked to 'Difficult diagnosis', as simple products are easier to diagnose (Hjorth Nielsen et al., 2023). SHA have fewer parts and are usually limited to a single function, making them easier to understand. Fault diagnosis is important because understanding the product failure could motivate consumers to repair (van den Berge et al., 2023). Moreover, 'Technical knowledge needed' to operate certain tools or to understand the product, and 'Visibility of components' are important in assessing product failures and their repairability (Hjorth Nielsen et al., 2023). Component visibility also affects the ability to disassemble the product or to access critical components (Flipsen et al., 2016).

Product accessibility

Accessible products are easier to repair (Blanco-Espeleta et al., 2024). Repair operations are complicated by 'Difficult disassembly and reassembly (Pozo Arcos et al., 2021). An 'Irreversible repair process' reduces consumer confidence and may discourage them from repairing (Bracquené et al., 2021). Bad 'Component accessibility' refers to tightly packed components, which are typically found in SHA due to the limited space available. Other cases are disorganised product architectures, hidden fasteners or long disassembly sequences to access a single component. (Boix Rodríguez & Favi, 2022; Bracquené et al., 2021).

Impossibility to repair

Some articles mention product repair difficulties related to its design, that's the 'Product can't be repaired (generic)' barrier (Laitala et al., 2021). More specific cases are when products 'Can't be opened', given consumer's tools or skills (Pozo Arcos et al., 2021; Rudolf et al., 2022). 'Integral products', where the product has complex, integrated electronics or encapsulated or confined components (Bracquené et al., 2021; Pozo Arcos et al., 2020) which impede component interchangeability and fault diagnosis. Moreover, products 'Designed to be discarded' (Sonego et al., 2022; van den Berge et al., 2023), which is essentially the main reason behind most barriers, as the focus of SHA design is on cost reduction rather than repairability. In contrast, larger appliances are designed to be repairable by technical support because users expect them to be repaired rather than replaced. Finally, there's the use of 'Digital locks', software, encryption, licenses, supported by legal mechanisms, to impede independent repair (Roskladka et al., 2023).

Obsolescence

Mentions of obsolescence without further details are coded as the 'Obsolescence (generic)' barrier (Hertzum, 2024). Cooper (2004) divides obsolescence into: "absolute obsolescence" and "relative obsolescence", which includes "technological", "economic" and "psychological obsolescence". In this article,

obsolescence barriers have been subdivided in three: 'Physical obsolescence', when the product fails for physical damage or is worn out (Russell et al., 2023), 'Technological obsolescence', when the product software is too demanding for its hardware, new products in the market have superior functions and old products can't be updated (Amend et al., 2022; Roskladka et al., 2023), and 'Perceived obsolescence': psychological and social factors making consumers perceive a product as outdated, not trendy or just too old (Amend et al., 2022; Jensen et al., 2021). SHA are more prone to psychological obsolescence as users don't form strong attachments.

Safety concerns

When consumers are faced with the decision to repair, previous experience is positive (Sandez et al., 2023). However, skills and knowledge about repair are declining and consumers see it as a dangerous activity, even more if products are electric or electronic (Lefebvre et al., 2018), making SHA specially affected by this barrier. Other design aspects can make repair hazardous, such as sharp edges (van den Berge et al., 2023).

Perceived quality of the product

This barrier is different from 'Perceived obsolescence' because a newly purchased product can break, and consumers decide not to repair because they see it as cheap, low quality and not worth repairing, rather than because it is obsolete. Usually, price is seen as a factor of quality (Laitala et al., 2021). SHA have more affordable prices and are thus considered easier to replace than to repair, in terms of time and cost (Sonego et al., 2022). Even repair services can advise consumers of this practice (Lefebvre et al., 2018). Material quality can also decrease consumers' intention to repair when time passes (Jensen et al., 2021).

Tools required

Repair gets more complicated when there are 'Special tools required', like soldering equipment or digital multimeters (Hjorth Nielsen et al., 2023). 'Non-commercial tools required' refers to the use of tools such as screwdrivers with special shapes that are uncommon in the average household. (Flipsen et al., 2016). Sometimes this is done to prevent self-repair for safety reasons.

Type of fasteners

Fasteners are recognised as a key aspect of repairability, being usually an indicator in different repairability assessment methods, such as EN 4554 and RSS (Dangal et al., 2022). The 'Use of permanent fasteners' such as welding make it difficult to disassemble the product (Boix Rodríguez & Favi, 2023; Roskladka et al., 2023). 'Use of adhesives', while being a type of permanent fastener, has been considered an independent barrier given its recurrency in the literature and its relevance. Adhesives are very difficult to remove, requiring great effort and special tools like heat guns (Dangal et al., 2022; Flipsen et al., 2016). They're usually used when the product is small and there's limited room for other fasteners. Finally, 'Fragile components and fasteners' are used (Roskladka et al., 2023). For example, some SHA enclosures tend to use fragile snap-fits to avoid screws for aesthetic reasons.

Product-service system barriers

A variety of stakeholders and factors outside of the physical product generate a repair ecosystem. Barriers outside the 'Product System' level form a 'Product-Service System' level, and are listed in Table 2.

Product-Service System barriers	Qty.
Economic factors	**17**
- Price of repair VS price of a new product	8
- Price of repair service	7
- Product is out of warranty	5
- Economic factors (generic)	4
- Price of spare parts	4
Consumer factors	**17**
- Lack of time	13
- Lack of ability	10
- Having a physical space to repair	1
Access to information	**15**
- Access to information (generic)	13

- Lack of relevant repair information in the manuals	3
- Not knowing where to take the product to repair	2
- Lack of publicly available repair information	1
Lack of support by Original Equipment Manufacturers (OEM)	**12**
- Access to spare parts by the product user	5
- Lack of repair alternatives (generic)	5
- Access to spare parts (generic)	4
- Lack of independent repair services	3
- Access to spare parts by independent services	2
- Poor customer service	1
Mistrust	**9**
- Mistrust in repair services	6
- Mistrust in repair quality	6
Legal barriers	**3**

Table 2: Repair related product-service system barriers found in the literature and number of mentions.

Economic factors

Economic factors are especially relevant. Some specific barriers found are 'Price of spare parts', 'Price of repair service' (Lundberg et al., 2024) or not repairing because the 'Product is out of warranty' (Russell et al., 2023), while some articles discuss the "price of repair" but don't elaborate, that's the 'Economic factors (generic)' barrier (Hertzum, 2024). However, the most common decision consumers face when considering repair is 'Price of repair VS price of a new product' (Sandez et al., 2023). Around 20% of the original product price is a common limit (Rudolf et al., 2022). In the market for SHA, this barrier is exacerbated as these product's prices tend to be very adjusted, and there are less "premium products" which are seen as worth repairing. Results from Pérez-Belis et al. (2017) indicate consumers aren't willing to pay more than 20€ for electric kettles.

Consumer factors

'Lack of time' refers to the capacity of consumers to invest their own time repairing by themselves, gathering information or living without their product while it is being repaired. (Huang et al., 2016). Secondly, 'Lack of ability' is when consumers don't have the skills for repairing themselves (Lundberg et al., 2024). When common SHA are cheaply replaced, users aren't incentivised to waste their time and effort on repairs. Finally, 'Having a physical space to repair' barrier is only mentioned once (Flipsen et al., 2016).

Access to information

The associated inconvenience with repair starts with the consumer collecting information about the product and how to repair it, where to take it, and other aspects (Blanco-Espeleta et al., 2024). User manuals are relevant to install a product, use it for the first time or carry out maintenance operations, but it's uncommon to have useful repair information in them OEMs argue this is due to security issues, but common, safe and simple repairs could be explained in manuals (Pozo Arcos et al., 2023). Consumers also face 'Not knowing where to take the product to repair' (Sonego et al., 2022) and 'Lack of publicly available repair information' about a specific product in public sources like OEMs' web page or internet forums (Russell et al., 2023).

Lack of support by OEM

Involvement of OEM is crucial for repair. 'Access to spare parts', be it in a generic way, for the product user or for independent repair services is a recurrent barrier directly related to the willingness of the OEM to provide these (Blanco-Espeleta et al., 2024; Terzioğlu, 2021). 'Lack of independent repair services' limits consumers' repair capacity and is influenced by OEMs when they take legal action against third party repairers or limit the number of authorised repairers (Roskladka et al., 2023). 'Lack of repair services (generic)' doesn't specify what kind of services (Laitala et al., 2021) . Finally, consumers find repair inconvenient when OEMs provide 'Poor customer service' (Lefebvre et al., 2018).

Mistrust

There are two types of mistrust. 'Mistrust in repair service', dealing with the relationship between repair businesses and consumers, who often point at a lack of transparency, (Sonego et al., 2022). 'Mistrust in repair quality' is when consumers don't trust the services to do a good job (Fachbach et al., 2022) or the product to keep working in good condition after a repair (Roskladka et al., 2023). Closely related to the economic factors, consumers won't waste money on a repair that may fail when they can just buy a new product at a lower price.

Legal barriers

There are different legal mechanisms which aren't necessarily made with the intention of difficulting repair operations, but can limit independent service and consumers capacities. Legal instruments like intellectual property, contracts, unauthorizing independent repair businesses, consumer laws, tax laws, and chemical laws (Russell et al., 2023; Sonego et al., 2022).

Discussion and conclusion

A scoping review of 26 articles has been made, giving out 56 barriers related to repair of small household appliances. Barriers were identified in the literature and clustered according to their thematic similarities. The interdependencies between barriers sometimes made clustering challenging because barriers were difficult to separate.

From the product system level, the most relevant barriers were 'Understanding of product operation' (specially 'Product complexity'), 'Product accessibility' (specially 'Difficult disassembly and reassembly'), 'Impossibility to repair', 'Obsolescence' and 'Safety concerns'. From the product-service system level, the most relevant were 'Economic factors', 'Consumer factors' (specially 'Lack of time'), 'Access to information' and 'Lack of support by OEM'.

Having analysed the various barriers, it's clear that several of them stem from a product design culture focused on reducing production costs, where repairability is not considered. This trend, present in many industries, is exacerbated in the SHA market where products are seen as 'workhorses' and expected to be low cost and easily replaceable. This shift in focus would mean the end of the 'impossibility to repair' barriers.

Designers could elevate the SHA product category, making it more influential and meaningful in the creation of the user's identity, which in turn would increase the consumer's attachment to products and therefore their willingness to repair them. Obsolescence in its various forms would reduce its prominence in SHA products. Moreover, moving design towards repairability can open up new ways of approaching the consumer's relationship with products. This means getting the user more involved in the care and maintenance of the product and becoming more aware of waste.

Although some OEMs resist repair movements in order to maintain a model based on the sale of new products, increased consumer involvement and support for repair could lead to greater consumer satisfaction and brand loyalty. Greater OEM repair support and increasing access to product information can reduce understanding of product operation and product accessibility related barriers.

Adopting these measures would mean reducing the large number of poor quality products on the market and increasing consumer interest in product repair, with the associated waste reduction and environmental benefits. The redesign of products for repairability wouldn't be constrained by extremely tight cost margins, as consumers would be willing to pay more for higher quality and more durable products.

This study can serve as a design checklist for future SHA redesigns to remove some of the barriers to the repairability of this type of product.

Future research could find policy and product design solutions in the literature and point out relationships with the barriers found in this article. Further research could validate the effectiveness of design solutions to overcome different repair barriers through prototyping, user testing and workshops.

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References

Amend, C., Revellio, F., Tenner, I., & Schaltegger, S. (2022). The potential of modular product design on repair behavior and user experience – Evidence from the smartphone industry. Journal of Cleaner Production, 367, 132770. https://doi.org/10.1016/j.jclepro.2022.132770

Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: Exploring product life extension through design. Journal of Cleaner Production, 69, 10-16. https://doi.org/10.1016/j.jclepro.2014.01.028

Blanco-Espeleta, E., Pérez-Belis, V., & Bovea, M. D. (2024). Repair index of energy-related products: Application to capsule coffee machines. Sustainable Production and Consumption, 46, 146-160. https://doi.org/10.1016/j.spc.2024.02.011

Boix Rodríguez, N., & Favi, C. (2022). Disassembly Analysis of Gas Cooktops: Towards Eco-Design Rules for Product Repairability. Volume 5: 27th Design for Manufacturing and the Life Cycle Conference (DFMLC), V005T05A017. https://doi.org/10.1115/DETC2022-89860

Boix Rodríguez, N., & Favi, C. (2023). De-manufacturing Analysis for Product Repairability and Serviceability in Cooking Systems. En F. G. Galizia & M. Bortolini (Eds.), Production Processes and Product Evolution in the Age of Disruption (pp. 452-460). Springer International Publishing. https://doi.org/10.1007/978-3-031-34821-1_49

Bracquené, E., Peeters, J., Alfieri, F., Sanfélix, J., Duflou, J., Dewulf, W., & Cordella, M. (2021). Analysis of evaluation systems for product repairability: A case study for washing machines. Journal of Cleaner Production, 281, 125122. https://doi.org/10.1016/j.jclepro.2020.125122

Cooper, T. (2004). Inadequate Life?Evidence of Consumer Attitudes to Product Obsolescence. Journal of Consumer Policy, 27(4), 421-449. https://doi.org/10.1007/s10603-004-2284-6

Dangal, S., Faludi, J., & Balkenende, R. (2022). Design Aspects in Repairability Scoring Systems: Comparing Their Objectivity and Completeness. Sustainability, 14(14), 8634. https://doi.org/10.3390/su14148634

Fachbach, I., Lechner, G., & Reimann, M. (2022). Drivers of the consumers' intention to use repair services, repair networks and to self-repair. Journal of Cleaner Production, 346, 130969. https://doi.org/10.1016/j.jclepro.2022.130969

Flipsen, B., Bakker, C., & Van Bohemen, G. (2016). Developing a reparability indicator for electronic products. 2016 Electronics Goes Green 2016+ (EGG), 1-9. https://doi.org/10.1109/EGG.2016.7829855

Hertzum, M. (2024). Sustainability and Home Automation: The Case of Repairing or Replacing Vacuum Cleaners. En A. Bramwell-Dicks, A. Evans, M. Winckler, H. Petrie, & J. Abdelnour-Nocera (Eds.), Design for Equality and Justice (Vol. 14535, pp. 340-347). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-61688-4_33

Hjorth Nielsen, A. S. A., Laursen, L. N., & Tollestrup, C. (2023). Can you fix it? An investigation of critical repair steps and barriers across product types. PROCEEDINGS 5th PLATE Conference, 409-416.

Huang, J., Esmaeilian, B., & Behdad, S. (2016). Design for Ease-of-Repair: Insights From Consumers' Repair Experiences. Volume 4: 21st Design for Manufacturing and the Life Cycle Conference; 10th International Conference on Micro- and Nanosystems, V004T05A017. https://doi.org/10.1115/DETC2016-59685

Jaeger-Erben, M., Frick, V., & Hipp, T. (2021). Why do users (not) repair their devices? A study of the predictors of repair practices. Journal of Cleaner Production, 286, 125382. https://doi.org/10.1016/j.jclepro.2020.125382

Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021). Barriers to product longevity: A review of business, product development and user perspectives. Journal of Cleaner Production, 313, 127951. https://doi.org/10.1016/j.jclepro.2021.127951

Joore, P., & Brezet, H. (2015). A Multilevel Design Model: The mutual relationship between product-service system development and societal change processes. Journal of Cleaner Production, 97, 92-105. https://doi.org/10.1016/j.jclepro.2014.06.043

Korsunova, A., Heiskanen, E., & Vainio, A. (2023). Consumer decision-making on repair in a circular economy: A process model based on experiences among young adults and stakeholders in Finland. Journal of Cleaner Production, 405, 137052. https://doi.org/10.1016/j.jclepro.2023.137052

Laitala, K., Klepp, I. G., Haugrønning, V., Throne-Holst, H., & Strandbakken, P. (2021). Increasing repair of household appliances, mobile phones and clothing: Experiences from consumers and the repair industry.

Journal of Cleaner Production, 282, 125349. https://doi.org/10.1016/j.jclepro.2020.125349

Lefebvre, M., Lofthouse, V., & Wilson, G. (2018, junio 28). Towards a Circular Economy: Exploring factors to repair broken electrical and electronics products by users with pro-environmental inclination. Design Research Society Conference 2018. https://doi.org/10.21606/drs.2018.556

Lundberg, P., Vainio, A., Viholainen, N., & Korsunova, A. (2024). Consumers and self-repair: What do they repair, what skills do they have and what are they willing to learn? Resources, Conservation and Recycling, 206, 107647. https://doi.org/10.1016/j.resconrec.2024.107647

Pérez-Belis, V., Braulio-Gonzalo, M., Juan, P., & Bovea, M. D. (2017). Consumer attitude towards the repair and the second-hand purchase of small household electrical and electronic equipment. A Spanish case study. Journal of Cleaner Production, 158, 261-275. https://doi.org/10.1016/j.jclepro.2017.04.143

Pozo Arcos, B., Bakker, C., & Balkenende, R. (2023). How User Manuals Support the Diagnosis of Common Faults in Household Appliances: An Analysis of 150 Manuals. Circular Economy and Sustainability, 3(1), 535-555. https://doi.org/10.1007/s43615-022-00195-5

Pozo Arcos, B., Bakker, C., Flipsen, B., & Balkenende, R. (2020). Practices of fault diagnosis in household appliances: Insights for design. Journal of Cleaner Production, 265, 121812. https://doi.org/10.1016/j.jclepro.2020.121812

Pozo Arcos, B., Dangal, S., Bakker, C., Faludi, J., & Balkenende, R. (2021). Faults in consumer products are difficult to diagnose, and design is to blame: A user observation study. Journal of Cleaner Production, 319, 128741. https://doi.org/10.1016/j.jclepro.2021.128741

Purkiss, D., Pencheva, P., Munro, B., & Miodownik, M. (2024). A systems approach to growing the UK electronics and appliance repair economy. Frontiers in Sustainability, 5, 1432655. https://doi.org/10.3389/frsus.2024.1432655

Roskladka, N., Jaegler, A., & Miragliotta, G. (2023). From "right to repair" to "willingness to repair": Exploring consumer's perspective to product lifecycle extension. Journal of Cleaner Production, 432, 139705. https://doi.org/10.1016/j.jclepro.2023.139705

Rudolf, S., Blömeke, S., Niemeyer, J. F., Lawrenz, S., Sharma, P., Hemminghaus, S., Mennenga, M., Schmidt, K., Rausch, A., Spengler, T. S., & Herrmann, C. (2022). Extending the Life Cycle of EEE—Findings from a Repair Study in Germany: Repair Challenges and Recommendations for Action. Sustainability, 14(5), 2993. https://doi.org/10.3390/su14052993

Russell, J. D., Svensson-Hoglund, S., Richter, J. L., Dalhammar, C., & Milios, L. (2023). A matter of timing: System requirements for repair and their temporal dimensions. Journal of Industrial Ecology, 27(3), 845-855. https://doi.org/10.1111/jiec.13280

Sandez, S., Pérez-Belis, V., Juan, P., & Bovea, M. D. (2023). Do users have the ability to self-repair non-complex electrical appliances? Design and development of a self-guided workshop with repair documentation in different formats. Sustainable Production and Consumption, 39, 244-256. https://doi.org/10.1016/j.spc.2023.05.007

Sonego, M., Echeveste, M. E. S., & Debarba, H. G. (2022). Repair of electronic products: Consumer practices and institutional initiatives. Sustainable Production and Consumption, 30, 556-565. https://doi.org/10.1016/j.spc.2021.12.031

Terzioğlu, N. (2021). Repair motivation and barriers model: Investigating user perspectives related to product repair towards a circular economy. Journal of Cleaner Production, 289, 125644. https://doi.org/10.1016/j.jclepro.2020.125644

van den Berge, R., Magnier, L., & Mugge, R. (2023). Sparking the repair "can-co" attitude: Enhancing users' willingness to repair through design support in fault diagnostics. https://doi.org/10.57698/V17I3.02

Von Gries, N., & Bringezu, S. (2022). Using New Spare Parts for Repair of Waste Electrical and Electronic Equipment? The Material Footprint of Individual Components. Resources, 11(2), 24. https://doi.org/10.3390/resources11020024

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Is This the End? - Lifetime of Electrical and Electronic Equipment

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Keywords: E-waste; Product Lifetime; Waste Management; Obsolescence; Sustainable Design.

Abstract: The rapid advancement of technology, coupled with global digitalisation and the growing demand for innovative consumer electronics, has led to a dramatic increase in the production and consumption of electrical and electronic equipment (EEE). This trend has raised significant concerns regarding the sustainability of EEE usage, particularly in terms of their obsolescence, disposal, and environmental impact. Addressing these concerns, this study surveyed 600 undergraduate students, who reported on 14 different types of EEE, to explore the reasons for obsolescence (RQ1), the most common methods of managing obsolete devices based on their types (RQ2), and students' awareness of alternative waste management methods (RQ3). Results were reported using frequencies and percentages. Findings reveal that obsolescence is mainly driven by "broken beyond repair," "worn-out technology," "outdated technology," and "lack of required functions," indicating that absolute and technical obsolescence are the primary factors. The most common way of dealing with obsolete devices is to "keep it" across all device types, with "throwing away" emerging as another frequent method for electrical devices. More than half of the students are aware of accessible alternatives, such as "online sales" and "charity donations," though irregular or infrequent options tend to have lower awareness levels. This study highlights the behavioural trends and gaps in awareness among students regarding EEE obsolescence and disposal, emphasising the importance of promoting sustainable practices and raising awareness about accessible waste management alternatives.

Introduction

The rapid advancement of technology and global digitalisation has led to a significant increase in the use of electrical and electronic equipment (EEE). While the diversity of electronic devices and their widespread use have brought numerous benefits and conveniences, it has also given rise to a pressing issue: e-waste. The European Commission defines Waste Electrical and Electronic Equipment (WEEE) as one of the fastest-growing waste types in the world (Romagnoli et al., 2022). Industrialisation, urbanisation, and higher disposable income are the primary triggers of the EEE industry and e-waste (Forti et al., 2020). Moreover, higher consumption rates, short life cycles of EEE, and limited repair alternatives for broken EEE are some facilitators of e-waste generation, as illustrated in Figure 1 (Forti et al., 2020).

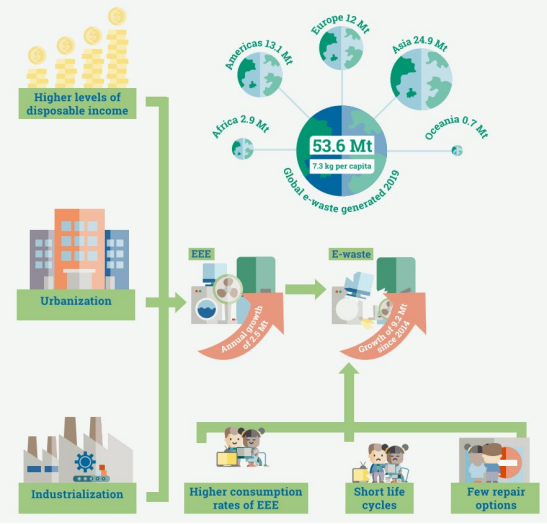


Figure 1. Overview of e-waste. © Forti et al., 2020.

Macleod, categorises the product life cycle as a holistic experience in three phases: on-boarding, usage and off-boarding, and emphasises that off-boarding is the most neglected phase of the service/product lifecycle (Macleod, 2017). This shows that most industry stakeholders reduce their engagement during the off-boarding phase. Users can become confused about the action they are supposed to

take when a product does not work as promised in advertisements or within the user manual.

This study draws on the findings of an online survey of 600 UK undergraduate students to investigate the reasons for obsolescence in electrical and electronic devices (research question 1 -RQ1-) with an aim to identify the most common methods of dealing with obsolete devices based on their types (research question 2 -RQ2-). Additionally, it explores the awareness levels of undergraduate students regarding alternative ways to manage electronic waste (research question 3 -RQ3-).

Obsolescence

Obsolescence is defined under varying categories in the literature. For example, van Nes et al. (1999), in their pioneering study systematically defined six obsolescence categories: technical, economic, ecological, aesthetic, feature and psychological obsolescence. In addition, Cooper (2004) defined absolute obsolescence as "needs to be distinguished from that arising from product failure". Cooper (2004) also explains obsolescence under three categories: psychological, economic, and technological and mentions absolute obsolescence.
Moreover, (Burns, 2016) drew attention to societal obsolescence by considering the impact of social norms on human behaviour. They also mention technological obsolescence is the most consistently occurring type of obsolescence due to rapid technological developments (Burns, 2016). More recently, Wilson et al. (2017) categorised obsolescence as absolute, functional, aesthetic, economic, technological, ecological, psychological, and societal by synthesising the existing literature (summarised above) according to their comprehensive literature review in their study focusing on hibernating mobile phones.

Alternative scenarios for end-of-lifetime of EEE

Vezzoli (2018) defines product life cycle processes with the following stages: pre-production, production, distribution, use, and disposal. King et al., (2006) explain that consideration of whole lifecycle from raw materials to final disposal is a way to achieve a closed loop design. They have created a timeline from new material to waste material and defined the stages as processing, assembly and sell and use.

Vezzoli (2018) also creates a product-system life cycle with a systemic approach by including chemical and physical inputs and outputs. Various user related terms, such as reuse and recycle, can be seen in this figuration even if it is not indicated in that way. It is important to evaluate product life cycle by considering user behaviour as it has a significant potential to extend product lifetime and reshape end of lifetime scenarios.

Methodology

Undergraduate students at Loughborough University's Loughborough campus were selected for purposive sampling for the study. The questionnaire was circulated online, and 600 responses were received between October and November 2023.
The devices included in the scope of the study are listed in Figure 2, along with their pictograms. The pictograms are introduced here to prevent confusion when used in data visualisations in the figures of the results section. In addition to the mentioned devices, an option for "other" was also included to determine whether there is a type of device common in the sampling group but not covered in the scope of the study.



Figure 2: Devices included in the scope with related pictograms

Questions were created that asked about current devices, obsolete devices, obsolescence reasons, and awareness of alternative ways to get rid of obsolete devices using a multiple selection format. Questions about actions taken with obsolete devices were in a multiple-choice format. The investigation of obsolescence reasons and actions taken with obsolete devices were repeated for each selected obsolete device. Thus, it was possible to get results for all devices separately.

Questions regarding obsolescence reasons and associated actions taken with obsolete devices were adapted from Wilson et al., (2017). Some obsolescence reasons from their study were excluded or altered to tailor choices to the scope of this study, as their study only focused on mobile phones.
Initially, the clarity of the questionnaire was tested with four participants, and later further clarified with two additional participants, to ensure comprehension.
The participant profiles, current and obsolete devices were reported using frequencies and percentages, providing insights into ownership and obsolescence trends. Obsolescence reasons and actions taken with obsolete devices were summarised similarly. Low-response reasons were deemed insignificant, while the most frequent reasons (higher than 30%) were highlighted for enhanced data visualisation using figures.
Line graphs were created to illustrate patterns of awareness for alternative ways to deal with e-waste, whilst further enhancing the understanding of e-waste disposal behaviours among participants.

Results

The majority of respondents (more than 80%) consisted of home students. This aligns with the ratio of home to international students at Loughborough University as stated in their statistics (Loughborough University, 2023). As such, the results of this study can be reliably utilised to represent the undergraduate student population at Loughborough University. 600 respondents reported 4,444 devices they currently own and use, corresponding to an average of 7.4 devices per person.
Table 1 provides insights into the current ownership and obsolescence rates of various electronic devices, establishing their ownership frequency and usage patterns. Mobile phones are the most prevalent among the listed devices, with 600 responses indicating current ownership. However, a significant portion of respondents (459) have at least one obsolete mobile phone. This data might refer to respondents' rapid turnover or replacement cycle for mobile phones while considering the age range of undergraduate students. Respondents specified devices, such as Bluetooth speakers, cameras, and battery chargers under the “other” option, but the response frequencies were not high enough to include them within the analysis.

Device	Current	Obsolete
Mobile phone	600	459
Headphone	593	308
Laptop / MacBook	579	293
Screen / TV	344	92
Tablets	331	226
Electric toothbrush	331	122
Hair styling appliance	321	86
Game console	270	168
Smartwatch	256	86
Personal grooming devices	224	56
Smart speaker	221	47
Desktop computer	154	63
Electrical beauty devices	102	23
E-book reader	101	69
Other	17	9

Table 1. Number of participants with current and obsolete devices.

Obsolescence Reasons

'Broken beyond repair' was the most frequently selected reason for the obsolescence of wearable electronic devices, with 30% of smartwatches and 57% of headphones. This trend was also observed in the results for hair styling appliances (49%), electric toothbrushes (41%), electrical beauty devices (35%)’ and personal grooming devices (33%) (Figure 3).

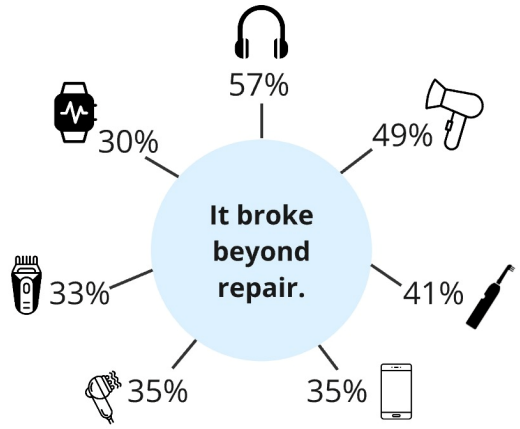


Figure 3. Obsolescence reason: It broke beyond repair.

Technological wear was cited as a reason for obsolescence for 55% of mobile phones, 52% of laptops, and 47% of tablets (Figure 4).

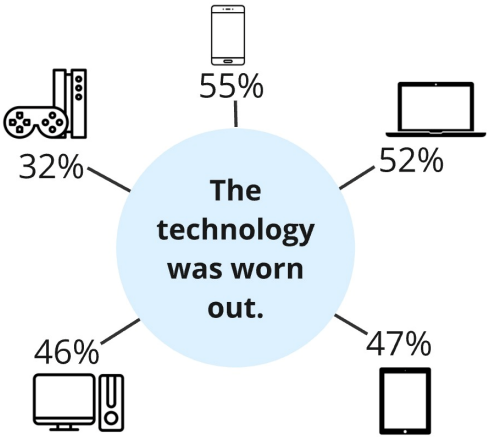


Figure 4. Obsolescence reason: The technology was worn out.

Outdated technology was identified as a factor for 50% of mobile phones, 45% of laptops, and 40% of tablets (Figure 5).

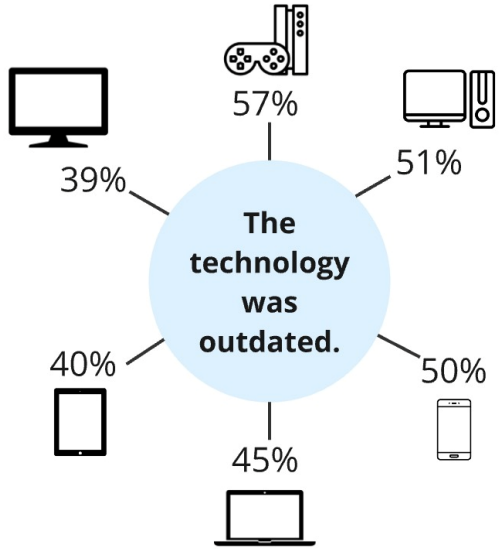


Figure 5. Obsolescence reason: The technology was outdated.

"It no longer had the specific function I required" was another popular answer for laptops, smart speakers and e-book readers, with more than 30% of responses (Figure 6).

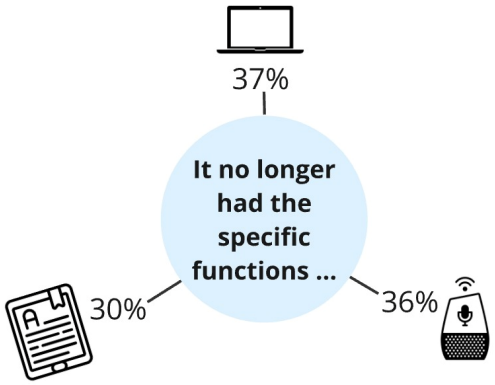


Figure 6. Obsolescence reason: It no longer had the specific functions I required.

Actions Taken with Obsolete Devices

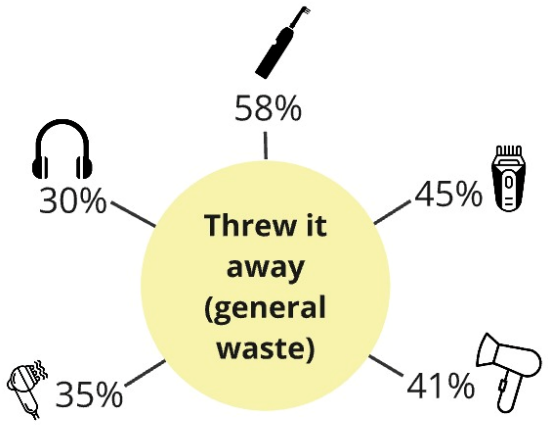


Figure 7. Actions taken: Threw away.

According to the responses, the most common way to deal with obsolete electronic devices (mobile phones, laptops, tablets, e-book readers, desktop computers, screens/TVs, game consoles, smartwatches, smart speakers, headphones) appeared to be keeping hold of them, whilst, for electrical devices (hair styling appliances, electric toothbrushes, personal grooming devices and electrical beauty devices), it seemed that throwing them away was a more common route for disposal (Figure 7, Figure 8).

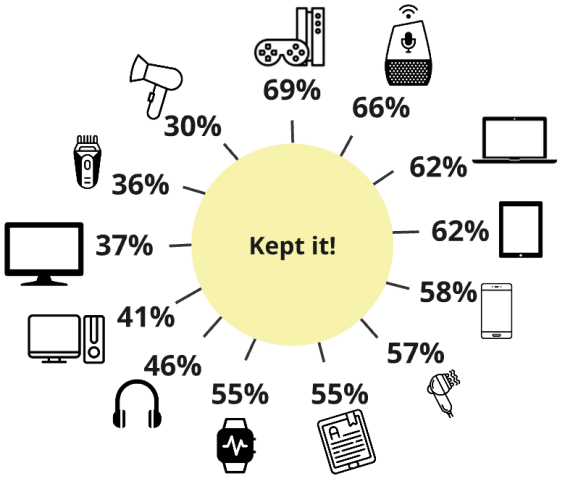


Figure 8. Actions taken: Kept it.

Awareness of Current Alternatives

Alternative ways to deal with an obsolete electrical or electronic device were listed by considering the living area of the sample group. In addition to all common alternatives, Give n Go is an alternative offered by the university that allows on-campus resident students to get rid of their electrical and electronic devices at the end of semesters. All alternative ways were captured in the questionnaire by adding an option for "other". Respondents were asked to select "none" if they were unaware of any alternatives. The number of students that selected an alternative is listed in Figure 9.

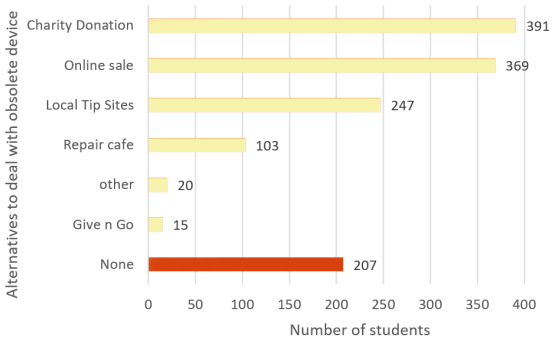


Figure 9. Awareness of alternative ways to deal with obsolete devices.

Even if charity donations and online sales were acknowledged by more than half of the respondents, when they were asked about their actions taken with obsolete devices, it was identified that these alternative ways were not utilised for their own obsolete devices.

Discussion

Most of the research investigating e-waste focuses on general awareness (Adanu et al., 2020; Miner et al., 2020; Mor et al., 2021) or just a single electronic device, specifically mobile phones (Huang & Truong, 2008; Jang & Kim, 2010; Ongondo & Williams, 2011; Wilson et al., 2017; Ylä-Mella et al., 2015). Apart from mobile phones, there is a noticeable gap in the literature regarding the understanding of users' behaviour, especially within device-specific research.

Absolute obsolescence refers to a product's physical failure (Cooper, 2004) which has been integrated in the related question's choices as "It broke beyond repair" and "The technology is worn out". These two appear as the most common reasons for obsolescence.

"The technology was outdated." represented technological obsolescence as inferior to newer products in a way that affected the results (Burns, 2016; Van Nes et al., 1999).

Lastly, the lack of specific functions means that the product is incapable of fulfilling the user's functional requirements, which is referred to as functional obsolescence by Cooper (2004).

Actions taken with obsolete devices have been illustrated with related sustainability terms on Table 2.

	Related terms
Kept it	Hibernation, repurpose
Recycled it	Recycle
Traded it in for a new one.	Repair, Refurbish
N/A	N/A
Gifted it	Reuse, Repurpose
Threw it away (general waste)	N/A
Gave it to a charity	Repair, Reuse
Sold it on Marketplace or another second-hand selling platform/app	Reuse, Repair
Other	N/A

Table 2. Actions taken with obsolete devices and related terms.

Various possible actions were given as an option in the multiple-choice question for each obsolete device. All possible actions were evaluated based on their association with life cycle assessment alternatives.
"Kept it" meant that the device is no longer used for its primary purpose; it is in hibernation or in use for a small task (e.g. using an old phone as an alarm clock).
"Gifted it", in the context of this questionnaire, meant that the mentioned device was given to someone with no financial return to keep the device in use and fulfil someone else's needs.
"Gave it to a charity" represents giving an obsolete electronic device to a charity. This option was considered in two ways: the charity gives the electronic device to someone who needs it, or the charity facilitates the repair/recycling of the electronic device (Guo & Xu, 2021).
Kiddee et al. (2013) explained the health and environmental risks of recycling and disposal of electronic devices by referencing studies on the levels of hazardous substances exposed to people living near areas where e-waste is recycled. Accordingly, giving obsolete devices to a charity can be categorised as related to recycling and partly related to environmental risk. Similarly, "recycled it" is related to recycling and partly to environmental risk. Additionally, in the case of giving the electronic device to someone who needs it, it is categorised as partly related to reuse.
"Threw it away" was evaluated as the most environmentally damaging way to deal with obsolete devices because of their high potential to pollute the environment (Kiddee et al., 2013).
While considering the perspectives of various companies, “trade in”, in the context of this questionnaire, was seen to consist of two potential processes: repairing (refurbishing) or recycling (Curvelo Santana et al., 2021). For this reason, "Traded it in for a new one" was related to repairing and refurbishing the device.
The finding regarding students’ awareness of alternatives to deal with e-waste points to potential gaps in students’ knowledge or their accessibility to e-waste options that could be addressed through targeted awareness campaigns, but this required further investigation for justification.

All the terms mentioned above from the literature related to actions taken with obsolete devices were illustrated with actions and the product life cycle process (Figure 10). Product life cycle terms were adapted from Vezzoli, (2018) and illustrated in grey rectangles, related terms were written in white rectangles and actions taken with obsolete devices visualised in green circles.

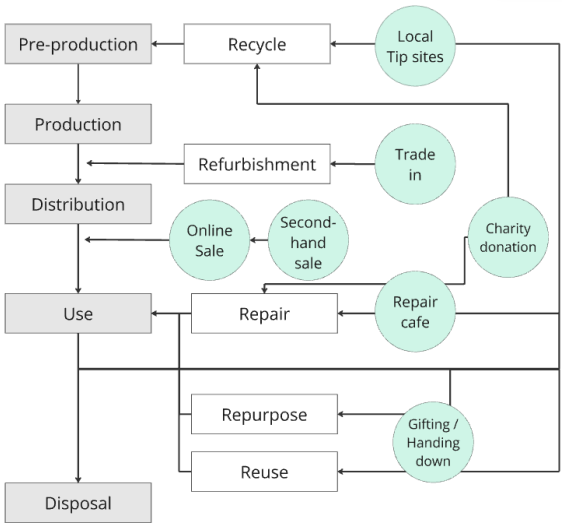


Figure 10. Initial model of user actions affecting product life cycle.

Conclusions

This study provided answers to the three research questions defined in the introduction.
RQ1: The most common reasons for obsolescence are broken beyond repair, worn-out technology (incapable of running the main required functions), outdated technology (has fallen behind the latest technology), and lack of function that the user requires. It shows that

absolute and technical obsolescence are the main reasons why people stop using electrical and electronic devices.
RQ2: This study found the most common methods of dealing with obsolete devices based on their types as “kept it” for all types of devices, but for electrical devices (including headphones), throwing away is another common alternative.
RQ3: The study determined that more than half of the students are aware of alternative ways, which are available at any time, to deal with obsolete electrical and electronic devices, even if they are not preferred, such as online sales and charity donations. On the other hand, irregular or non-frequent alternatives, such as repair cafés or “give n go” currently are not desirable alternatives. This shows that accessibility and frequency are variables that affect awareness of alternative ways to deal with obsolete electrical and electronic devices.

Further studies

A literature-based approach could examine the environmental impact of different disposal actions to understand the relative sustainability of various choices better. Additionally, follow-up studies could investigate the motivations and barriers that influence students' decisions to keep or dispose of their obsolete devices, and potential drivers that could encourage more sustainable actions. There is also an opportunity to investigate students' perceptions of responsibility for e-waste and to explore why some disposal options, like repair cafés or campus Give 'n' Go initiatives, remain underutilised. Understanding these behaviours and perspectives in greater detail will support the development of strategies that encourage more environmentally responsible e-waste management practices among the student population.

Acknowledgments

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References

Adanu, S. K., Gbedemah, S. F., & Attah, M. K. (2020). Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie, Ghana. *Heliyon*, *6*(8). https://doi.org/10.1016/j.heliyon.2020.e04548

Burns, B. (2016). Re-evaluating Obsolescence and Planning for It. In T. Cooper (Ed.), *Longer Lasting Products* (pp. 39–60).

Cooper, T. (2004). Inadequate Life? Evidence of Consumer Attitudes to Product Obsolescence. *Journal of Consumer Policy*, *27*, 421–449. https://doi.org/10.1007/s10603-004-2284-6

Curvelo Santana, J. C., Guerhardt, F., Franzini, C. E., Lee Ho, L., Rocha Ribeiro Júnior, S. E., Cânovas, G., Kenji Yamamura, C. L., Vanalle, R. M., & Berssaneti, F. T. (2021). Refurbishing and recycling of cell phones as a sustainable process of reverse logistics: A case study in Brazil. *Journal of Cleaner Production*, *283*. https://doi.org/10.1016/j.jclepro.2020.124585

Forti, V., Baldé, C. P., Kuehr Ruediger, & Bel, G. (2020). *Quantities, flows, and the circular economy potential The Global E-waste Monitor 2020*.

Guo, H., & Xu, X. (2021). Exploring the barriers that influence intention to donate and role of the charity shop within the multi-tier supply chain. *Journal of Humanitarian Logistics and Supply Chain Management*, *11*(3), 522–549. https://doi.org/10.1108/JHLSCM-07-2020-0055

Huang, E. M., & Truong, K. N. (2008). Breaking the Disposable Technology Paradigm Opportunities for Sustainable Interaction Design for mobile phones. *CHI 2008 Proceedings · Green Day*, 323–332.

Jang, Y. C., & Kim, M. (2010). Management of used & end-of-life mobile phones in Korea: A review. In *Resources, Conservation and Recycling* (Vol. 55, Issue 1, pp. 11–19). https://doi.org/10.1016/j.resconrec.2010.07.003

Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. *Waste Management*, *33*(5), 1237–1250. https://doi.org/10.1016/j.wasman.2013.01.006

King, A. M., Burgess, S. C., Ijomah, W., & McMahon, C. A. (2006). Reducing waste: Repair, recondition, remanufacture or recycle? *Sustainable Development*, *14*(4), 257–267. https://doi.org/10.1002/sd.271

Loughborough University. (2023, December). *Facts and figures 2023 - 2024*. https://www.lboro.ac.uk/services/pla

nning/facts-figures/facts-figures-2023-24/

Macleod, J. (2017). *Ends: Why We Overlook Endings for Humans, Products, Services and Digital: and why We Shouldn't*.

Miner, K. J., Rampedi, I. T., Ifegbesan, A. P., & Machete, F. (2020). Survey on household awareness and willingness to participate in e-waste management in jos, plateau state, Nigeria. *Sustainability (Switzerland)*, *12*(3). https://doi.org/10.3390/su12031047

Mor, R. S., Sangwan, K. S., Singh, S., Singh, A., & Kharub, M. (2021). E-waste Management for Environmental Sustainability: An Exploratory Study. *Procedia CIRP*, *98*, 193–198. https://doi.org/10.1016/j.procir.2021.01.029

Ongondo, F. O., & Williams, I. D. (2011). Greening academia: Use and disposal of mobile phones among university students. *Waste Management*, *31*(7), 1617–1634. https://doi.org/10.1016/j.wasman.2011.01.031

Romagnoli, V., de Bruijne, E., Drapeau, P., Ollion, L., & Anaëlle, C. (2022). *Study on options for return schemes of mobile phones, tablets and other small electrical and electronic equipment in the EU*. https://doi.org/10.2779/237189

Van Nes, N., Cramer, J., & Stevels, A. (1999). A practical approach to the ecological lifetime optimization of electronic products. *Proceedings - 1st International Symposium on Environmentally Conscious Design and Inverse Manufacturing, EcoDesign 1999*, 108–111. https://doi.org/10.1109/ECODIM.1999.747592

Vezzoli, C. (2018). Design for environmental sustainability: Life cycle design of products: Second edition. *Design for Environmental Sustainability: Life Cycle Design of Products: Second Edition*, 1–330. https://doi.org/10.1007/978-1-4471-7364-9/COVER

Wilson, G. T., Smalley, G., Suckling, J. R., Lilley, D., Lee, J., & Mawle, R. (2017). The hibernating mobile phone: Dead storage as a barrier to efficient electronic waste recovery. *Waste Management*, *60*, 521–533. https://doi.org/10.1016/j.wasman.2016.12.023

Ylä-Mella, J., Keiski, R. L., & Pongrácz, E. (2015). Electronic waste recovery in Finland: Consumers' perceptions towards recycling and re-use of mobile phones. *Waste Management*, *45*, 374–384. https://doi.org/10.1016/j.wasman.2015.02.031

Appendix I

Obsolescence reasons for devices

	Mobile phone	Laptop / MacBook	Tablets	E-book reader	Desktop computer	Screen / TV	Game console	Smartwatch	Headphones	Smart speaker	Hair styling appliance	Electric toothbrush	Personal grooming devices	Electrical beauty devices	Other
All respondent	459	293	226	69	63	92	168	86	308	47	86	122	56	23	9
It broke beyond repair.	**161 (35.1%)**	83 (28.3%)	59 (26.1%)	11 (15.9%)	11 (17.5%)	23 (25%)	8 (4.8%)	**26 (30.2%)**	**175 (56.8%)**	6 (12.8%)	**42 (48.8%)**	**50 (41%)**	**40 (32.8%)**	**8 (34.8%)**	1 (11.1%)
The technology was worn out.	**252 (54.9%)**	**153 (52.2%)**	**105 (46.5%)**	12 17.4%)	**29 (46%)**	18 (19.6%)	**54 (32.1%)**	17 (19.8%)	69 (22.4%)	10 (21.3%)	16 (18.6%)	27 (22.1%)	18 (14.8%)	5 (21.7%)	1 (11.1%)
It no longer had the specific functions that I required.	97 (21.1%)	**107 (36.5%)**	64 (28.3%)	**21 (30.4%)**	16 (25.4%)	23 (25%)	43 (25.6%)	21 (24.4%)	47 (15.3%)	**17 (36.2%)**	17 (19.8%)	11 (9%)	14 (11.5%)	6 (26.1%)	0
It was no longer clean, shiny, or new.	23 (5%)	12 (4.1%)	7 (3.1%)	1 (1.4%)	0	7 (7.6%)	6 (3.6%)	3 (3.5%)	11 (3.6%)	1 (2.1%)	4 (4.7%)	16 (13.1%)	5 (4.1%)	1 (4.3%)	0
It was no longer novel, stylish or prestigious.	24 (5.2%)	4 (1.4%)	4 (1.8%)	0	2 (3.2%)	3 (3.3%)	10 (6%)	4 (4.7%)	14 (4.5%)	3 (6.4%)	0	2 (1.6%)	3 (2.5%)	1 (4.3%)	0
It cost too much money to repair (if broken).	71 (15.5%)	34 (11.6%)	21 (9.3%)	0	5 (7.9%)	2 (2.2%)	4 (2.4%)	8 (9.3%)	25 (8.1%)	3 (6.4%)	2 (2.3%)	2 (1.6%)	1 (0.8%)	0	0
The technology was outdated.	**228 (49.7%)**	**132 (45.1%)**	**91 (40.3%)**	20 (29%)	**32 (50.8%)**	**36 (39.1%)**	**95 (56.5%)**	18 (20.9%)	78 (25.3%)	8 (17%)	14 (16.3%)	7 (5.7%)	8 (6.6%)	2 (8.7%)	1 (11.1%)
It was bad for the environment.	1 (0.2%)	0	0	0	2 (3.2%)	2 (2.2%)	1 (0.6%)	0	0	0	2 (2.3%)	3 (2.5%)	1 (0.8%)	0	0
I am more emotionally attached to the replacement.	7 (1.5%)	7 (2.4%)	5 (2.2%)	5 (7.2%)	2 (3.2%)	2 (2.2%)	14 (8.3%)	3 (3.5%)	23 (7.5%)	2 (4.3%)	2 (2.3%)	3 (2.5%)	3 (2.5%)	0	1 (11.1%)
It was no longer socially acceptable to use	15 (3.3%)	2 (0.7)	1 (0.4%)	1 (1.4%)	1 (1.6%)	0	17 (10.1%)	1 (1.2%)	4 (1.3%)	1 (2.1%)	0	0	2 (1.6%)	0	0
Other	24 (5.2%)	10 (3.4%)	26 (11.5%)	11 (15.9%)	4 (6.3%)	6 (6.5%)	22 (13.1%)	15 (17.4%)	16 (5.2%)	7 (14.9%)	5 (5.8%)	19 (15.6%)	35 (28.7%)	1 (4.3%)	**5 (55.6%)**

Appendix II

Actions taken with obsolete devices

	Total respondent	Kept it	Gifted it	Gave it to a charity	Recycled it	Trew it away (general waste)	Traded it in for a new one.	Sold it on Marketplace or another second-hand selling platform/app	Other
Mobile phone	459	**267 (58.2%)**	56 (12.2%)	0	28 (6.1%)	11 (2.4%)	55 (12%)	40 (8.7%)	2 (0.4%)
Laptop / MacBook	293	**182 (62.1%)**	46 (15.7%)	26 (8.9%)	13 (4.4%)	12 (4.1%)	10 (3.4%)	3 (1%)	1 (0.3%)
Tablets	226	**141 (62.4%)**	20 (8.8%)	3 (1.3%)	21 (9.3%)	14 (6.2%)	8 (3.5%)	14 (6.2%)	5 (2.2%)
E-book reader	69	**38 (55.1%)**	11 (15.9%)	1 (1.4%)	9 (13%)	8 (11.6%)	0	1 (1.4%)	1 (1.4%)
Desktop computer	63	**26 (41.3%)**	6 (9.5%)	5 (7.9%)	13 (20.6%)	6 (9.5%)	2 (3.2%)	3 (4.8%)	2 (3.2%)
Screen / TV	92	**34 (37%)**	10 (10.9%)	4 (4.3%)	14 (15.2%)	15 (16.3%)	2 (2.2%)	11 (12%)	2 (2.2%)
Game console	168	**115 (68.5%)**	15 (8.9%)	10 (6%)	3 (1.8%)	2 (1.2%)	3 (1.8%)	18 (10.7%)	2 (1.2%)
Smartwatch	86	**47 (54.7%)**	7 (8.1%)	1 (1.2%)	9 (10.5%)	9 (10.5%)	3 (3.5%)	8 (9.3%)	2 (2.3%)
Headphone	308	**141 (45.8%)**	24 (7.8%)	2 (0.6%)	29 (9.4%)	**91 (29.5%)**	6 (1.9%)	4 (1.3%)	11 (3.6%)
Smart speaker	47	**31 (66%)**	8 (17%)	0	3 (6.4%)	3 (6.4%)	1 (2.1%)	1 (2.1%)	0
Hair styling appliance	86	**26 (30.2%)**	8 (9.3%)	1 (1.2%)	13 (15.1%)	**35 (40.7%)**	1 (1.2%)	1 (1.2%)	1 (1.2%)
Electric toothbrush	122	34 (27.9%)	0	0	16 (13.1%)	**71 (58.2%)**	1 (0.8%)	0	0
Personal grooming devices	56	**20 (35.7%)**	1 (1.8%)	0	9 (16.1%)	**25 (44.6%)**	0	0	1 (1.8%)
Electrical beauty devices	23	**13 (56.5%)**	0	0	0	**8 (34.8%)**	0	1 (4.3%)	1 (4.3%)
Other	9	**4 (44.4%)**	1 (11.1%)	0	1 (11.1%)	1 (11.1%)	0	1 (11.1%)	1 (11.1%)

Research paper
6th PLATE 2025 Conference
Aalborg, Denmark, 2-4 July 2025

Improving the sustainability and durability of performance swimwear through consumer knowledge and usage habits

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Keywords: Performance Swimwear; Sustainability; Durability; Longevity; Aftercare.

Abstract: As with any sport, the desire to progress in swimming by any means is unending. There are constant advancements being made in the textile technology of performance fabrics, with most technologic developments being focused on synthetic fabrics. Synthetic fibres, such as polyester can take from 20 up to 200 years to degrade and can release a range of chemicals having a detrimental effect on the planet (Uren, 2024). This paper explores performance swimwear's environmental impact and proposes solutions for both industry and users. Key issues include the reliance on synthetic fibres, fabric deterioration, and insufficient consumer knowledge about reducing environmental impact and extending garment longevity.

The study begins with a comprehensive literature review, which dissects the issues at hand and begins to deliberate possible solutions. Gaps in knowledge were identified and addressed through a series of qualitative interviews to gain first-hand insight from consumers and users of performance swimwear. The findings suggest that consumer knowledge around aftercare is insufficient. There is a lack of communication from brands on this subject, as well as a reluctancy from consumers to seek out this information. Thus, the common areas of wear and lack of knowledge on aftercare result in premature disposal of swimwear. The suggestion of designing for emotional durability presents a potential solution to increasing the longevity of swimwear. In addition to this, implementing upcycling schemes could reduce environmental impact and improvements in aftercare, such as improved communication and access to information is recommended.

Introduction

The fashion industry's environmental impact is increasingly of concern, with 92 million tonnes of waste and 79 trillion litres of water utilised annually (Niinimäki, 2020). Synthetic fibres are particularly problematic due to fossil fuel extraction and prolonged biodegradation rates. Swimwear is a product sector that relies predominately on the use of synthetic fibres, in addition to the use of harmful substances such as perfluorinated chemicals for water repelling (Cappelletti et. Al., 2023). There are few studies addressing the sustainability of swimwear and even fewer focusing on the performance swimwear sector. However as discussed by Pandey (2020) “there has been a tremendous change in the swimwear sector…, who are demanding performance enhanced fabrics which at the same time are sustainable as well’. When considering which fabric is best for a swimsuit, most articles would lead towards polyester or a blend of multiple synthetic fibres to improve functionality and fit (Peeke, 2018).

In addition to the environmental effects of fabrics used in swimwear, there are larger issues surrounding the longevity of swimwear currently. The high frequency use of swimsuits by athletes, as well as the exposure to chlorine results in a much shorter lifespan, leading to the premature disposal of swimwear and therefore more suits being sold.

The lack of knowledge about how to care for clothing post-purchase, is a topic gaining more popularity. Through interviews, this study will gather further insight into how much knowledge consumers have and how they implement such knowledge is to be explored. A better relationship between all stakeholders is needed to increase the understanding around aftercare which could result in longer lasting garments (Webb, 2020).

This paper aims to explore the sustainability, durability and relationship consumers have with performance swimwear. It sets out to find ways to reduce the environmental impact of performance swimwear production. The subject

will be split into two subthemes: durability and longevity, and after-care of garments, which will be referred to throughout the paper to address issues and present potential solutions. This research is necessary to lead advancements of performance swimwear in a sustainable and circular direction. It aims to inform the reader and build on information about sustainability and technological advances to create a more functional, longer lasting and ecological outcome.

Literature Review

Durability & Longevity

Durability in swimwear is widely studied, as shown by works like Afifi, Qurashi, & Gabr (2024) and Potočić Matković, Salopek Čubrić, & Krstović (2024). Competitive swimmer blogs, such as *Swim World Magazine* (2024), provide tips to improve suit longevity. Much of the literature around improving durability focuses on polyester, nylon and chemical coatings being the solution, lacking consideration of environmental impacts. A study was conducted testing degradation of swimwear which suggested that even synthetic fabrics do not have much resistance against sunlight, chlorine and sea water (Epps, 1987), leading research towards consideration of natural fibres for future innovation. More recently, studies by Islam, Mondal and Chandra Das (2021) and Pandey (2020) investigated ways that natural textiles could be treated to improve their functionality and therefore appropriateness for application. Both studies concluded that there is potential to design with natural fibres that are treated to improve functionality whilst reducing environmental impacts.

It is essential to consider a garment's overall impact through the whole product lifecycle, moving beyond source, to acknowledge the impacts of consumer use. Laitala, Klepp, & Henry (2018) evidenced that the production and use phase hold more of an impact than distribution and disposal. Critical considerations include the potential loss of microfibres, product lifespans, quality, and functionality (Laitala, Klepp, & Henry, 2018). Laitala and Boks (2012) emphasise the importance of the consumer use phase in achieving more sustainable products. When aiming to improve longevity they suggest, enhancing quality and designing for emotional connection to increase product satisfaction.

Emotional durability has been defined as an approach to increase longevity, with research aiming to understand the complex relationship between consumption and the meaning of products to consumers (Jensen, 2021). Studies based on emotional attachment explore how designers can implement this design approach in clothing to extend and prolong product use. Appalatch, are a company intending to utitlise emotional attachment to improve the sustainability of their business (Spanne, 2015), as they discovered that fashion-conscious consumers were attracted to the emotional story of clothing. Their website encourages consumers to value the relationship with clothing and build connections with people based on this shared ideal (Ibid).

Niinimäki and Armstrong (2013) corroborate this explaining that 'garments could represent an accomplishment and include the effort invested'. This could be a predominant reason for a swimmer to emotionally attach to a product as they relate their swimwear to big accomplishments within their sport.

Aftercare of Garments

Misconceptions about clothing care are common, yet it contributes around 30% of a garment's carbon footprint (Webb, 2020), often being positioned as a primary reason for brands to focus on sustainability. Swimwear unlike most textile products, shouldn't ever be washed or dried in a machine (simpleswim, 2021). Many consumers are unaware that swimwear is cared for differently, resulting in fast deterioration of these garments. Information on aftercare is available on some brand websites; however, it is often hard to find, leaving consumers to actively seek out this information, often from different sources.

As sustainability becomes a core focus of business strategy, brands are beginning to take some responsibility for informing their consumers on aftercare (Brown, 2019). Currently, many brands use care labels as a form of protection, to reduce returns, rather than using it as an informative tool (Webb, 2020). This results in many clothing labels claiming 'dry clean only' or 'wash with similar colours' when that isn't necessary. Perez and Lonsdale (2018) established that most buyers lacked knowledge in clothing care and better labelling was needed. It is apparent that it is not

for lack of interest that people do not care for their clothes, but for lack of knowledge.
Brands like Patagonia and Finisterre lead the way in providing extensive care guides to help consumers reduce their environmental impact and extend garment longevity. The information available on their website details laundering, stain removal guides and fabric care, categorised by each individual fabric they sell (Patagonia, 2021).
A lot of information regarding how to care for swimwear is readily available through online blogs. Ness Swimwear (2019) provide detailed care instructions for competition swimwear. This, however, raises questions about who is responsible for providing information to swimmers and consumers alike. Blogs, whilst being accessible and informative, do not have access to specific information on technical fabrics, which is particularly important as brands continue to develop innovative fabric compositions which may have different care requirements. This is demonstrated by the Speedo LZR Racer, a page on the Speedo website explains, 'as highly technical garments, designed with a smart-fusion combination of fabrics… these garments require care when being handled' (Speedo, 2021a). Current industry strategies are lacking information on post purchase care. Although Speedo has some pages on how to take care of swimwear, they are located on their FAQ's or blog section of their website making it difficult to find (Speedo, 2021).

Methodology

To address the issues within durability and after-care of performance swimwear qualitative research was undertaken. An inductive approach was used to gather qualitative data through semi-structured interviews. Secondary research was carried out, in the form of a literature review, to find the gaps in knowledge within the chosen subject.
To frame the rationale of this research, it was necessary to evaluate the knowledge that exists within this field and where further research is needed. Semi-structured interviews provided authentic swimmer accounts, aiding final recommendations for the industry.
It is difficult for the researcher to experience the subject to a degree that gives them the knowledge and awareness to conduct research (Collins, 2010). The research is therefore improved, by talking to people that practice the subject on a regular basis, e.g., frequent swimmers. Participants were chosen through existing personal networks within swimming organisations and selected through referral sampling, also known as snowball sampling (Evans and Rooney, 2018). Participants were selected based on their frequent use of performance swimwear throughout their life. The applicants had developed knowledge and opinions on this subject over a significant period. Using a sample group of swimmers at different levels enhanced the data collected, as opinions varied from the different experiences.

Data Analysis

To analyse the data the researcher focused on inductive approaches, with thematic analysis, allowing the researcher to cross-analyse interviews, pinpointing commonalities and differences (Harding, 2019).
To begin the analysis process all interviews were transcribed, through this process themes and similarities in the data began to emerge. Thematic analysis was used to divide the data into subsequent groupings and inductive coding was used to further analyse the data to pinpoint reoccurring opinions or statements. Cross-analysis was conducted comparing all participants data so that coding could be re-evaluated to group codes into relevant subsections.

Findings & Discussion

The thematic analysis of interview data resulted in five main thematic areas, which have been evaluated and explained. The findings have been ordered in a way to express the issues from the beginning of purchasing and manufacturing of swimwear, through to the disposal/relationship that results at the end of the products life.

Washing Habits

75% of participants explained their washing habits as rinsing their swimwear in the shower after swimming. These participants also expressed doubt, that this was the correct thing to do, participant 2 saying 'I just tend to like rinse them in cold water after training and then hang them all up. But now I'm like, oh, I should probably actually wash them". When participant 4 was asked how often they washed their swimwear they replied 'probably never', however went on to explain they would rinse the suit out. This implying that the participant didn't class rinsing a costume, as washing it.

This links to the societal perception that nothing is clean unless it has undertaken a wash cycle in a machine. As stated in the literature review, swimwear shouldn't be washed in a machine (simpleswim, 2021). These results also justify that many consumers are unaware that swimwear is cared for and washed differently.

Care Labels

100% of participants revealed they had never looked at a care label. Most participants had an idea of what a care label looked like, but had never thought to look at one, expressing they didn't know what the symbols on care labels meant. Throughout the interview participant 2 looked at a care label on their swimwear and commented, 'there's four symbols on this label, but I honestly have no idea what they mean'. Participants had not sought care information and most stated that although they would find this useful, they would only do so for expensive garments. Participant 3 said 'I'm sure I looked at labels with my racing suits, because they were more money, so I probably gave them a bit more care'.

As detailed in the literature review, although some swimwear brands have information on aftercare online, it isn't easy to find. Aftercare information needs to be made easily accessible and digestible to consumers to be useful and successful in extending the life of garments. Participant 3 explained, 'I think the racing ones (costumes) usually come with like a leaflet or something a little bit more informative as well. But yeah, I can't say I've ever really looked at them'. This justifies brand's efforts to inform consumers but highlights the disconnect in communication of this information. Further research is needed to investigate ways in which this could be communicated for consumers to engage with it.

End of Life

Participants were asked what they did with swimwear when they considered it no longer usable. 75% of the participants confessed they threw swimwear in the bin with participant 2, expressing, 'they were so worn when I was done with them, they'd be useless to anyone else'. When asked if they had ever considered recycling or donating swimwear there was a mixed response. Some said they felt donating swimwear would be unhygienic. Participant 4 spoke about upcycling schemes they had heard of from friends 'you just post them off and then they can be remade into something', expressing a desire to try this to give swimsuits another life. Undeniably there was a lack of knowledge from all participants around what to do with swimwear at the end of its life.

Highlighted in the literature review, the information around aftercare from brands is lacking, as is the responsibility they take to improving disposal of garments. Some brands already have systems in place for recycling of garments, such as the H&M scheme, they offer a £5 store voucher in return for bringing unwanted items to their in-store recycling bins (Gould, 2017). Similar schemes could be put in place for swimwear brands to encourage recycling or upcycling.

Durability

Participants were asked to list reasons for disposal and to highlight areas that show deterioration first. Participant 1 and 3 mentioned that their costumes often start to go see through. When asked what the main reason for disposal was, participant 3 said 'it'd just be once they started going see through'. This is shown in figure 1.



Figure 1. Worn fabric on the stomach which allows the lining to be visible. Interview Image (Participant 2).

Loss of elasticity was mentioned by 75% of the participants, participant 4 explained that lack of elasticity was apparent in poor quality swimwear, explaining, 'we had to wear the Adidas costumes, but they were really poor quality and were really baggy'. Shown in figure 2.



Figure 2. Loss of elasticity in straps. Interview image (Participant 2).

Fabric pilling was mentioned in relation to the bottom area of a swimsuit. All participants revealed that pilling was a reason for disposal. 50% of the participants established the relationship with both issues explaining that the fabric covering the bottom would become 'furry or bobbly', relating to pilling. Participant 3 expressed this as one of the main factors when choosing swimwear, explaining 'the first tick was, is it one of the chlorine resistant ones? Because they last longer, otherwise they're going to go furry after a few weeks'. Participant 2 also responded to this question 'on the bum and stuff, where it goes all white and bobbly, that's one of the reasons'. Pilling can be seen in figure 3.



Figure 3. Visible pilling of fabric. Interview Image (Participant 2).

Durability issues in swimwear can be related to fabric choices and garment design. Consumer's aftercare habits heavily affect the loss of elasticity. Misconceptions about clothing care are common, and the participants lack of knowledge about washing and usage habits could lead to premature loss of elasticity.

Emotional Attachment

Half of the participants interviewed stated that they had felt an emotional attachment to their swimwear. Participant 2 described that if she achieved a personal best wearing a costume, she would wear it for important races after that, as she felt the swimsuit had 'good luck'. Participant 4 reiterated this feeling, explaining 'even if its maybe not in as good condition anymore, sometimes it doesn't matter how good the quality is, it's about how it makes you feel mentally'. Referring to how, emotional and mental feeling is extremely important in sports. Participant 4 explained, 'I'm a bit of a hoarder. I have like a hundred costumes in my drawer upstairs and I just don't know what to do with them'. Expressing this resistance to dispose of swimwear but lacking the knowledge on options for end of life. They continued, 'my friend told me about something, where you can post off your costumes and I had thought about that. I kind of have that bit of attachment towards them'. Highlighting how emotional attachment can reduce the likelihood of premature disposal.

As previously established in the literature review section on designing for emotional attachment, garments often represent an accomplishment and effort invested (Niinimäki and Armstrong, 2013). This can then lead to consumers holding onto the item for an extended period, which was displayed in the findings.

Conclusions

The aim of this paper was to improve the sustainability and durability of performance swimwear through consumer knowledge of after-care. In addition to this it investigated the communication of this knowledge from brands and the level of interest from consumers. The following recommendations can be applied to brands, individual consumers and the industry with the aim of reducing environmental impact within this product sector.

As pointed out in the literature review section, durability is always a priority for swimwear brands. However, longevity must now be brought to the forefront when creating swimwear for it to become more sustainable.

Regarding research on durability, methods of design have been investigated throughout this paper. Designing for emotional durability was investigated within the literature review and through primary research and it was proven implementation could be affective.

In relation to emotional durability, recycling and upcycling schemes were suggested within interviews. Implementation of these schemes would give consumers an incentive to recycle their costumes, as well as the option to give swimwear that consumers had emotional connection with, another life. Consumer interviews indicate confusion over swimwear disposal, and this would provide an ideal solution if paired with accessible information to various disposal options.

To improve sustainability in performance swimwear, aftercare must be a focus from both brands and consumers. The information provided by brands must be specific to each product and fabric they produce. This is especially important for 'tech' suits as they require more specific care, due to the complexity of the fabrics.

In addition to this, improved communication of this information to consumers is needed. Through interviews it was discovered that most consumers aren't willing to go out of their way to find this information, therefore brands need to encourage consumers by making the information as accessible as possible.

These recommendations are direct actions that could be taken to improve sustainability and durability within the performance swimwear industry.

1. Provide aftercare information that is specific to individual products and fabrics and is easily accessible to consumers.

2. Improve the communication of aftercare from brands to consumer, specifically provide links between the physical garment and the information online.

3. Implement upcycling and recycling schemes to reduce waste and increase awareness on how to dispose of swimwear in more sustainable ways.

4. Create a balance between designing for function, comfort and aesthetics. A bigger differentiation between the needs of a training costume and a racing costume could improve this.

5. Implement different design strategies such as designing for disassembly and designing for emotional durability.

6. Lead the way in change, take responsibility for action and devise strategies to encourage others to do the same.

Limitations and Future Work

This paper is limited to investigating the actions of individuals, with the consideration of social practice theory and the influence of this on participants behaviors was not considered. Articles have investigated the application of social practice theory to pro-environmental change and have found difficulties in attempts to change practices, over and above individuals' attitudes or values which instead often resume the organization of everyday life (Ward, 2011). As the research used a small number of participants it is difficult to categorise and generalize behaviours and expanding the study will be developed in future work.

References

Afifi, S. R. I., Qurashi, W. A.-R., & Gabr, B. G. (2024). Swimwear longevity: A comprehensive analysis of factors affecting durability and replacement. Clothing Cultures, 9(1–2), p. 93–116. https://doi.org/10.1386/cc_00060_1

Speedo. (2021). 4 easy ways to care for your swimming goggles. Speedo. Retrieved March 19, 2025, from https://www.speedo.com/blog/swimwear/4-ways-to-care-for-your-swimming-goggles/

Brown, H. (2019). The afterlife: Why fashion aftercare is on the rise. Drapers. Retrieved October 28, 2021, from https://www.drapersonline.com/insight/analysis/the-after-life-why-fashion-aftercare-is-on-the-rise#comments

Cappelletti, F., Menghi, R., Rossi, M., & Germani, M. (2023). Comparison between LCA results and consumers-perceived environmental sustainability of three swimming products. International Journal on Interactive Design and Manufacturing (IJIDeM, 17, 1905–1932. https://doi.org/10.1007/s12008-023-01284-x

Collins, H. (2010). Creative research: The theory and practice of research for the creative industries. AVA Publishing. Available from ProQuest Ebook Central. [19 August 2021].

Epps, H. H. (1987). Degradation of swimwear fabrics: effects of light, sea water and chlorine. Sage Journal, 5(2), https://doi.org/10.1177/0887302X8700500205

Evans, A. N., & Rooney, B. J. (2018). Methods in psychological research (4th ed.). SAGE Publishing.

Goodwin, D. (2018, June 8). Swimsuit durability: How long do they last, how long could they? AquaMobile Swim School Blog. Retrieved October 25, 2021, from https://aquamobileswim.com/blog/swimsuit-durability-long-lasting/

Gould, H. (2017, May 26). Zara and H&M back in-store recycling to tackle throwaway culture. The Guardian. Retrieved November 26, 2021, from https://www.theguardian.com/sustainable-business/2017/may/26/zara-hm-step-up-instore-recycling-tackle-throwaway-culture

Harding, J. (2019). Qualitative data analysis – from start to finish (2nd ed.). London: Sage.

Islam, J., Mondal, M., & Chandra Das, S. (2021). Fundamentals of natural fibres and textiles. Woodhead Publishing UK, 657–690.

Jensen, M. B. (2021). Emotional durability: Strategies and future integration – A case study (Master's thesis, University of Borås, Faculty of Textiles, Engineering and Business). DiVA. https://www.diva-portal.org/smash/get/diva2:1591142/FULLTEXT01.pdf

Laitala, K., Boks, C. (2012). Sustainable clothing design: use matters. Journal of Design Research, 10(1/2), #121-139#. DOI:10.1504/JDR.2012.046142

Laitala, K., Klepp, I. G., & Henry, B. (2018). Does use matter? Comparison of environmental impacts of clothing based on fiber type. Sustainability, 10(7), 2524. https://doi.org/10.3390/su10072524

Medelyan, A. (2021). Coding qualitative data: How to code qualitative research. Insights. Retrieved November 20, 2021, from https://getthematic.com/insights/coding-qualitative-data/

Ness Swimwear. (2019, September 7). How to look after your swimming race suit. Ness Swimwear Blog. Retrieved October 26, 2021, from https://www.nessswimwear.co.uk/blog/competition-swimwear-care-guide/

Niinimäki, K., & Armstrong, C. (2013). From pleasure in use to preservation of meaningful memories: A closer look at the sustainability

of clothing via longevity and attachment. International Journal of Fashion Design, Technology and Education, 6(3), 190–199.

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. Nature Reviews Earth & Environment, 1, 189–200. https://doi.org/10.1038/s41558-020-0698-0

Pandey, G. (2020). Sustainability matters: Design and development of multi-functional bamboo and modal fabrics for active swimwear. Our Heritage, 68(54), 17.

Patagonia. (2021). Repairs. Patagonia. Retrieved December 7, 2024, from https://www.patagonia.com/repairs/

Peeke, J. (2018, June 13). Why do you need chlorine-resistant swimwear? ProSwimwear Blog. Retrieved March 11, 2021, from https://www.proswimwear.co.uk/blog/why-do-you-need-chlorine-resistant-swimwear/

Perez, A., & Lonsdale, M. (2018). Garment label design and companion information to communicate fashion sustainability issues to young consumers. Visible Language, 52(3), 114–139. Retrieved October 27, 2021, from https://www.researchgate.net/publication/330533771_Garment_label_design_and_companion_information_to_communicate_fashion_sustainability_issues_to_young_consumers/link/5c5145b4a6fdccd6b5d34455/download

Potočić Matković, V. M., Salopek Čubrić, I., & Krstović, K. (2024). The impact of chlorinated water and sun exposure on the durability and performance of swimwear materials. Polymers, 16(21), 3050. https://doi.org/10.3390/polym16213050

Soke, A. (2021, August 10). 11 best sustainable swimwear brands. Durability Matters. Retrieved October 24, 2021, from https://durabilitymatters.com/sustainable-swimwear-brands/

Spanne, A. (2015, January 17). Want people to buy a product that lasts? Sell them an emotional connection. The Guardian. Retrieved July 3, 2021, from https://www.theguardian.com/vital-signs/2015/jan/17/the-struggle-to-sell-to-products-that-last

Swim Swam. (2021). Speedo's Fastskin 4.0: The future of fast. Retrieved October 22, 2021, from https://swimswam.com/speedos-fastskin-4-0-the-future-of-fast/

Swimming World Magazine. (2024). 10 ways to increase the life of your racing suit. Swimming World Magazine. Retrieved December 7, 2024, from https://www.swimmingworldmagazine.com/news/10-ways-to-increase-the-life-of-your-racing-suit/

Uren, A. (2024, March 18). How sustainable is polyester? Good On You. Retrieved December 7, 2024, from https://goodonyou.eco/how-sustainable-is-polyester/

Vine, R. (2014, October 24). Why you should never, ever wash your jeans (unless you really, really have to). The Guardian. Retrieved December 7, 2021, from https://www.theguardian.com/fashion/2014/oct/24/why-you-should-never-ever-wash-your-jeans-unless-you-really-really-have-to

Warde, A. (2011). Consumption and theories of practice. *Journal of Consumer Culture, 11*(3), 279–303. https://doi.org/10.1177/1469540510390500

Webb, B. (2020). A new movement to reduce the hidden environmental cost of clothing care. Vogue Business. Retrieved March 11, 2021, from https://www.voguebusiness.com/sustainability/a-new-movement-to-reduce-the-hidden-environmental-cost-of-clothing-care

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Making Mends: Visibly Mending the Circular Economy

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Keywords: Repair; Visible mending; Product-life extension; User agency; Circular Economy.

Abstract: This paper introduces the Making Mends Workshop, a workshop format centering on the practice of visible mending as a means to explore broader notions of repair and care in the context of the Circular Economy. The workshop is structured into three parts: a reflective exercise that encourages participants to consider the practical and conceptual meanings of mending, a brief lecture and practice session that provides basic knowledge and skills of visible mending, followed by the participants repairing a personal item. Findings suggest the potential impacts of the visible mending workshop as a catalyst for fostering user agency through skill acquisition and meaning-making. The workshop highlights visible mending as a communal repair practice supporting the Circular Economy by extending product life and preserving material and emotional value. The notion of Mending for Others was identified as a valuable addition to communal repair, where repair strategies benefit from social interactions that involve sharing knowledge and skills, care, and joy, ultimately leading to durable repairs.

Introduction

Wasteful trends of the linear take-make-use-dispose model, led by mass consumption and materialism habits, are being counteracted in the Circular Economy (CE). The Ellen MacArthur Foundation elaborates on three principles guiding circular design: (1) eliminating waste and pollution, (2) circulating products and materials at their highest value, and (3) supporting natural processes and regenerating nature (Ellen MacArthur Foundation, 2013). One significant strategy within the circular model is slowing down resource loops, which concerns designing durable and long-lasting products and extending product life through repair and remanufacturing (Bocken et al., 2016).

Rise in initiatives such as the EU's Right-to-Repair, and global expansions of Repair Cafes and other DIY platforms have shown that repair has gained traction as a strategy for product-life extension. Repair involves extending the lifetime of a product by restoring its functionality, making it as good as new after fixing defects or replacing broken parts. Users can perform repairs themselves or use a company or third-party repair service, either for a fee or as an act of service. (Reike et al., 2018). By enabling the retention of product value and contributing to a slower rate of consumption (Dewberry, 2016), repair makes for a crucial strategy within the CE. In the context of our clothing, obsolescence is driven by the rapid pace of the dominant fast-fashion industry, which revolves around following short-lived trends, resulting in the premature disposal of items (Durrani, 2018; Durrani et al., 2021). Research has shown that compared to 15 years prior, clothing production approximately doubled in volume, while the effective use time of garments decreased by 36% (Ellen MacArthur Foundation, 2017; Niinimäki & Durrani, 2020). Maldini et al. (2019) argue that promoting usage and longer lifetimes of clothing can have significant environmental advantages as long as they contribute to a reduction in the production of new clothes. However, extending the use phase of clothing through repair is encountering several barriers. Users may not have enough time, knowledge, or confidence to fix their garments, and the cost of repairing items may be relatively higher than buying new ones. (Gwilt, 2014; Niinimäki & Durrani, 2020). Global networks of repairers, collectively known as the 'Fixer Movement', have established various initiatives to address the barriers to repair, for instance, through hosting public events where repair and mending experts assist people in learning how to fix their broken items (Niinimäki & Durrani, 2020).

This paper introduces the Making Mends Workshop, a workshop format centring on the

practice of visible mending as a means to teach people techniques to fix their broken possessions and explore broader notions of repair and care in the context of the CE. Visible mending is a particular style of repair, generally used for clothing and other textile-based products. Rather than concealing the repair to restore an item to its original condition, visible mending highlights repair through bold hand-stitched patterns and the use of brightly coloured threads and fabrics (Jones & Girouard, 2021). The term was popularized by Tom Van Deijnen, who coined the hashtag #visiblemending on social media and started the Visible Mending Programme in Brighton, UK, in 2010. This marked the beginning of an online community focused on visible mending (Sekules, 2020), which has increasingly propelled the practice's popularity. It has continued to grow online through how-to and ASMR videos shared on social media platforms (Mattern, 2024). Repaired garments are also gaining attention in luxury segments, with artist Celia Pym becoming a finalist for the Loewe Craft Award in 2017 for her visibly mended 'Norwegian Sweater' (Wolstenholme, 2017).

The Making Mends Workshop and related tools align with a practice-based design research approach (Nicolini, 2011; Sade, 2021), and use the workshop format as a research method (Ørngreen & Levinsen, 2017) to gain insights into people-product relations and explore broader meanings of repair and care that could benefit the fields of design and design research. A key aspect is that the workshop tries to promote active engagement among participants (Andersen & Wakkary, 2019), ensuring benefits for attendees, alongside designers and researchers, in terms of knowledge and skill-building. Making Mends has a dual purpose. First, it aims to teach participants, with varying skills in sewing, visible mending methods through simple exercises and repairing a beloved personal item. Second, the workshop and its tools are designed to fulfil a research purpose. Throughout the workshop, visible mending is used as an exploratory practice that aims to initiate dialogue on various aspects of repair. This approach thereby aims to broaden the scope of designing for a CE and move us beyond a traditional industrial design context towards a more comprehensive, socially and ecologically inclusive vision for the CE.

The following sections introduce the elements of the Making Mends workshop and describe its intentions and experiences.

The Making Mends Visible Mending Workshop

Making Mends started from a personal interest in gaining insights into people-product relationships and understanding people's motivations for keeping or letting go of their belongings. By hosting the workshop in a physical space, each participant is encouraged to repair a personal item through visible mending practices, materializing and sharing their relationship and motivations for the repair.

The choice of visible mending as a leading factor in our exploration is rooted in our recognition of and appreciation for its practical and metaphorical strengths: First, visible mending provides a solution for fixing the commonplace issue of having broken garments. Due to daily use practices, clothing items are naturally prone to wear, tear and stains. Most textiles are suitable for updating through patching or darning. Although some garments require professional skills, many fixes are relatively easy to do by oneself with accessible tools and materials and comprehensible techniques. The visibly mended area becomes a new characteristic feature that gives the garment a personal touch. A garment that appeals to our senses can have a lasting, meaningful presence in our lives (Bruggeman, 2020). Chapman & Marmont (2017) argue that a product that stays in motion is better able to withstand obsolescence. Through time and effort spent adding layers of repair and alteration, the act of visible mending has the potential to create a bond between the mender and the garment (Sekules, 2020). Mending is an act of care that allows the garment to grow and transform with us, taking on a new life and carrying with it the memories of previous ones. Second, visible mending opens up space for thinking about broader meanings of repair. A metaphorical quality lingers between the layers built with each repairing thread or piece of fabric, nudging thoughts that go beyond the tactile on what it means to repair, and how we might otherwise perceive what is broken.

Over approximately one year (2023-2024), 11 workshop sessions were conducted in both Japan and the Netherlands on various

occasions (Table 1), engaging a total of 75 participants. Data was collected through written notes and observations, audio transcripts and photographs. Participants were given workbooks to fill in and refer to throughout the session, which also functioned as data collection tools. Digital scans or photos were taken of the workbooks to be archived before being returned to the participants to take home as a memento post-workshop. Online or printed questionnaires were used to gain additional insights into participants' backgrounds and their prior experiences regarding mending and repair.

Date	City, Country	Sessions	Participant Number
10-06-2023	Kyoto, JP	2	18
21-07-2023	Amsterdam, NL	1	8
08-08-2023	Almere, NL	1	6
16-03-2024 17-03-2024	Tokyo, JP	4	21
28-03-2024	Rotterdam, NL	1	8
17-09-2024	Rotterdam, NL	1	11
29-09-2024	Utrecht, NL	1	3

Table 1. Overview of workshop sessions.

Elements of the workshop

The workshop offers a space for learning how to visibly mend and reconnect with one's beloved wearable items. Participants are encouraged to bring personal items that need repairing, such as a backpack with holes, or a stained sweater. Yarns, fabrics and sewing equipment are provided, though participants are allowed to bring their own. The workshop is designed for beginners while providing creative space for more experienced individuals. The duration of one session varies between 90 minutes to 3 hours, depending on the setting and collaborators. The workshop is divided into three parts: (1) Mending a leaf, (2) Practicing visible mending, and (3) Mending a personal item. A workbook is used as a leading tool for the participants to work with throughout the session. The workbook's purpose from a data collection perspective was to unobtrusively gather insights into people's 'everyday ways of knowing' (Pink, 2015). It aimed to unravel the often unspoken stories behind people's daily behaviour and their relationships with their garments. Each individual receives one at the start of the workshop to document their thoughts and plans for mending their item. The workbook intends to seamlessly integrate into the mending process, acting as a step-by-step guide allowing everyone to progress at their own pace. By adding a layer of playfulness, the workbook becomes part of the mending experience, fostering the participants' creative thinking and heightening their sense of materiality. The layout allows participants to add notes, drawings and material swatches to clearly express their ideas and track their progress. Questions and hints guide the participants towards successfully mending their items. Additionally, an overview of the visible mending techniques taught in the workshop is included as a reference. After the session, each participant takes their workbook home as a keepsake and resource to inspire future mending projects.

Part 1: Mending a leaf

During the first part of the workshop, each participant is given a leaf and instructed to "mend" it in 10-15 minutes. This tangible thought experiment utilizes the unique silhouettes of the leaves to create a connection to the idea of mending while allowing participants to be creative and contemplate broader meanings of mending and reimagining repair. The open-ended prompt allows participants to approach the task of mending without feeling constrained, as there are no right or wrong methods to mend a leaf. This fosters improvisation and encourages trust in their intuition as they react to the material in their hands and make their creative decisions. The prompt aims to reduce barriers to hands-on making before any formal instructions are given. While working on their leaf, participants were asked to think about what mending means to them and share their thoughts with the group after the exercise. A myriad of reflections unfolded, both material and immaterial. As each leaf was different and



Figure 1. A leaf mended using needle and thread to stitch the torn part.



Figure 2. A leaf mended using a needle, thread, and a piece of fabric.



Figure 3. Participant 4 initially thought to mend the holes in the leaf she guessed were made by bugs, "But then I realised they're actually too small to fix with needle and thread, and then I started asking myself if there was a need to fix them." Instead, she chose a ribbon with "the organic pattern to try to make a frame for the holes rather than fixing them."

uniquely 'broken', participants had to navigate their leaf's materiality and perceived 'repair needs' with the utmost care. Some participants opted for a repair where holes and tears were sewn shut (Figure 1), while others chose to patch and reinforce the leaf by adding a new layer to the original structure (Figure 2). The leaves opened up conversations about various aspects of mending, including functional and aesthetic purposes, restoration, reconstruction, and storytelling. A few participants questioned the brief, activating considerations about the necessity of repairing the leaf, and the reasons behind our motivations for repair (Figure 3).

Part 2: Practicing visible mending

In Part 2, the shift is made to textiles. Participants are introduced to the concept of visible mending and practice different techniques for repairing holes and covering stains. Over time, the introduction has become more comprehensive, incorporating a range of historical and contemporary mending examples to provide participants with a more holistic understanding. We have gradually included more visual references that showcase the techniques used by previous participants to mend their broken items, which have proven to be a useful source of inspiration for attendees of subsequent workshops to inform their own repairs. They contribute to Making Mends a state of flow and constant development (Konovalov et al., 2023).

The focus of the practice session, like the overall attitude of the workshop, is on learning by doing. Practising with small fabric pieces first (Figure 4) helps participants understand material characteristics, guiding their choices for mending their items. We have identified several recurring themes in participants' mending experiences, such as materiality, connection to memories, physical challenges, and knowledge sharing (see Table 2). Participant 3 wrote about his struggle to grasp the suitable distance between each stitch (Figure 5). He continued to describe how he gradually understood the method and how the process brought back memories of his mother repairing his belongings. Similarly, Participant 15 shared her past experiences of how she used to sew for herself and her family. She

Participant No.	Quote	Theme
3	“It felt like the fabric began to fall apart if I stitched too close to the edge of the hole."	Materiality
13	"I really had to handle it (the leaf) with care because of it falling apart if you pushed it too hard, or… Because I had this one [needle], but the holes were too big, so it was already falling it apart more than…"	
15	[I used to sew for family and myself …] “But now, because my eyes… when you put a needle… I am not anymore patient about it, so I said ‘’ah, I love to do it, but oh, I cannot see it.’’ So that’s the thing.”	Physical Challenges
17	"Do you have glue?....Because I’m having a hard time with one hand, you know?"	
3	"It (mending his jacket) reminds me of Mom. (My mom fixed it for me on New Year's Eve.) When I went back to my parents' house, I told her to fix it and she fixed it."	Memory of Mending
22	“I started wearing it less since it’s broken... I’m so happy that I can wear it again!”	Pride/Joy in Result
19	“I’m happy because I feel like I can really wear it again without feeling embarrassed about the stains.”	
69	“It’s personal and I like the fact that I can make it look cute, fun and different for my daughter!”	Mending for Others
2	"At times I felt frustrated because I didn't want to make mistakes and make it look perfect for my friend!"	
2	"Feeling very encouraged to finish this project as it would be nice to give my friend the mended trousers"	
7	"It was so nice to take the time to consider the actions I was taking to repair my item. I find life can get busy so to put aside the time felt very good"	User Agency
8	"I would like to continue to incorporate this into my daily life and I am very proud of myself!"	
3	"I wanted to fix it but didn't have time, so I'm glad I was able to do it! I'm also glad that I have the freedom to fix it however I want."	

Table 2. Overview of identified themes and corresponding participant quotes.

was an experienced sewer but needed assistance threading her needle due to poor eyesight. Participant 17 attended the workshop with an arm injury and quit sewing halfway through the session due to physical difficulties. Despite this, she remained engaged throughout, sharing her knowledge of handicrafts, and advising others. These experiences highlight that mending relies heavily on participants' eyesight and physical mobility, prompting the need for reflections on accessibility in the mending process to minimize potential barriers. Solutions suggested during the workshop included assistance with threading needles and using firmer fabrics. Participant 15 noted that rigid fabrics were easier to work with. Furthermore, these instances demonstrate that engagement in mending is not solely tactile; it can also involve sharing knowledge and providing guidance to others.

Part 3: Mending a personal item

Once participants feel comfortable with the practice, they start interacting with their personal items. This part showcases the wide range of possibilities for mending, which includes fixing signs of wear and tear, covering stains, and altering for a better fit. As mending has been identified as essential for supporting the longevity of garments and facilitating sustainable transitions in clothing use practices (Durrani, 2018), it was important to invite workshop participants to bring and mend a personal item to emphasize individual practices of use and facilitate longer product use through repair. The workbook prompts participants to reflect on their mending process, their feelings about the results, and where they picture they would wear their mended item in the near future. Multiple participants shared remarks expressing their excitement to wear the personal items in public again (Table 2).

Several participants brought items belonging to their children for mending. Participant 2 brought an item belonging to a friend (Figure 7). During one session, participants with no items repaired the belongings of others who brought extra items. We found acts of Mending for Others valuable as they lead to successful repairs and highlighted the entanglement of the material and the social in communal repair practices (Van de Velden, 2021; Durrani, 2018). Communal repair provides individuals



Figure 4. A participant's practice piece of patching a hole.

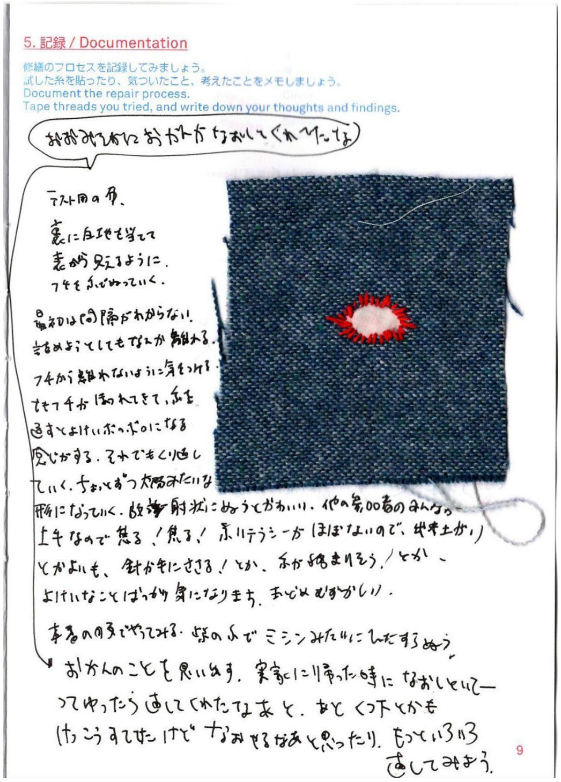


Figure 5. Participant 3's workbook documenting his thoughts during the process of learning to mend.

with a direct and tangible opportunity to contribute to a CE. Combining material efforts with social interaction through communal repair supports circular goals of product-life extension and waste reduction, while also fostering social values, including sharing, a sense of achievement and emotional attachment, and care for others. The instances of Mending for Others that we observed



Figure 6. Mending result of Participant 19. The stains on the t-shirt were 'framed' with stitches to make them less visible.

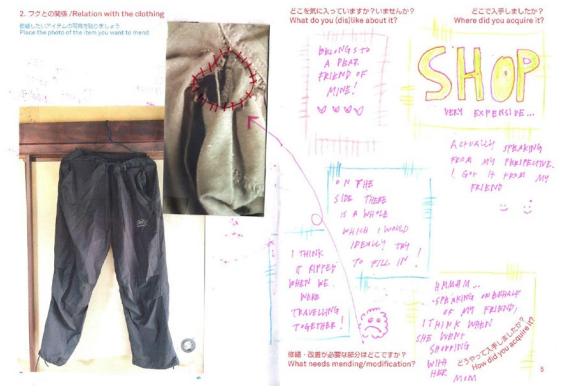


Figure 7. Scan of the workbook of Participant 2. The trousers belong to her close friend, who trusted her to repair them. They got ripped while they were travelling together. She chose an invisible mend because she believed it would create a neater appearance that her friend would like, while minimizing the visibility of any mistakes she might make as a beginner in sewing.

involved individuals who were connected through friendships and other close relationships; Participant 69 expressed a sense of joy in mending something for someone you care about. We noted a thoughtful consideration of the needs and preferences of the person whose item was being repaired. Mending for Others demonstrates that repair strategies are informed by social interactions (Van der Velden, 2021), igniting conversations and collaborative tryouts that lead to meaningful repairs that can last. On the other hand, this suggests that a lack of such close relationships may impede the willingness to mend for others, or that at least a certain level of trust is necessary among those involved.

Visible mending is both a collective and an individual endeavour. When someone joins the table with an item they have owned for a decade or several months, they not only engage in the act of mending but also share stories behind the item. They learn how to repair from and with others, fostering a sense of community around the mending process (DiSalvo et al., 2013). To keep the mending going post-workshop, we have set up an online Making Mends Map (Figure 8). Several posts indicate that items mended during the workshop were still in use, and some participants repaired additional items after the workshop, for themselves and others. People felt excited to share their mending experiences with friends and relatives. One post proudly stated that they "motivated a few others to repair their garments and not throw them out".

Conclusions

The Making Mends Workshop is an in-depth exploration of meaning-making processes of repair through the act of visible mending. It provides a physical space where people can actively engage in visible mending in several ways. First, workshop participants contemplate both practical and conceptual meanings of mending and repair through a mind-provoking creative exercise of mending a leaf. Second, the workshop aims to give further context to visible mending by sharing historical and contemporary practices. Third, participants learn various visible mending techniques and apply their skills to repair a personal item. Through this process, participants reflect on how they are restoring meaning in their relationship with the item.

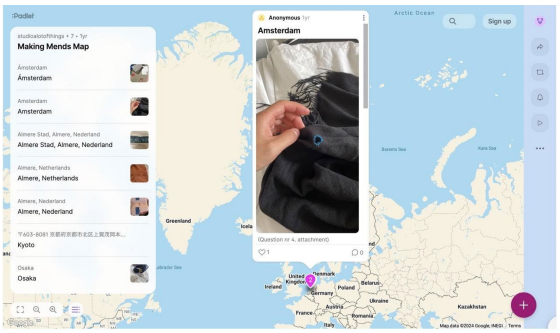


Figure 8. Screenshot of the Making Mends Map, created on the collaborative web platform Padlet. The map can be accessed via: https://sites.google.com/view/studio-a-lot-of-things/more-things/making-mends-map

Making Mends aims to add to the research of previous scholars regarding 'meaningful' relationships between people and products (Chapman & Marmont, 2017; Fletcher, 2016). Key in Making Mends is promoting user agency by fostering skill and knowledge development while encouraging creativity and positive emotions, such as pride and joy, when individuals engage in repairing their possessions. The workshop showcased visible mending as a significant practice of communal repair that can contribute to the CE by promoting product-life extension, maintaining both material and emotional value. We identified Mending for Others as a valuable addition to communal repair, where repair strategies benefit from social interactions that involve knowledge and skill sharing, expressing care, joy, and creativity, ultimately leading to durable repairs. We acknowledge the limitations of our small data set and recognize that further research is needed to expand the effectiveness of Mending for Others as a worthwhile practice. Through interactions with participants, the reliance on physical mobility during the mending process was identified as a potential barrier, pressing for more research on the accessibility of visible mending.

This paper outlines the experiences and findings of the first year of Making Mends, during which we engaged a diverse group of participants and collaborated with various organisations in education, business and creative practices. Moving forward, we aim to continue our investigation through the Making Mends workshop, involve many more stakeholders and expand our reach to get more people mending. We hope that Making Mends serves as a source of inspiration for action and reflection, and that our preliminary findings can enrich how we design and repair within a CE, fostering environmentally and socially responsible actions.

Acknowledgments

We wish to thank our participants and collaborators for their great energy in joining Making Mends.

References

Andersen, K., & Wakkary, R. (2019). The Magic Machine Workshops: Making Personal Design Knowledge. CHI Conference on Human Factors in Computing Systems, 1–13. https://doi.org/10.1145/3290605.3300342

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a CE. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bruggeman, D. (2020). Searching for the New Luxury? Fashion Colloquium 2018 revisited. APRIA Journal, 1(1), 1–10. https://doi.org/10.37198/APRIA.01.00.a1

Carr, C. (2023). Repair and care: Locating the work of climate crisis. Dialogues in Human Geography, 13(2), 221–239. https://doi.org/10.1177/20438206221088381

Chapman, J., & Marmont, G. (2017). The Temporal Fallacy: Design and emotional obsolescence. In Routledge Handbook of Sustainable Design. Routledge. https://doi.org/10.4324/9781315625508

Corwin, J. E., & Gidwani, V. (2021). Repair Work as Care: On Maintaining the Planet in the Capitalocene. Antipode, anti.12791. https://doi.org/10.1111/anti.12791

Dewberry, E. (2016). A landscape of repair.

DiSalvo, C., Clement, A., & Pipek, V. (2013). Communities: Participatory Design for, with and by communities. In Routledge International Handbook of Participatory Design. Routledge.

Durrani, M. (2018). "People Gather for Stranger Things, So Why Not This?" Learning Sustainable Sensibilities through Communal Garment-Mending Practices. Sustainability, 10(7), Article 7. https://doi.org/10.3390/su10072218

Durrani, M., Niinimäki, K., & Mclauchlan, S. (2021). Designing for and with Garment Repair: An Exploration of Future Possibilities. PLATE – Product Lifetimes And The Environment, Berlin, Germany. https://doi.org/10.14279/depositonce-9253

Ellen MacArthur Foundation. (n.d.). The Circular Design Guide. Retrieved January 17, 2022, from https://www.circulardesignguide.com/

Ellen MacArthur Foundation. (2017). A New Textiles Economy: Redesigning fashion's future. https://www.ellenmacarthurfoundation.org/a-new-textiles-economy

Fletcher, K. (2016). Craft of use: Post-growth fashion. Routledge, Taylor & Francis Group. https://doi.org/10.4324/9781315647371

Konovalov, M., Noronha, J. V., & Kuusk, K. (2023). Layers of repair increasing the emotional durability of fashion and textiles.

Maldini, I., Stappers, P. J., Gimeno-Martinez, J. C., & Daanen, H. A. M. (2019). Assessing the impact of design strategies on clothing lifetimes, usage and volumes: The case of product personalisation. Journal of Cleaner Production, 210, 1414–1424. https://doi.org/10.1016/j.jclepro.2018.11.056

Mattern, S. (2024). Step by Step. Places Journal. https://doi.org/10.22269/240227

Niinimäki, K., & Durrani, M. (2020). Repairing Fashion Cultures: From Disposable to Repairable. In Transitioning to Responsible Consumption and Production. MDPI. https://doi.org/10.3390/books978-3-03897-873-2

Pink, S. (2015). Doing sensory ethnography (Second edition). Sage Publications.

Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The CE: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the CE through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling, 135, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Sekules, K. (2020). Mend! A refashioning manual and manifesto. Penguin Books.

van der Velden, M. (2021). 'Fixing the World One Thing at a Time': Community repair and a sustainable CE. Journal of Cleaner Production, 304, 127151. https://doi.org/10.1016/j.jclepro.2021.127151

Wolstenholme, H. (2017, March 15). Celia Pym is mending the human heart through knit. 1 Granary. https://1granary.com/designers-3/schools/royal-college-of-art/celia-pym

Extended Abstract
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Repair as a vehicle for grassroots leadership in transition towards circular economy

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Keywords: Repair; Circular Economy; Transition; Participatory Design; Grassroots Leadership.

Introduction

In 2020 the UK generated the 2nd largest quantity of e-waste per capita in the world (Forti et al., 2020). Trends predicted that by 2024 the UK could become the world's largest e-waste generator (Ali, 2023). Much of this waste contains toxic substances and is exported to non-OECD nations (Odeyingbo et al., 2017; Puckett et al., 2018). The situation is driven by excessive consumption and structural problems with recycling. This perhaps also indicates a lack of agency to participate effectively at personal and community levels in the transition towards circular economy (CE).

This paper reports initial insights from an ongoing project to develop localised repair infrastructure in the West Gateshead area (WG) of Northeast England. Insights are drawn from experiences of organising and engaging in repair cafes as expert fixers, and engaging research expertise in contribution to the development of the project. Emergent understandings of the wider value of repairing, beyond simply restoring the original function of a thing, have been gained empirically through ethnographic observation. These understandings are framed by current discourse relating to barriers to participation in CE.

CE concepts focus predominantly on material and financial capitals. This inquiry takes the critical stance that a pluralistic understanding of capitals and their modes of exchange is crucial to enabling greater participation in CE. The integration of social dimensions with CE remains unclear and underdeveloped in much of the literature (Geissdoerfer et al., 2017). Prevailing CE conceptualisation tends to overlook the social dimension of sustainable development (Kirchherr et al., 2017) and conflicts with arguments in favour of degrowth strategies. The 9 Rs framework (van Buren et al., 2016) provides a pathway towards establishing CE, within which repair and reuse are crucial enablers. CE strategies are typically characterised by 'top-down' regulations and policies (Ghisellini et al., 2016; Pesce, Tamai & Guo, 2020; Deniz, 2021), however 'bottom-up' multi-stakeholder engagement is increasingly recognised as crucial to CE transition.

Research Context

The inquiry is situated within WG and involves two local community regeneration groups (CRGs). Past withdrawal of primary industry from the area is a significant determining factor for increased levels of social deprivation now present in WG. Both CRGs are generally involved in holistically addressing localised challenges of social, economic and environmental wellbeing, although their respective goals are nuanced:

- CRG 1 is a *transitions* group (global transitions movement) that advocates for individual and community responses predominantly focused on concerns of climate, ecology and environment.
- CRG 2 is a regeneration group that supports community-led social and economic development through the creation and maintenance of community infrastructure, responding to issues of social deprivation.

The interview sample group includes: two social entrepreneurs who run repair café events, and a third who is developing a service model to provide local, accessible repair capacity; three members of the CRG organisations; two community leaders who work with the CRGs with particular interests in strategies for collaboration, increasing opportunities for learning and skills attainment, and informing local policy.

Methods

This inquiry is a single case study is situated within a wider *action research* project, centred on the practice of design leadership in the context of community regeneration. The inquiry adopts methods common to Design Ethnography (Baskerville & Myers, 2014; Crabtree, Rouncefield & Tolmie, 2012), where the object of design is a community-led repair service system. Working with the CRGs and key collaborators, researchers are embedded within the conception-planning-execution-evaluation of community-led initiatives. Primary data was gathered through participation in seven pop-up repair events, alongside semi-structured interviews with eight individuals. Interviews took place in-situ either during the preparation for, or delivery of, repair events. Due to their situated nature, interviews were documented through field notes, and analysed using conventional content analysis (Hsieh & Shannon, 2005). Practitioner reflection is embedded in sense-making of the dynamic participatory situation in respect emerging themes, critical issues and scholarship.

Key Observations

During 12 months of engagement a rich narrative is developing about the value of repair and repairing in the community. Findings are limited by the small sample size and single research site. The modelling of themes is propositional and intended to inform subsequent action. Positive impacts can be visualised as rippling outwards (figure 1) from the object, through individuals and groups involved, to the wider community, and potential beyond. Forms of value have been articulated by collaborators and stakeholders in relation to the following thematic foci:

1. **Repaired object:**
- Extending lifespan and reduction in waste.
- Feedback loops back into industry, manufacturers and value-chain.
- Warranties as a way of holding manufacturers to account for the longevity and fitness of their goods.

2. **Repairer:**
- Personal satisfaction of successfully effecting a repair.
- Emphasis on practical discovery and hands-on learning.

3. **Repairers and service users:**
- Helping people avoid expense of replacing goods.
- Fostering community relatedness.
- Benefitting from the exchange of time, knowledge and skills within the community.
- Helping people become aware of- and embrace- a different mindset of consumption.
- Formalising ways of working to rethink waste by leverage creativity.

4. **Wider community:**
- Developing local micro-economic opportunities and new revenue streams.
- Community repair resource as a skills development platform to support confidence and employability.
- Developing localised models to increase participation in CE transition through repair capacity, informing local policy and increasing stakeholder cooperation.
- Helping address some prevalent challenges for the local demographic; social isolation, loneliness, unemployment.

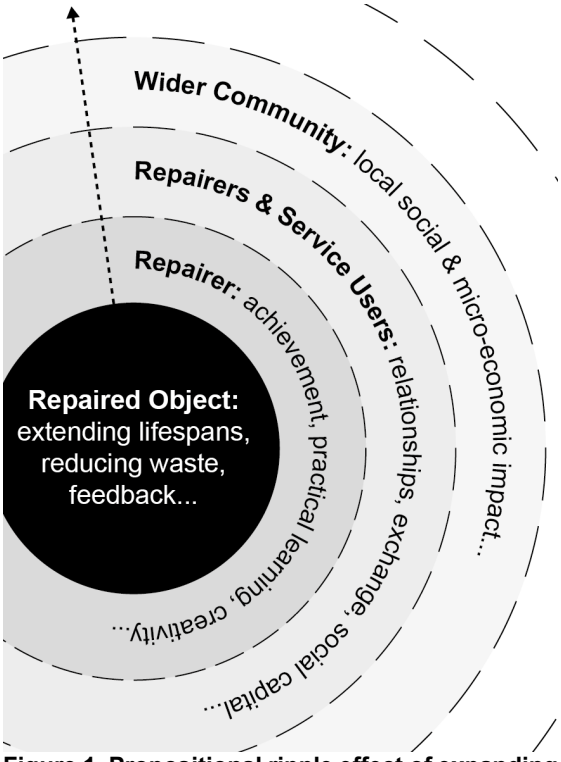


Figure 1. Propositional ripple effect of expanding degrees of value as speculation relating to the social dimension of CE transition.

Conclusions

The value of repair is often characterised in terms of reducing waste, extending product lifespans and avoiding replacement costs. However, when enacted through active community participation, this overlooks a multitude of wider contributions spanning more diverse forms of value. According to those substantively involved in developing and delivering the project, the value of *repairing* incorporates empowering individuals to take control of their own consumption; creating a locus for collective action and building community; fostering the exchange of knowledge, skills, tools and time as a fuller spectrum of capitals.

This case study shares insights from a project in its formative stages, where the priority is towards action and knowledge exchange, with funding granted according to these purposes. More detailed, summative outcomes will follow as the project progresses. However, the project is revealing tangible and concrete links to an expanded understanding of circularity, which are relatable at a local community level and open to intervention through grassroots leadership. This demonstrates through practice the importance of bottom-up approaches in transition towards the circular economy.

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References

Ali, R. (2023, January). Mobile Emissions. Uswitch. https://www.uswitch.com/mobiles/compare/sim-only-deals/mobile-emissions/

Baskerville, R. and Myers, M. (2014). Design ethnography in information systems. Information Systems Journal, 25(1), 23-46. https://doi.org/10.1111/isj.12055

Crabtree, A., Rouncefield, M., & Tolmie, P. (2012). Doing design ethnography. Human–Computer Interaction Series. https://doi.org/10.1007/978-1-4471-2726-0

Deniz, D. (2021). Sustainable design thinking and social innovation for beating barriers to circular economy. WIT Transactions on Ecology and the Environment. https://doi.org/10.2495/sc210191

Forti, V., Baldé, C. P., Kuehr, R., Bel, G., Jinhui, L., Khetriwal, D. S., Linnell, J., Magalini, F., Nnororm, I. C., Onianwa, P., Ott, D., Ramola, A., Silva, U., Stillhart, R., Tillekeratne, D., Van Straalen, V., Wagner, M., & Yamamoto. (2020). The Global E-waste Monitor 2020: Quantities, Flows, and Resources. In Ensure healthy Lives and Promote Well-being for All. Experiences of Community Health, Hygiene, Sanitation and Nutrition.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. Qualitative Health Research, 15(9), 1277–1288. https://doi.org/10.1177/1049732305276687

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11-32. https://doi.org/10.1016/j.jclepro.2015.09.007

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127(September), 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Lacy, P., et al., 2015. Circular Advantage: Innovative Business Models and Technologies to Create Value in a World Without Limits to Growth. Available at: https://www.accenture.com/t20150523T053139__w__/us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Strategy_6/Accenture-Circular-Advantage-Innovative-Business-Models-Technologies-Value-Growth.pdf.

Odeyingbo, O., Nnorom, I., & Deubzer, O. (2017). Assessing import of used electronic and electronic equipments into Nigeria, Person in the port project.

Pesce, M., Tamai, I., Guo, D., Critto, A., Brombal, D., Wang, X., … & Marcomini, A. (2020). Circular economy in china: translating principles into practice. Sustainability, 12(3), 832. https://doi.org/10.3390/su12030832

Puckett, J., Brandt, C., & Palmer, H. (2018). Holes in the Circular Economy: WEEE Leakage from Europe. A Report of the e-Trash

Transparency Project. A Report of the E-Trash Transparency Project, 120. www.ban.org

van Buren, N., Demmers, M., van der Heijden, R., & Witlox, F. (2016). Towards a circular economy: The role of Dutch logistics industries and governments. Sustainability (Switzerland), 8(7), 1–17. https://doi.org/10.3390/su807064

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The Value of Emerging Technologies for Enhancing Consumer Trust and Adoption of Repair Electronics

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Keywords: Design for Repair; Sustainable consumer behaviour; IoT; Ai; Immersive Technology.

Introduction

Consumers often replace electronic products prematurely due to performance issues (Van den Berge et al., 2021). Repair is a promising strategy to extend product lifetime by correcting faults to restore functionality (Pamminger et al., 2017) or realigning the product performance with users' functional expectations via upgrades (Godfrey et al., 2022). However, repair activities declined over the past decades with 60% consumers disregarding repair when products malfunction (Magnier & Mugge, 2022). Recent consumer studies have revealed the barriers to repair. Consumers often struggle to diagnose product failures (Ackermann et al., 2018; Pozo Arcos et al., 2021), causing uncertainty about repair paths. Previous negative repair experiences further demotivate repair (Sonego et al., 2022), making consumers doubt its value (Svensson-Hoglund et al., 2022). The uncertainty about the availability of spare parts, clear repair instructions, and trustworthy repair services increase concerns about repair (Jaeger-Erben et al., 2021; Sonego et al., 2022). These lead to a lack of consumers' trust, acceptance and adoption of repair practices.

Current "design for repair" studies focus on product architecture, especially ease of disassembly (Dangal et al., 2022). These tackle the technical ability to repair but do not address consumers' willingness to repair (Van den Berge et al., 2022). There are two notable exceptions. Van den Berge et al. (2023) revealed that a sensor-based fault indication enhanced consumers' self-efficacy and repair willingness. Similarly, Tadeja et al. (2023) found that Augmented Reality (AR)-based guidance for 3D-printer repair reduce cognitive workload, thereby boosting users' confidence in repair.

Research in automotive and industrial sectors have demonstrated that emerging technologies can provide many more opportunities for repair (Palmarini et al., 2018). However, a comprehensive overview of the potential impact of emerging technologies on facilitating consumer electronics repair is still missing.

This study explores how the value of emerging technologies, applied in broader repair domains, can be adapted to support consumer electronics repair. It bridges the gap between technology capabilities and consumer repair barriers, contributing to the fields of repair and sustainable consumer behaviour.

Method

We conducted a literature review of patents and academic papers to identify existing tech-enabled repair solutions from broader domains including the industrial and automotive sectors. Through this analysis, we translated these insights into opportunities for technologies to facilitate consumer electronics repair.

The World Economic Forum (2024) has identified 10 emerging technologies. Artificial Intelligence (AI), Immersive Technology, and IoT-enabled applications were selected for this study based on two criteria: 1) consumers can directly engage with this technology, and 2) this technology is applicable to product design or interaction design or product service design.

The selection criteria for design solutions are as follows: (1) the product category should fall within white or brown goods, transportation, industry equipment; (2) the technology implemented should be AI, Immersive Technology, IoT or a combination; (3) the solution should describe the functions related to repair; (4) the solution should indicate the impact on the human workflow in repair.

Preliminary Findings

Through literature review, we have gained a comprehensive understanding of the repair

journey, identified several challenges, and explored the potential capabilities of various technologies.

Five Stages in Repair Practice

The repair journey (Figure 1) was iterated from 'five steps of repair' (Lefebvre, 2019; Russell et al., 2022), including: *Repair interest; Repair pathfinding; Repair arrangement; Repair action;* and *Post repair*. Instead of a single decision, we perceive repair as a journey of multiple product value trade-offs, involving 1) choices between DIY repair and service repair, and 2) potential product disposal in every stage.

Repair interest begins when consumers perceive misalignment between a product's condition and their functional expectations (Godfrey et al., 2022). Consumers either adapt to these misalignments, pursue repair or dispose of the product. *Repair pathfinding* is an information gathering process, including fault diagnosis (Pozo Arcos et al., 2020), accessing repair guidance and service information (Güsser-Fachbach et al., 2023). Disposal may occur due to the difficulty in identifying suitable repair paths (Van den Berge et al., 2021). *Repair arrangement* concentrates on gathering necessities, such as purchasing spare parts (Pamminger et al., 2017) and assessing service cost (Godfrey & Price, 2023). Disposal remains possible due to unacceptable cost or inaccessible parts. *Repair action* involves practical steps of adjusting product functionality, including disassembly, parts replacement, reassembly, and functional testing (Pozo Arcos et al., 2018). Failure, such as component breakage during repair (Pamminger et al., 2017) or irreversibility of fasteners (De Fazio et al., 2021), can still lead to disposal. In *Post repair*, normally consumers will continue using the repaired product but it is also possible that they still replace or dispose of the product, for example if they perceive a low product reliability after repair (Raihanian et al., 2016).

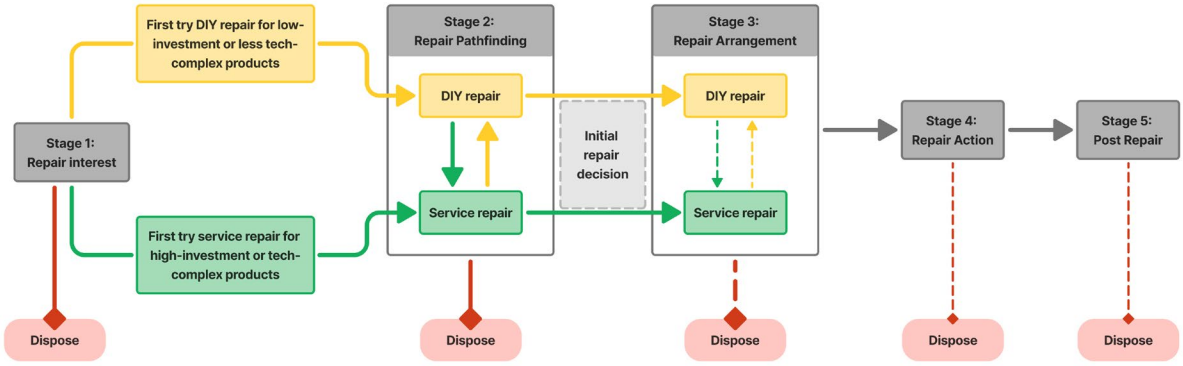


Figure 1.Overview of Repair Journey

Technology Capabilities

A literature review was conducted to define the capabilities of IoT-enabled applications (Ingemarsdotter et al., 2019), AI (Baltrėnaitė-Gedienė et al., 2020; Nishant et al., 2020), and Immersive Technology (Eswaran et al., 2023; Tadeja et al., 2023) in the context of repair. This resulted in the initial framework of technology capabilities and repair opportunities (Figure 2).

Analysis of Design Solutions

After collecting design solutions, we categorised them according to the following criteria: 1) Repair Type: DIY repair/service repair/both; 2) Product Category; 3) Implemented Technology. We include repair type because the design for service repair and DIY repair differs largely in terms of functional requirements and interactions.

Each design solution is mapped onto the framework to show the technology capabilities it implements and how it effectively facilitates consumer repair. We discuss: 1) effective technology capabilities in facilitating consumer electronics repair, 2) ways in which technologies could impact different stages of the repair journey. We demonstrate the initial findings with examples in Figure 2, an AR assisted repair of industrial machine (Aromaa et al., 2018), an IoT repair system for automotive manufacturing equipment (Chen et al., 2019) and AI predictive maintenance implementation (Ucar et al., 2024).

	Technology Capabilities	Definition	Example in Facilitating Consumer Repair Process
IoT- enabled Applications	Tracking	Ability to collect the up-to-date information of the product's identity and/ or location.	Track the availability and location of spare parts to ensure service transparency and reduce waiting time based on demand forecasting (Chen et al., 2019). - *Repair Arrangement Stage*
	Monitoring	Ability to provide the information of a product's use, condition, including alerts and notifications.	Continuous monitoring of the equipment's condition could provide consumers with early notifications about potential issues (Chen et al., 2019). - *Repair Interest Stage*
	Control	Ability to change the product and system parameters (remotely and locally)	Adjust the operation of product in time to prevent further destroy (Chen et al., 2019), indicating the potential impact of malfunction and urgency of repair. - *Repair Interest Stage*
	Optimization	Ability to improve the product operations through the algorithms and analytics to in-use or historical data.	Schedule maintenance beforehand based on fault prediction to optimize product performance and repair system operations (Chen et al., 2019). - *Repair Arrangement Stage*
Artificial Intelligence	Learning	Ability to collect real-time and historical data from products and users to generate information that didn't exist before.	Learn from historical product data and past repair logs to generate specific, up-to-date repair steps (Ucar et al., 2024). - *Repair Action Stage*
	Pattern recognition	Ability to detect trends, correlations within the real-time and historical data.	Detect the potential faults based on real-time prognostics data (Chen et al., 2019), reducing the perceived technical barrier in fault diagnosis. - *Repair Pathfinding Stage*
	Reasoning	Ability to deduce the root causes based on the input information.	Deduce causes based on the predicted failure mode and the current state of the equipment to decide on the appropriate repair strategy (DIY/service/mix) (Chen et al., 2019). - *Repair Pathfinding Stage*
	Natural interaction	Ability to understand and respond to humans via speech, text and visual data.	AI repair assistant can give instructions through natural, conversational interactions (Ucar et al., 2024), enhancing understandability to reduce knowledge barriers - *Repair Action Stage*
Immersive Technology	Real environment capture	Ability to collect spatial information of the object and the context.	AR enables 3D visual repair reports (Aromaa et al., 2018), improving the understandability for consumers to enhance service transparency and build trust. - *Repair Arrangement Stage*
	Object positioning	Ability to identify a specific object and correctly position the virtual scene over real-world physical objects.	The system identifies components and visualizes clickable hotspots (Aromaa et al., 2018), allowing users to check component health for fault diagnosis. - *Repair Pathfinding Stage*
	Real-time rendering	Ability to process and display virtual information seamlessly overlaying it onto physical objects or environments.	Overlay system runtime data visually on the physical equipment (Aromaa et al., 2018), creating a tangible and urgent reminder for timely repair. - *Repair Interest Stage*
	Multi-sensory interaction	Ability to interact with digital elements within the physical space through gestures, touch, or gaze etc.	Gesture-based interaction with virtual repair guidance streamlines the repair workflow (Aromaa et al., 2018), eliminating the need to pause to check instructions. - *Repair Action Stage*
	Design Evolution	Ability to provide diverse data feedback from product lifecycle back to design.	The new 3D repair logs benefit knowledge sharing among technicians and design team (Aromaa et al., 2018), optimizing the repair service and product iteration.

Figure 2.Capabilities of technologies defined in the context of repair

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References

Ackermann, L., Mugge, R., & Schoormans, J. (2018). Consumers' perspective on product care: An exploratory study of motivators, ability factors, and triggers. *Journal of Cleaner Production*, *183*, 380-391. https://doi.org/10.1016/j.jclepro.2018.02.099

Aromaa, S., Väätänen, A., Hakkarainen, M., & Kaasinen, E. (2018). User Experience and User Acceptance of an Augmented Reality Based Knowledge-Sharing Solution in Industrial Maintenance Work. *Advances in Usability and User Experience, Ahfe 2017*, *607*, 145-156. https://doi.org/10.1007/978-3-319-60492-3_14

Baltrėnaitė-Gedienė, E., Ghoreishi, M., Happonen, A., & Iticescu, C. (2020). New promises AI brings into circular economy accelerated product design: a review on supporting literature. E3S Web of Conferences. https://doi.org/10.1051/e3sconf/202015806002

Chen, J., Gusikhin, O., Finkenstaedt, W., & Liu, Y.-N. (2019). Maintenance, Repair, and Operations Parts Inventory Management in the Era of Industry 4.0. *IFAC-PapersOnLine*, *52*(13), 171-176. https://doi.org/10.1016/j.ifacol.2019.11.171

Dangal, S., Faludi, J., & Balkenende, R. (2022). Design Aspects in Repairability Scoring Systems: Comparing Their Objectivity and Completeness. *Sustainability*, *14*(14). https://doi.org/10.3390/su14148634

De Fazio, F., Bakker, C., Flipsen, B., & Balkenende, R. (2021). The Disassembly Map: A new method to enhance design for product repairability. *Journal of Cleaner Production*, *320*. https://doi.org/10.1016/j.jclepro.2021.128552

Eswaran, M., Gulivindala, A. K., Inkulu, A. K., & Raju Bahubalendruni, M. V. A. (2023). Augmented reality-based guidance in product assembly and maintenance/repair perspective: A state of the art review on challenges and opportunities. *Expert Systems with Applications*, *213*. https://doi.org/10.1016/j.eswa.2022.118983

Forum, W. E. (2024). *Top 10 Emerging Technologies of 2024*. I. c. w. Frontiers. https://www.weforum.org/publications/top-10-emerging-technologies-2024/

Godfrey, D. M., & Price, L. L. (2023). How an ethos of repair shapes material sustainability in services. *Journal of the Academy of Marketing Science*. https://doi.org/10.1007/s11747-023-00993-9

Godfrey, D. M., Price, L. L., Lusch, R. F., Fischer, E., Giesler, M., & Ger, G. (2022). Repair, Consumption, and Sustainability: Fixing Fragile Objects and Maintaining Consumer Practices. *Journal of Consumer Research*, *49*(2), 229-251. https://doi.org/10.1093/jcr/ucab067

Güsser-Fachbach, I., Lechner, G., & Reimann, M. (2023). The impact of convenience attributes on the willingness-to-pay for repair services. *Resources, Conservation and Recycling*, *198*. https://doi.org/10.1016/j.resconrec.2023.107163

Ingemarsdotter, E., Jamsin, E., Kortuem, G., & Balkenende, R. (2019). Circular Strategies Enabled by the Internet of Things—A Framework and Analysis of Current Practice. *Sustainability*, *11*(20). https://doi.org/10.3390/su11205689

Jaeger-Erben, M., Frick, V., & Hipp, T. (2021). Why do users (not) repair their devices? A study of the predictors of repair practices. *Journal of Cleaner Production*, *286*. https://doi.org/10.1016/j.jclepro.2020.125382

Lefebvre, M. (2019). *To repair or not to repair: An investigation of the factors influencing prosumer repair propensity* Loughborough University].

Magnier, L., & Mugge, R. (2022). Replaced too soon? An exploration of Western European consumers’ replacement of electronic products. *Resources, Conservation and Recycling*, *185*. https://doi.org/10.1016/j.resconrec.2022.106448

Nishant, R., Kennedy, M., & Corbett, J. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. *International Journal of Information Management*, *53*. https://doi.org/10.1016/j.ijinfomgt.2020.102104

Palmarini, R., Erkoyuncu, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing*, *49*, 215-228. https://doi.org/10.1016/j.rcim.2017.06.002

Pamminger, R., Kuso, S., Wimmer, W., & Podhardsky, G. (2017). *Re-design of a digital voice recorder to meet*
the needs of circular economy-Status analysis 2016 Electronics Goes Green 2016+, Berlin.

Pozo Arcos, B., Bakker, C., Flipsen, B., & Balkenende, R. (2020). Practices of fault diagnosis in household appliances: Insights for design. *Journal of Cleaner Production*, *265*. https://doi.org/10.1016/j.jclepro.2020.121812

Pozo Arcos, B., Balkenende, A. R., Bakker, C. A., & Sundin, E. (2018). *Product Design for a Circular Economy: Functional Recovery on Focus.* Proceedings of the DESIGN 2018 15th International Design Conference. https://doi.org/10.21278/idc.2018.0214

Pozo Arcos, B., Dangal, S., Bakker, C., Faludi, J., & Balkenende, R. (2021). Faults in consumer products are difficult to diagnose, and design is to blame: A user observation study. *Journal of Cleaner Production*, *319*. https://doi.org/10.1016/j.jclepro.2021.128741

Raihanian, M. A., Esmaeilian, B., Cade, W., Wiens, K., & Behdad, S. (2016). Mining consumer experiences of repairing electronics: Product design insights and business lessons learned. *Journal of Cleaner Production*, *137*, 716-727. https://doi.org/10.1016/j.jclepro.2016.07.144

Russell, J. D., Svensson-Hoglund, S., Richter, J. L., Dalhammar, C., & Milios, L. (2022). A matter of timing: System requirements for repair and their temporal dimensions. *Journal of Industrial Ecology*, *27*(3), 845-855. https://doi.org/10.1111/jiec.13280

Sonego, M., Echeveste, M. E. S., & Debarba, H. G. (2022). Repair of electronic products: Consumer practices and institutional initiatives. *Sustainable Production and Consumption*, *30*, 556-565. https://doi.org/10.1016/j.spc.2021.12.031

Svensson-Hoglund, S., Russell, J. D., & Richter, J. L. (2022). A Process Approach to Product Repair from the Perspective of the Individual. *Circular Economy and Sustainability*, *3*(3), 1327-1359. https://doi.org/10.1007/s43615-022-00226-1

Tadeja, S. K., Solari Bozzi, L. O., Samson, K. D. G., Pattinson, S. W., & Bohné, T. (2023). Exploring the repair process of a 3D printer using augmented reality-based guidance. *Computers & Graphics*, *117*, 134-144. https://doi.org/10.1016/j.cag.2023.10.017

Ucar, A., Karakose, M., & Kırımça, N. (2024). Artificial Intelligence for Predictive Maintenance Applications: Key Components, Trustworthiness, and Future Trends. *Applied Sciences*, *14*(2). https://doi.org/10.3390/app14020898

Van den Berge, R., Magnier, L., & Mugge, R. (2021). Too good to go? Consumers' replacement behaviour and potential strategies for stimulating product retention. *Current Opinion in Psychology*, *39*, 66-71. https://doi.org/10.1016/j.copsyc.2020.07.014

Van den Berge, R., Magnier, L., & Mugge, R. (2022). *Enhancing consumers' willingness to repair electronic products: How design can nudge sustainable behaviour.* DRS2022: Bilbao. https://doi.org/10.21606/drs.2022.335

Van den Berge, R., Magnier, L., & Mugge, R. (2023). Sparking the Repair "Can-Do" Attitude-Enhancing Users' Willingness to Repair through Design Support in Fault Diagnostics. *International Journal of Design 17*. https://doi.org/10.57698/v17i3.02

Extended Abstract
6th PLATE 2025 Conference
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Repair-focused social enterprises for environmental and social resilience

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Keywords: Repair-led design; Lived experience; Place-based; Social impact; Creative repair.

Introduction

Social enterprises have solidified their position as being effective in addressing pressing environmental problems in the past few decades. Repair has emerged as a driving force behind many of them, especially in urban contexts where repair services have been dwindling due to the vast availability of cheap products. In addition to their value as resource maintenance services, they confront societal gaps such as rising unemployment amongst young people in disadvantaged areas (Barraket, Qian & Riseley, 2019). Various examples showcase how, by providing training in repair and reuse, they overcome the barriers of the labour market (Gutberlet, 2016), especially for young people that had some interaction with the legal system (Soppitt, Oswald & Walker, 2021) and at-risk due to early school leaving. In that way, they become the means to pursue environmental and social resilience, in condition of growing precarity.

CISERR – A Creative Repair Social Enterprise

Following this, the paper discusses an example of a newly-established social enterprise with an emphasis on creative repair, situated in Maryborough, a town in regional Queensland. The social enterprise is part of an ongoing initiative titled The Creative Industries, Social Enterprise, Repair and Restoration (CISERR), which has been operating since 2022 by Testimony Arts, a for purpose company, offering creative repair, literacy and numeracy, and life skills workshops to at-risk youth. The initiative has so far been directed toward young men that had some interaction or in danger of a future encounter with the youth justice system. Moreover, it is available as an alternative educational option to young men (15 – 19 years) that have been disengaged from conventional schooling. The impending need of employability pathways for CISERR's youth participants was predominant in the Monitoring, Learning and Evaluation (MEL) findings[1] from the pilot study (2021) and two iterations (2022-2023)[2] of the initiative. For that reason, the third round of the initiative was anchored in creating the circumstances to start a social enterprise in order to support at-risk youth getting prepared for employment or becoming self-employed.

The activities of the third round were grounded in putting together an infrastructure for the social enterprise and training young men to deal with the complexities of running it. This entailed the building of a trailer (figure 1) by the youth participants in collaboration with volunteers from the local Men's shed, to transfer and exhibit the artefacts created during the creative repair and art workshops. Furthermore, the third round consisted of dividing the youth participants into three creative specialisations (visual arts, arts communication and creation, repair and restoration), designed to prepare them for the

[1] This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Research Ethics and Integrity Office for Research, Griffith University (variation approved 27/02/2023—GU Ref No: 2021/734). Informed consent (to participate and/or to publish) was obtained from individual participants and parents/guardians.

[2] CISERR was based on a pilot study under the name Transformative Repair for Social Change (TRSC). A more detailed description of the MEL and findings from the pilot and two rounds are provided in other publications (Kalantidou and Brennan, 2024a; Kalantidou and Brennan,2024b).

production and curation/communication of the creative repair and art artefacts to be sold via the trailer.



Figure 1. CISERR's trailer. ©TammyBrennan.

Its use was trailed at the local markets in the fourth round of CISERR, which run between August and October of 2024, together with the readiness of the youth participants to operate a social enterprise by sourcing materials, producing creative repair and art artefacts, budgeting, setting up, selling merchandise and interacting with customers.

Methodologies and methods

To evaluate the effectiveness of the framework that was employed for this round as part of the MEL process, a mixed-methods methodology was adopted to collect data. This entailed quantitative data such as the number of artefacts, the consecutive weeks the trailer was taken to the markets and the respective sales as well as the youth participants' attendance rate. Regarding qualitative data, interviews were conducted with 11 youth participants, three youth workers and CISERR's director.

During this round, the CISERR trailer participated in the markets on eight consecutive Thursdays and over 70 artefacts were sold. The youth participants' attendance was almost 100 per cent. Their experience of using the trailer and repurposing artefacts through creative repair was captured via interviews, which focused on questions related to: the evaluation of the activities of the program; creative repair skilling opening employability pathways; and their willingness to go back to school. The youth workers' and director's interviews emphasised the effectiveness of the initiative, their role in it and their perception of the youth participants operating the trailer/social enterprise. Photographic material was also collected from the practice of creative repair, artefacts and market activity. For the analysis of the interviews and visual material, content analysis and visual content analysis were used, respectively.

Findings

The themes that emerged from the content analysis of the youth participants were: increased self-confidence by having a social interface and receiving positive feedback from the local community; self-capacity to repurpose artefacts and provide services at the market; a clearer vision of a future professional direction; and the possibility of self-employment through the social enterprise. The themes that arose from the youth workers' answers were related to: how the markets empowered the skills that CISERR offers (creative repair, art, literacy and numeracy, life skills); and the sharper focus of future employability that the trailer and the social enterprise provided. The youth workers also highlighted the behavioural shift of the young men while at the markets, their increased social skills and the gratification they experienced by being able to operate the trailer. They additionally stressed the necessity for a permanent space from which the social enterprise can function, where the youth participants would also have a 'home'. Finally, a separate interview with the director of CISERR outlined the steps that led to the realisation of the social enterprise, the possibility of it being a viable employability pathway for young people in Maryborough and the need to more actively involve the community and local schools in this effort. The visual and quantitative data reinforced the themes that surfaced from the interviews by evidencing the volume and quality of the creative repair work grounded in mentor-youth collaboration, youth participation and engagement.

Conclusions

Without disregarding the challenges that an endeavour like running a repair-led social enterprise with at-risk young men encompasses such as constant involvement of youth workers, ongoing funding to keep the workshops running, a permanent base for creation and storage, and greater community involvement, the CISERR social enterprise has set up the conditions for self, communal and material repair. The findings from the MEL process demonstrated that by establishing a physical and digital infrastructure, it gave agency to the youth participants to learn in

action, keep alive skills handed down through transgenerational exchange, demonstrate the creative side of working with repair and reuse, and re-engage with their local community. From an environmental and social perspective, the CISERR social enterprise salvages resources and introduces to the local public ways of repairing and reusing their things while it simultaneously repairs the relationship/perceptions between at-risk youth and their community. Envisioned as next steps are a permanent space also operating as a repair café and activating a community-based repair/reuse/share/exchange scheme.

Acknowledgments

We acknowledge the Traditional Owners/Custodians of the lands on which we work and live on across Australia, and their continuing connection to Country (land, sea and sky). We pay our respects to Elders, past and present. The success of the program is attributed to its people; the volunteers from the Men's Shed, the artists and repair/craftspeople, the cultural liaisons, the facilitators and most importantly the youth participants. The knowledge presented in this paper derived from the sharing of the participants' lived experience, evaluation and reflections on the CISERR initiative.

References

Barraket, J., Qian, J. and Riseley, E. (2019). *Social Enterprise: A people-centred approach to employment services. Report for Westpac Foundation*. Australia: Westpac Foundation and the Centre for Social Impact Swinburne.

Gutberlet, J. (2016). *Recovering resources-recycling citizenship: Urban poverty reduction in Latin America*. Routledge. https://doi.org/10.4324/9781315604084

Kalantidou, E., & Brennan, T. (2024a). Community Resilience by Repair: Skilling At-Risk Youth for Social Impact and Environmental Sustainability. In E. Kalantidou, G. Keulemans, A. Mellick Lopes, N. Rubenis (Eds.), *Design/Repair: Place, Practice & Community* (pp. 213-240). Springer Nature. https://doi.org/10.1007/978-3-031-46862-9_9

Kalantidou, E., & Brennan, T. (2024b). Co-designing Resilience: Practical and Social Skilling through Place-based Repair. *Diseña*, (24), 5-5. https://doi.org/10.7764/disena.24.Article.5

Soppitt, S., Oswald, R., & Walker, S. (2022). Condemned to precarity? Criminalised youths, social enterprise and the sub-precariat. *Social Enterprise Journal*, *18*(3), 470-488. http://dx.doi.org/10.1108/SEJ-06-2021-0044

Extended Abstract
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Transformative repair beyond materiality: care, bereavement and loss

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Keywords: repair; design, care; bereavement; death; transformative repair.

Introduction

Intuitively, the practice of repair is an act of care, a service that restores function to products supporting human activities concerned with comfort, pleasure, wellbeing or health. Repair can also be understood as an act of care for the environment, by helping to slow down accumulation of product in landfill, and by reducing energy and pollution intensive production of replacement goods. Literature on repair references care in relation to cities (Hall & Smith, 2014), the climate crisis (Carr, 2022; McLaren, 2018) and community repair cafes (Meißner, 2021). Repair is proposed as an inherently ethical and careful way of designing within "complex and traumatized ecological systems" (Crosby & Stein, 2020). Repair also extends an ethics of care across multiple domains and disciplines (Reeves-Evison & Rainey, 2018), beyond artefact typologies, suggesting repair concerns a wider range of people than those typically labelled repairers (Denis & Pontille, 2017). Design as a discipline has been critiqued for its failure to care (Rodgers et al., 2019). However, repair also suffers from marginalisation within design industry, perceived as an in-expert practice outside the discipline (Herweck in Zambeletti, 2024) potentially harming integrity of form (Sadler et al., 2024), while non-designers paradoxically struggle with its expert requirements (Berge, Magnier & Mugge, 2023).

We contend that not only is repair within the discipline of design, there is also scope for expanding repair via *transformative* forms that firstly transcend the convention of repairing old objects to 'as new' functionality, and secondly potentialize broader transformations in discipline, industry, culture or economy. To explore these possibilities, we introduce repair to designers and craftspeople in ways that leverage their professional skills for its innovation, to extend the capacity of design and craft, as material practices, beyond the repair of objects and towards the care of human relations.

Repair as a material practice is a form of craft that conserves and restores functional components within broken objects. In working with what already exists, in contrast to paradigms of design focussed on creating artefacts anew from raw materials, repair craft is literally 'careful' in the practical sense; broken objects can be fragile and must be treated with care to repair without causing further damage. Repair draws away from obsession with the creation of new things in hyper-consumerist cultures (Jackson, 2014), and so repair is 'carework' having social possibilities that challenge mainstream consumption culture (Reno & Isenhour, 2019). However, there is a tension to repair as an act of care noted by Drotbohm (2022):

> "On the one hand, the care concept features a protective and conservative dimension that is congruent with the past. On the other hand, the concept incorporates a transformational dimension through its notions of development, progress, and improvement."

Acknowledging the breadth and diversity of global repair practices, within the context of 21st Century affluent, Global North societies, the transformational dimension of repair is diminished by the marginalisation of repair in general. The advantages of repair to consumers are unclear when replacement products are less expensive and more easily accessed; circular economies need functioning

markets to work (Stahel, 2013), as addressed in our prior research on market-testing transformative repair (Keulemans et al, 2024). In this study, however, through participatory, practice-based research, we challenge this state of affairs by investigating how transformative repair processes can improve significance, aesthetics and values of care, in addition to restoring function. Evaluating a selection of case studies from the project Transformative Repair x JamFactory (TRxJF) conducted in 2023-24, we document and assess material transformations of objects connected to circumstances of loss and bereavement. These examples evidence the capacity for professional designers to creatively repair objects in ways that care for emotions, community wellbeing and other intangible values.

Theory and knowledge gap

In a material sense, all forms of repair are somewhat transformative. Largely missing from the literature on repair are examinations of creative styles of repair that explicitly intend to be visually, functionally or conceptually transformative. Our interest is how transformation may be intentionally designed to express care. We have, in prior research, instrumentalised Deleuzian-Guattarian concepts of affect to explore how transformative repair shifts affective 'assemblages', being the micropolitical arrangement of thoughts and perceptions within and between individuals (Keulemans, 2018). The transformative, yet traditional, Japanese ceramic repair practice of kintsugi was shown to resonate with care and catastrophe amelioration across wider macropolitical social and cultural registers (Keulemans, 2016). Affect is an appropriate framework for understanding the care within repair, because while there are other theories suitable for understanding the emotional impact of design, such as upcycling (Wegener, 2016) or emotionally durability design (Chapman, 2005), affect has a broader interrogative power to understand the "psychotechnologies" used by designers, including those of narrative-based marketing and experience economy (Marenko, 2010: 146).

However, as most widely practiced forms of repair are conventional, there is not many established transformative practices of repair upon which to examine personal, social or cultural impacts. It is our hypothesis that focussed study on transformative repair decisions made by professional designers will illuminate how improvements to social wellbeing can be intentionally delivered through repair practice. We do this in our methods by combining ethnography (interview of owners and designers to understand decision making) using narrative analysis (Reissman, 2001) with a qualitative aesthetic analysis of the repair outcomes informed by concepts of affect (Keulemans, 2015; 2016; 2018) however this work is ongoing and its full review beyond the scope of this article.

Methods

Working with industry partner JamFactory, an Adelaide-based craft and design organization, we released two Expressions of Interest (EOIs) seeking participants: people with objects in disrepair (Owners) and creative practitioners willing to repair them (Repairers). Submissions were reviewed and specific objects matched to specific repairers in consultation with both Owners and Repairers. As researchers, we mediated a negotiated cost of repair for Owners, additional to a fixed subsidy provided to Repairers. Participants were interviewed, and work in progress plus outcomes were documented in photography, exhibition and documentary video. The research process is diagrammed in Figure 1. A selection of three significant works from the eleven total works are illustrated. This sample size is small but sufficient for the project's qualitative focus on aesthetic and narrative analysis. Artefacts related to grief and loss were not sought nor expected from the EOI process, but their inclusion was not surprising either due to similarly linked objects emerging in our prior projects (Keulemans et at., 2017).

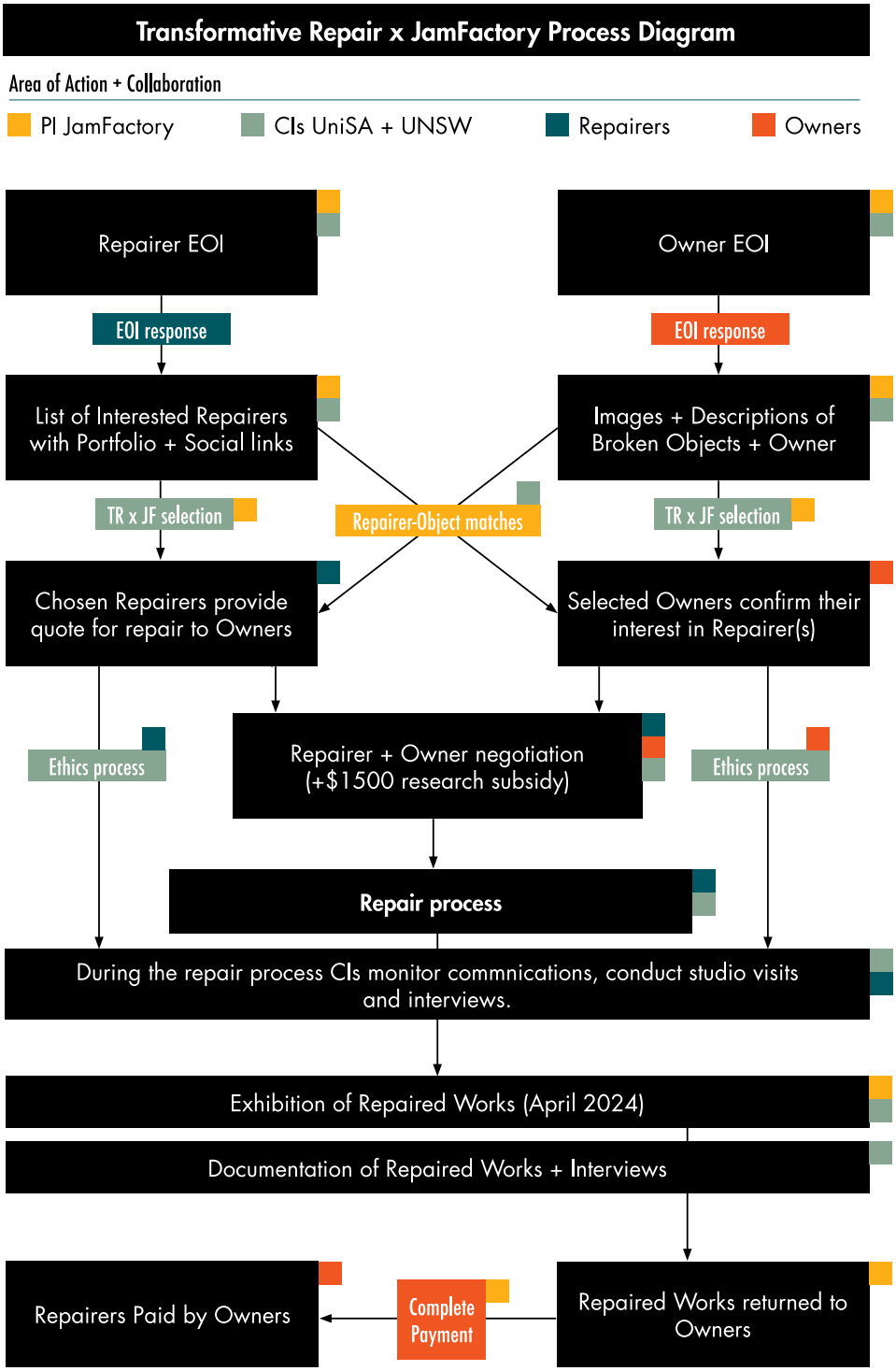


Figure 1. TRxJF Process Diagram ©TRxJF

Outcomes

The three selected objects and their repair are summarised:

A. Figures 2 & 3. A knitting table inherited by its owner upon the death of her mother. The colourful restoration of the table by Repairers Bolaji Teniola and Melvin Josy, using marquetry, staining and veneer bending, shifted the owner's appreciation for the table, helping to resolve complex feelings she had for her mother since inheriting the object.



Figure 2. Knitting Table, before repair ©TRxJF



Figure 3. Knitting Table, after repair by Bolaji Teniola and Melvin Josy ©TRxJF

B. Figures 4 & 5. Broken necklaces created by jeweller Alice Potter, an Adelaide designer who had recently died. The necklaces' owners sought approval from Alice's family before offering them to the project. The chosen Repairer, textile artist Kay Lawrence, found a collaborator to repair the necklaces conventionally, feeling it was inappropriate to transform them directly. Instead, she recreated their visual qualities into two new textile works, as a translation of Alice's particular skill in use of colour, inspired by Alice's experience of having synaesthesia (sensory crossover of numbers, colours and letters). The sensitivity and emotional impact of this repair was pre-figured in its earliest stages, as addressed by owner John:

"it wasn't long after Alice had died and it felt too raw or too soon, or maybe it didn't feel like my place to introduce those objects back into the world when people were still grieving. [but] maybe it is the right time for precisely those reasons. So … … [if] everyone feels like this might be a therapeutic or a healing thing, then we should try."



Figure 4. Alice Potter Necklaces, before repair ©TRxJF



Figure 5. Alice Potter Necklaces & new bandoliers after repair by Kay Lawrence ©TRxJF

C. Figures 6 & 7. Half a broken chair offered by notable Malay-Australian designer Khai Liew. Khai originally designed the chair in 2003; this particular chair belonged to a client. Tragically, Khai died from illness during the research project. Khai's passing inspired Repairer Andrew Carvolth to reflect on the influence and legacy of Khai's career. Inspired by agricultural grafting, in which young plants are bound onto old rootstock, Andrew joined a woven seat onto the chair back and rear legs, creating a metaphor for the transmission of craft knowledge from old to new generations.

Documentary videos for these examples and others from the project can be found on the transformativerepair.net website and Transformative Repair YouTube channel.



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Figure 6. Khai Liew chair, before repair ©TRxJF



Figure 7. K. Khai Liew chair, after repair by Andrew Carvolth ©TRxJF

Conclusion

We believe these works evidence that designers and craftspeople possess skills with potential to enhance the social value of repair, beyond the practical benefits of repair and the usual social benefits of design and craft. The application of design and craft skills via transformative repair within complex contexts, such as grief and loss, provides scope for repairers to revitalize artefacts for capacity to heal or ameliorate complex feelings borne from relationships with objects. This is likely an under-utilized and under-researched expertise in craft and design industry.

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References

Carr, C. (2023). Repair and care: Locating the work of climate crisis. *Dialogues in Human Geography,* 13(2), 221-239. https://doi.org/10.1177/20438206221088381

Chapman, J. (2005). *Emotionally durable design: Objects, experiences, and empathy*. Earthscan.

Crosby, A., & Stein, J. A. (2020). Repair. *Environmental Humanities,* 12(1), 179–185. https://doi.org/10.1215/22011919-8142275

Denis, J., & Pontille, D. (2017). Beyond breakdown: Exploring regimes of maintenance. *continent*, (6.1), 13-17.

Drotbohm, Heike. 'Care Beyond Repair'. *Oxford Research Encyclopedia of Anthropology,* Oxford University Press, 2022. DOI.org (Crossref), https://doi.org/10.1093/acrefore/9780190854584.013.411.

Hall, T., & Smith, R. J. (2015). Care and Repair and the Politics of Urban Kindness. *Sociology*, 49(1), 3-18. https://doi.org/10.1177/0038038514546662

Isenhour, Cindy, and Joshua Reno. (2009) 'On Materiality and Meaning: Ethnographic Engagements with Reuse, Repair & Care'. *Worldwide Waste,* vol. 2, no. 1, Jan. 2019, p. 1. DOI.org (Crossref), https://doi.org/10.5334/wwwj.27.

Keulemans, G. (2015). *Affect and the experimental design of domestic products* (Doctoral dissertation, UNSW Sydney). https://doi.org/10.26190/unsworks/18442

Keulemans, G. (2016). The Geo-cultural Conditions of *Kintsugi*. *The Journal of Modern Craft*, *9*(1), 15–34. https://doi.org/10.1080/17496772.2016.1183946

Keulemans, G. (2018). The Agency of Transformative Repair. In *Unmaking Waste 2018*. University of South Australia. https://doi.org/10.26190/unsworks/26997

Keulemans, G., Rubenis, N., & Marks, A. (2017). Object therapy: Critical design and methodologies of human research in transformative repair. In *PLATE: Product Lifetimes And The Environment* (pp. 186-191). IOS Press. DOI: 10.3233/978-1-61499-820-4-186

Keulemans, G., Jansen, T., Cahill, L. (2024). 'Luxury and Scarcity: exploring anachronisms in the market for transformative repair', in *Repair & Design: Place, Practice and Community,* Nature Springer. DOI: 10.1007/978-3-031-46862-9_3

Marenko, B. (2010). 'Contagious affectivity: the management of emotions in late capitalist design.' *6th Swiss Design Network Conference*, Basel, Switzerland.

McLaren, D. P. (2018). In a broken world: Towards an ethics of repair in the Anthropocene. *The Anthropocene Review,* 5(2), 136-154. https://doi.org/10.1177/2053019618767211

Meißner, Magdalena. (2021). 'Repair Is Care? - Dimensions of Care within Collaborative Practices in Repair Cafes'. *Journal of Cleaner Production*, vol. 299, May 2021, p. 126913. DOI.org (Crossref), https://doi.org/10.1016/j.jclepro.2021.126913.

Reeves-Evison, T., & Rainey, M. J. (2018). Ethico-Aesthetic Repairs: Introduction. *Third Text*, 32(1), 1–15. https://doi.org/10.1080/09528822.2018.1448516

Riessman, Catherine K. (2001). "Analysis of Personal Narratives". In Gubrium, J. F., & In Holstein, J. A. (2002). *Handbook of interview research: Context & method.* Thousand Oaks, Calif: Sage Publications. DOI: 10.4135/9781452218403.n26

Rodgers, P., Innella, G., Bremner, C., Coxon, I., Broadley, C., Cadamuro, A., ... & Winton, E. (2019). The Lancaster care charter. *Design Issues,* 35(1), 73-77. DOI: 10.1162/desi_a_00522

Simon Sadler, Tamara Kneese, Nina Briggs, Kavita Ramakrishnan, Aaron Cayer, Ifeoma Ebo, Elke Krasny, Johan Pries, Kyle Spence, Phineas Harper, Gabu Heindl. (2024). "Field Notes on Repair: 4," *Places Journal*, November 2024. Accessed 25 Mar 2025. <https://placesjournal.org/article/field-notes-on-repair-4/>

Stahel, Walter R. 2013. "Policy for Material Efficiency—Sustainable Taxation as a Departure from the Throwaway Society." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 371 (1986): 20110567. https://doi.org/10.1098/rsta.2011.0567.

Van den Berge, R., Magnier, L., & Mugge, R**.** (2023). Sparking the repair "can-co" attitude: Enhancing users' willingness to repair through design support in fault diagnostics. *International Journal of Design, 17*(3), 25-39. https://doi.org/10.57698/v17i3.02

Wegener, C. (2016). Upcycling. In: Glăveanu, V.P., Tanggaard, L., Wegener, C. (eds) *Creativity — A New Vocabulary. Palgrave Studies in Creativity and Culture*. Palgrave Macmillan, London. https://doi.org/10.1057/9781137511805_22

Zambeletti, F. (2024) "Conversations: The Great Repair: towards a new social contract", Interview with Florian Hertweck, Milica Topalović, Alex Nehmer and Markus Krieger, *koozArch,* [website]: https://koozarch.com/interviews/the-great-repair-towards-a-new-social-contract?utm_source=chatgpt.com

Extended Abstract
6th PLATE 2025 Conference
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The ReMake Cafes as a source of well-being: being, doing and interacting as motivations to participate

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Keywords: consumer repair; repair café; circular economy; well-being, fundamental human needs.

Introduction

The main goal of our study was to explore the range of motivations among residents of Helsinki to participate in ReMake café activities. While the literature on repair cafés often emphasizes the importance of repair cafes as communities for advancing citizen-driven progress in circular economy (e.g., Moalem & Mosgaard, 2021), our study brings forward additional aspects related to participation in repair and repurpose events, like improved well-being. In contrast to the focus on "having" as the main source of well-being, our study engages with the framework of fundamental human needs (Max Neef, 1991), highlighting how human well-being is dependent on different existential categories, including being, having, doing and interacting.

Recent studies have explored the drivers behind visiting the repair cafes, identifying environmental concerns; profiting from knowledge, skills and available materials; the desire to demonstrate the importance of repair; being part of the social movement; emotional and functional value of goods (Luukkonen & Van den Broek, 2024). Our study extends these findings by examining the motivations to participate through existential categories that contribute to fundamental human needs and improve human well-being.

Research context & method

Our study is based on data collected during ReMake café meetings organized monthly, between August 2023 – May 2024 (9 events). ReMake cafes were organized in the premises of the Museum of Technology in Helsinki, Finland. The ReMake cafes are similar to traditional repair cafes, where people can come to repair their goods and get advice from skilled repairers. In addition, the ReMake cafe meetings included other circular activities, such as doing crafts and repurposing, as well as hands-on workshops (e.g. learning how to grow mushrooms using spent coffee grounds).

The activities of the ReMake café were funded by City of Helsinki with the aim to improve the socializing opportunities for senior citizens and promote inter-generational exchange of skills. Due to this, information regarding ReMake cafes was distributed through networks like Finnish Pensioners Federation. In addition, information appeared on city website devoted to events and happenings, so it reached citizens of different ages. The data consists of 16 qualitative interviews and a short survey distributed among the participants of ReMake Cafes (n=63). Despite the focus on senior citizens, the visitors were of varying age groups (Table 1).

Table 1. Age of the survey respondents.

Age	Percent of respondents
Under 30 years old	17,5
30-39	23,8
40-49	15,9
50-59	12,7
60-69	14,3
70-79	15,9
Total	100

Results

Overall, visiting the ReMake Café was a pleasant experience, as 76% strongly agreed and 21% agreed with the statement: "The event was worth my time". About 3% of the respondents strongly disagreed with the statement. The information distributed on the pages of city of Helsinki generated interest towards ReMake cafes as urban happenings,

attracting all kinds of citizens, not just the ones who are interested in circularity. For instance, 29% of the survey respondents indicated that they had no previous repair experience.

Our preliminary analysis of the motivations to attend ReMake cafes shows a much wider variety of reasons than just repair of goods. For instance, in the multiple-response question on participation modes, the social aspect was highlighted: 56% of the 63 respondents said they listened to other people's stories and followed the activities of the participants. In addition, 51% wanted to socialize and meet other people. Less than half of respondents reported that they repaired the goods they brought with them and about 5% taught or helped others to repair.

Qualitative interviews provided further insights on the motivation of the participants. First, it became apparent that engaging in repair activities together with others was important for motivating to actually get the repairs done. It came up that an organized occasion, with a place and different tools and materials being available on-site were important motivators. It was also essential that repair professionals were available to give advice on the best way to repair the items. Some participants had broken or torn items for years before seizing this repair occasion.

Participants commented on relaxed settings, the nice chattering of the participants and the repairers, and the feelings of being social without the pressure of buying anything. The interviewees observed that on-site events have the advantage of people having the chance to directly interact with repairers, but also with each other. Even if sometimes online repair tutorials are convenient, the on-site interaction was experienced as motivating and inspiring. Some of the interviewees did not bring anything to repair, but came to watch activities and follow the event out of curiosity.

Discussion and conclusions

The ReMake cafes in our study offered a wider range of activities to their participants than a typical repair cafe. Yet we found similar motivations for participation as in previous studies focusing on the drivers to visit repair cafes, such as access to expertise, skills, tools and materials (Luukkonen & van den Broek, 2024).

In addition, we found that participants often had mixed motivations that drew on categories of being, doing and interacting (Max Neef, 1991). On top of repairing (doing), participants valued engagement with others (interacting) as part of the experience. Some participants came to ReMake cafes without any goods to repair, as they wished to just be present in the event (being). Since the event was of non-commercial nature, the possibility to learn was experienced as encouraging and relaxing.

The main limitation of this study is related to the fact that the event was advertised as a possibility to do repair and socialize. So, it probably attracted participants inherently interested in social aspects. However, the success of the ReMake cafe events in fulfilling the needs for being and interacting along repair and repurpose indicates that it is important to consider these aspects in mainstreaming circular consumption practices and positioning them as activities that positively contribute to several existential categories relevant to human well-being.

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References

Luukkonen, R., & van den Broek, K. L. (2024). Exploring the drivers behind visiting repair cafés: Insights from mental models. *Cleaner Production Letters*, *7*, 100070. https://doi.org/10.1016/j.clpl.2024.100070

Max-Neef, M. 1991. Human Scale Development: conception, application and further reflections. New York: Apex.

Moalem, R. M., & Mosgaard, M. A. (2021). A critical review of the role of repair cafés in a sustainable circular transition. *Sustainability, 13(22), 12351.* https://doi.org/10.3390/su1322123

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Dealing with barriers to repair from the repairers' perspective

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Keywords: Repair; repairability; circular economy; obsolescence; barriers to repair.

Abstract
Repair is a key component of the circular economy paradigm and holds great environmental potential. Our current linear economies, which rely on constantly expanding markets, are not conceived to be restorative and hence create structural barriers to repair. Through semi-structured interviews and questionnaires we explore the commercial repairers' perspective on barriers to repair, as well as their agency and the strategies they employ to overcome those barriers. Our research has shown that repairers tend to bypass barriers by means of specific repair techniques and cooperation networks.

Introduction
Repair is gaining attention in the academia due to its fundamental role in the circular economy paradigm. Repair is an activity which prolongs the useful lifespan of objects while using less resources and preventing waste (Stahel, 2013; Gharfalkar et al., 2016; Ellen MacArthur Foundation, 2015; Blomsma & Tennant, 2020). This makes repair a key strategy for better managing societal stocks, which is necessary for more sustainable economies (Victor, 2008; Daly 1996).
Despite its sustainability potential, modern economies are not conceived to be restorative. The current accumulation paradigm requires constantly expanding markets, which in turn creates incentives for replacing products rather than extending their use (Vence, 2023; Vence et al., 2024). Repair is faced with structural barriers to repair that either make it more difficult, less attractive or, in extreme cases, even impossible (Packard, 1960; Cooper, 2004 & 2010).
From the literature review we distinguish several categories of barriers to repair (Dalhammar et al., 2020; Svensson-Hoglund et al., 2021 & 2023), some of which may affect consumers (deter them from repairing) others may affect the repairers' ability to perform a repair. Nonetheless, repair studies show that repairers tend to be proactive in overcoming obstacles for which they use their creativity and ingenuity (Jackson, 2014; Graham & Thrift, 2007). The aim of our paper is to identify the strategies that repairers employ to overcome barriers to repair.

Methodology
To answer our research question we employ a questionnaire-based survey directed to independent repairers in the field of IT repair. Our respondents come exclusively from the European region of Galiza (ES11 in NUTS classification). This questionnaire was informed by several previous semi-structured interviews which helped identify some of the key aspects in overcoming barriers and the way to approach its research through questionnaires.
Questionnaires are a popular method when researching repair and have been used to approach the subject from varied perspectives (Dalhammar et al., 2020; Charter & Keiller, 2014; Türkeli et al., 2019; Andersson et al., 2018). Our research involves some novel aspects, particularly those regarding tools for overcoming obsolescence from a technical and a collaborative point of view.

Results and Discussion
Our results show that repairers tend to consider price related obstacles as the main ones: this include prices of new products, prices of repair and availability and prices of spare parts; all of them are key aspects in determining the relative price of repair. Promoting repair could imply improving the relative price of repair via taxation (Stahel, 2013; Vence & López Pérez, 2022). Unfortunately, the recent European policy mix

regarding repair did not make an attempt to improve the relative prices of repair, leaving them for the market to determine (López-Bermúdez & Vence, 2024 & 2025)

When inquired about barriers to repair most respondents agreed that repairs have increased in difficulty and that manufacturers do not design for repair: they do not provide enough information nor do they provide spare parts. This leads to a situation in which repairers must use alternative sources and methods to overcome obstacles. Collaboration is a fundamental tool in community repair (Graziano & Trogal, 2017) and even commercial repair (Orr, 1996).

Our results have shown that more than half of our respondents engage in collaboration networks with other repairers, particularly at the local level. This involves exchanging information, knowledge and even establishing informal commercial arrangements. This contrasts with the notion of the isolated repairer or the notion that competition harms repairers (Türkeli et al., 2019), when in fact they may benefit from it in line with what often occurs in other sectors.

Related to collaboration we also encountered the techniques of repair as fundamental strategies to overcome obsolescence. We find that independent repairers often engage in component level repair (rather than module level repair; modules being entire parts and components pieces of the modules). Component level repair requires additional knowledge, abilities and tools. Some design features greatly increase its difficulty, like miniaturization and microelectronics, which explains why repairers have also placed them as some of the main barriers. Despite this, component repair allows repairers to avoid the spare parts market controlled by manufacturers.

Conclusions

Our research has focused on barriers to repair from the perspective of independent repairers, specifically those working in the IT repair sector. Our questionnaires, informed by semi-structured interviews, offered interesting insights into the way commercial repairers deal with structural barriers to repair. Price related barriers have been noted as key obstacles, yet no efforts have been made at the European regulatory level to shift the price equilibrium in favor of repair. Regarding how to overcome barriers, our research showed that collaboration networks play a key role. Commercial repairers tend to engage in collaborative networks quite often. Collaboration often takes the form of knowledge and information sharing but also informal commercial arrangements. Besides collaboration, repairers tend to also engage in repair at the component level as a way to avoid a market of spare parts controlled by manufacturers themselves. This form of repair is more demanding in terms of knowledge and experience, but it is extremely cheap material wise. Our research shows that commercial repairers are indeed proactive in overcoming barriers, even moving around the margins and wrestling control from manufacturers in a fashion similar to community and activist repairers.

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References

Andersson, A., Carlestam, J., Gunnarsson, J., Henriksson, T., Kristoffersson, P., Mattsson, F., . . . Wessberg, N. (2018). *Circular Economy: Research into the availability and willingness to repair consumer electronic products.* Lund University.

Blomsma, F., & Tennant, M. (2020). Circular economy: Preserving materials or products? Introducing the Resource States framework. *Resources, Conservation and Recycling, 156*. https://doi.org/10.1016/j.resconrec.2020.104698

Charter, M., & Keiller, S. (2014). *Grassroots Innovation and the Circular Economy. A Global Survey of Repair Cafés and Hackerspaces.* The Centre for Sustainable Design.

Cooper, T. (2004). Inadequate Life? Evidence of Consumer Attitudes to Product Obsolescence. *Journal of Consumer Policy, 27*, 421-449. https://doi.org/10.1007/s10603-004-2284-6

Cooper, T. (2010). *Longer Lasting Products. Anternatives to the Throwaway Society.* Gower Publishing. https://doi.org/10.4324/9781315592930t

Dalhammar, C., Richter, J., Almén, J., Anehagen, M., Enstrom, E., Hartman, C., . . . Ohlsson, J.

(2020). *Promoting the repair sector in Sweden.* IIIEE.

Daly, H. (1996). *Beyond Growth.* Beacon Press.

Ellen MacArthur Foundation. (2015). *Towards a circular economy: business rationale for an accelarated transition.* Cowes: Ellen Macarthur Foundation.

Gharfalkar, M., Ali, Z., & Hillier, G. (2016). Clarifying the disagreements on various reuse options: repair, recondition, refurbish and remanufacture. *Waste Management & Research, 34*(10), 995-1005. https://doi.org/10.1177/0734242X16628981

Graham, S., & Thrift, N. (2007). Out of Order. Undestanding Repair and Maintenance. *Theory, Culture & Society 24 (3)*, 1-25. https://doi.org/10.1177/0263276407075954

Graziano, V., & Trogal, K. (2017). The politics of collective repair. Examining object-relations in a postwork society. *Cultural Studies 31*, 634-658. https://doi.org/10.1080/09502386.2017.1298638

Jackson, S. (2014). Rethinking Repair. Em T. Gillespie, P. Boczkowski, & K. Foot, *Media Technologies: Essays on Communication, Materiality and Society* (pp. 221-240). MIT Press.

López-Bermúdez, F., & Vence, X. (2024). The European Directive on Common Rules Promoting the Repair of Goods. A Critical Assessment of its Drafting Process. *Revista Galega de Economía, 33*(2), 1-24. https://doi.org/10.15304/rge.33.2.9429

López-Bermúdez, F., & Vence, X. (2025). A critical assessment of the European Directive proposal promoting the repair of goods . *Resources, Conservation and Recycling, 212*(107996). https://doi.org/10.1016/j.resconrec.2024.107996

Orr, J. (1996). *Talking about machines. An Ethnography of a Modern Job.* Cornell University Press.

Packard, V. (1960). *The Waste Makers.* Longmans.

Stahel, W. (2013). Policy for material efficiency-sutainable taxation as a departure from the throwaway society. *Philosophical Transactions of the Royal Society A*. https://doi.org/10.1098/rsta.2011.0567

Svensson-Hoglund, S., Richter, J., Maitre-Ekern, E., Russell, J., Pihlajarinne, T., & Dalhammar, C. (2021). Barriers, enablers and market governance: A review of the policy landscape for repair of consumer electronics in the EU and the U.S. *Journal of Cleaner Production, 288*. https://doi.org/10.1016/j.jclepro.2020.125488

Svensson-Hoglund, S., Russell, J., & Richter, J. (2023). A Process Approach to Product Repair from the Perspective of the Individual. *Circular Economy and Sustainability, 3*, 1327-1359. https://doi.org/10.1007/s43615-022-00226-1

Türkeli, S., Huang, B., Stasik, A., & Kemp, R. (2019). Circular Economy as a Global Business Activity: Mobile Phone Repair in the Netherlands, Poland and China. *Energies, 12*(498), 1-22. https://doi.org/10.3390/en12030498

Vence, X. (2023). Bases conceptuales para una economía circular transformadora y un cambio sistémico. Em X. (. Vence, *Economía circular transformadora y cambio sistémico* (pp. 55-108). Fondo de Cultura Económica.

Vence, X., & López Pérez, S. d. (2022). Reforming VAT to boost repair services and the circular economy. *Contaduría y Administración, 67*(2), 1-25. https://doi.org/10.22201/fca.24488410e.2022.3233

Vence, X., Pereira, Á., Laperche, B., & Pansera, M. (2024). Circular Economy, Sustainability and Degrowth. *Revista Galega de Economía, 33*(2), 1-6. https://doi.org/10.15304/rge.33.2.10036

Victor, P. (2008). *Managing Without Growth. Slower by Design, Not Disaster.* Cheltenham: Edward Elgar.

Extended Abstract
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Repairing and regenerating the community: a study in activating garment repair initiatives with stakeholders at local level

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Keywords: Garment Repair; Circular Economy; Repair Skills; Community Repair; Socio-Material Practice.

Introduction

Garment Repair as Regenerative solution

The focus on the process of independent garment repair as a regenerative practice at community level is increasingly important in reducing linear disposal practices and encouraging circularity. Repair is an effective way of contributing to the replacement of cradle-to-grave operations, emulating natural systems and contributing to the nurturing of natural capital (Hernandez, et al., 2020).

This paper investigates the function of independent, non-professional, informal repair initiatives (repair hubs) at community level comprising local non-profit organisations and community stakeholders or citizens and explores their inherent challenges and opportunities in operationalising and scaling up small-scale repair initiatives. It explores the role of local garment repair and regeneration initiatives to reduce the environmental impact of fashion consumption by extending clothing lifetimes, facilitating knowledge exchange and upskilling. The focus will be on the benefits and challenges in terms of the process and type of knowledge exchange, including active learning and additional outcomes.

The principles embedded in the circular economy facilitate a regeneration of traditional values in making and mending practices, manifested in a restored appreciation of material management, resulting in extended use. It is also possible to view repair as a regenerative process using socio-material practices (Van Der Velden, 2021).

Theoretical framework

Socio-material practice theory (Fenwick, 2015) describes how objects and people interact through social behaviours and material actions to create change. This framework forms the basis of the conceptual structure, allied to behaviour change theory (Hargreaves, 2011) to enable a deeper investigation into both the 'why' people engage in repair practices; and the 'how' and 'what' of repair practices where learning takes place through participatory action (Purvis et. al., 2025). Adopting a living systems perspective emphasises the need for distribution by fostering communal skills that extend product lifespans, minimize raw material extraction, improve resource efficiency, and promote local cooperative initiatives (Bradley and Persson 2022). Repair workshops were investigated as a site of collective knowledge acquisition (knowledge and skills), sustainable repair practice (sustainability and materials) with social connections linked in a socio-material matrix with tangible outcomes for behavioural change.

Methodology

Acknowledging repair as a socio-material practice, the data collection process involved a multi-methods approach (Cresswell, 2015) including participant observation, interviews, participant reflections and focus group discussions. The first case features a launch event off-campus for the Chopwell Regeneration Shop offering services using both hand and machine sewing techniques. The second case covers the Repair Hub, part of Responsible Design Week at Northumbria University 2024, a two-day open studio session attracting students, staff and local community members interested in sharing and learning mending skills. Participants had the opportunity to learn techniques such as darning, re-sewing seams, plus visible and invisible mending practices (See Figures 1, 2 and 3).

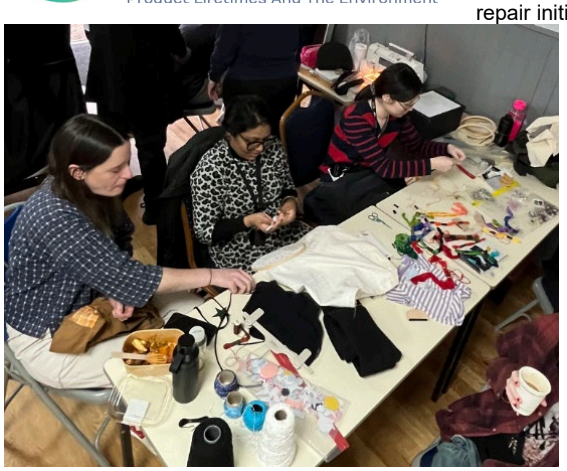


Figure 1. Chopwell, launch event repair group.



Figure 2. Responsible Design Week, repair in progress.



Figure 3. Responsible Design Week, sharing repair methods.

The resulting qualitative data generated was analysed using open coding to identify key themes highlighting the benefits, opportunities and challenges regarding various forms of knowledge exchange and learning generated by the workshops and their environmental and societal outcomes while also acknowledging the barriers to implementing community-based initiatives more frequently and more widely in geographic terms.

Findings and Discussion

Findings from participants illustrate how local, community-centered activities can initiate and sustain garment repair initiatives by fostering knowledge exchange, develop repair skills, and build social networks around sustainability. The six main themes emerging from the participants in both workshops can be summarised in as social/community benefits; personal creative fulfilment; well-being; educational/upskilling; emotional durability; empowering personal/social time and space.

One salient theme emerging from the data was the social aspect of the repair hub emphasising the supportive group dynamic and collaborative environment across varied demographic groups created in sharing skills, while engaging in conversations and working on individual repair projects resulting in personal empowerment. Many participants saw the collective repair process extending beyond the practical mending of materials to encompass a

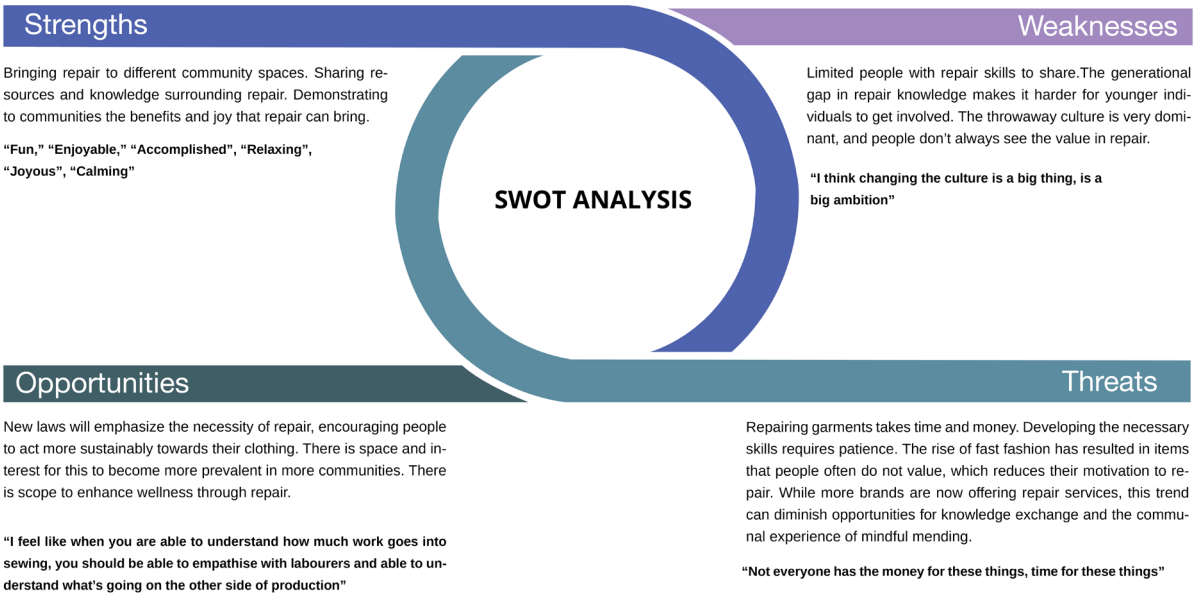


Figure 4. SWOT analysis of repair workshop responses.

creative and emotionally fulfilling output. Enhanced well-being and mental relaxation and meditative benefits of stitching, darning and sewing were linked with holistic healthfulness benefits. To facilitate social and health benefits, many participants foregrounded the importance of earmarking personal time and space to facilitate the collective endeavour of repair to learn and share and acquire skills. This linked with another key theme of the need for upskilling and education including the need to embed garment design and making skills in the educational curriculum at all levels.

Emotional attachment was a common consideration, as many respondents had brought items owned or pre-loved to the second workshop. Barriers and disbenefits also emerged from respondent feedback in three main themes regarding the challenges of replacing the slow practice of mending to negate the disbenefits of the fast fashion system to encourage people to take responsibility for better clothing management. Allied to this was the shared desire for a fundamental culture shift driven by consuming less and buying better for longer. This included changes in how people value garments and the need for top-down initiatives embedded in policy and legislation to fund and support sustainable repair practices. It was acknowledged that people needed dedicated time and space to undertake repair which were often unattainable luxuries by many with other responsibilities. Some questioned how inclusive and accessible these initiatives were and how some might feel intimidated by perceived lack of skills and financial resources to get involved.

The workshop findings are represented as a SWOT diagram (See Figure 4) summarising the strengths, opportunities, weaknesses and threats from workshop respondent data providing a realistic assessment of the potential for scaling-up across and beyond bounded local communities at regional and national levels. Overall, positive strengths and opportunities were gained in social, educative and mental health benefits of participating in repair hubs that appear to outweigh the weaknesses and threats in the form of the lack of resources, the need for major cultural change and required policy, financial, infrastructural and legislative directives and investment. In quantitative terms, during the repair events, an average of 30 garments were repaired each day. Using WRAP's repair displacement rate of 82.2%, with four new purchases being displaced for every five garments repaired, this resulted in a displacement rate of 24 garments per session (WRAP 2025). This suggests that garment repair activities have measurable, positive environmental impact for potential discarded material objects.

Positive social, material and sustainability aspects of community repair hubs are compelling for all participants demonstrating overlapping socio-material benefits as an entanglement of people and things (Van Der Velden, 2021) fulfilling social, skills/knowledge-based and sustainability expectations of stakeholders (see Figure 5). Yet, structural enablers and facilitators must be in place (Gwilt, 2014), or repair initiatives cannot survive or thrive.

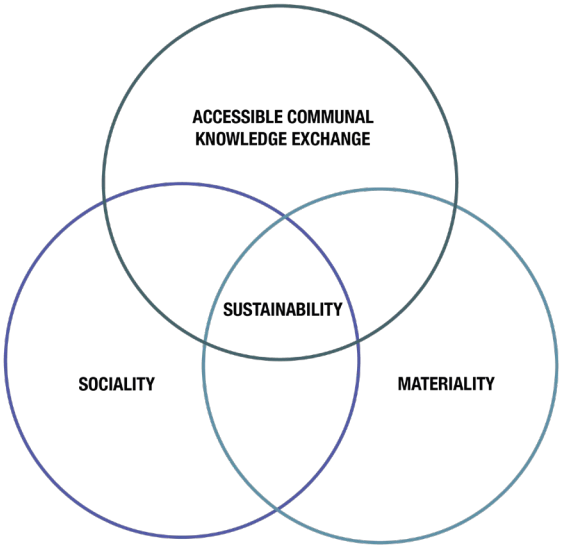


Figure 5. Socio-material expectations and outcomes of repair events.

Conclusion

Communal learning through knowledge sharing took various forms of equal importance, including sustainable, social and material perspectives. Workshop participants representing a broad demographic range, acknowledged that they learned a transformative range of repair skills extending garment use, offering usage options before discarding garments, enhancing considered garment management, imparting self-sufficiency, while elevating self-confidence and empowerment in a therapeutic, inclusive, supportive social space. The study has significance for future propagation and scaling-up local participatory repair practices, enabling communities to activate local solutions for global ecological issues and behavioural change concerning environmental and socio-material solutions. This is dependent on resources requiring a re-evaluation of current garment ownership and mindful consumption habits.

References

Bradley, K., and Persson, O. (2022). Community repair in the circular economy – fixing more than stuff. Local Environment, 27(10–11), 1321–1337. https://doi.org/10.1080/13549839.2022.2041580\

Creswell, J. W. (2015). A Concise Introduction to Mixed Methods Research. Thousand Oaks, CA: SAGE Publications.

Fenwick T. (2015). Socio-materiality and learning: a critical approach. In: Scott D & Hargreaves E (eds.) The SAGE Handbook of Learning. London: SAGE, 83-93. https://uk.sagepub.com/en-gb/eur/the-sage-handbook-of-learning/book242764

Gwilt, A. (2014). What Prevents People Repairing Clothes?: An Investigation into Community-Based Approaches to Sustainable Product Service Systems for Clothing Repair. Making Futures Journal, 3, https://drive.google.com/file/d/1uSN81PEUEBiEAXWk4d9UBqdGUXinAIy4/view

Hargreaves, T. (2011). Practice-ing behaviour change: Applying social practice theory to pro- environmental behaviour change. Journal of Consumer Culture. 11, 79–99. https://doi.org/10.1177/1469540510390500

Hernandez, R.J., Miranda, C., and Goñi J., (2020). Empowering sustainable consumption by giving back to consumers the 'Right to Repair'. Sustainability 12: 850. https://doi.org/10.3390/su12030850 .

Purvis, B., Else, T., Genovese, A., Jimenez, A., & Venkataraman Guru, R. (2025). Grassroots initiatives for a bottom-up transition to a circular economy: exploring community repair. Local Environment, 1-17. https://doi.org/10.1080/13549839.2025.2467385

Van Der Velden, M. (2021). 'Fixing the World One Thing at a Time': Community repair and a sustainable circular economy. Journal of Cleaner Production, 304, 127151. https://doi.org/10.1016/j.jclepro.2021.127151

WRAP (2025). Displacement rates untangled: a standardised methodology. https://www.wrap.ngo/sites/default/files/2025-02/WRAP-Textiles-2030-Displacement-rate-report-REV1.pdf [accessed 10 March, 2025]

Extended Abstract
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AI-Powered Consumer Electronics Repair towards a Digital Circular Economy

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Keywords: Repair; AI-Powered Repair; Circular economy; Consumer electronics; EEE

Introduction

Electronic waste is a growing global challenge, with projections indicating a significant increase from 58 million metric tons in 2021 to an alarming 112 million metric tons by 2050 (Forti et al., 2020; Parajuly et al., 2019). This surge underscores the urgent need for circular solutions in managing the lifecycle of electronic products. Furthermore, the current economic and marketing dynamics often make replacement seem more appealing than repair (Sonego et al., 2022; Terzioğlu et al., 2015; VandenBerge et al., 2023). Addressing this challenge requires understanding the multifaceted barriers users face, which the Repair Motivation and Barriers Model categorizes into technical, emotional, and value-related aspects of repair (Terzioğlu, 2021). This research aims to tackle these barriers by introducing an Artificial Intelligence (AI)-powered tool called AI-Fixer that provides step-by-step repair instructions, building user confidence, and enabling self-repair practices.

Within the field of Circular Economy, researchers are increasingly investigating the role of emerging digital technologies in enabling circular practices (Bressanelli et al., 2018; Sherpa & Sinha, 2021). Among these, AI holds significant promise offering capabilities such as diagnostics, predictive maintenance, and real-time repair support.

This study explores the feasibility of AI-Fixer in assisting users with repairing consumer electronics. It specifically investigates whether AI can assist and empower users to repair devices.

Methods

This research employed a co-design workshops and interviews to evaluate the feasibility of AI-Fixer. Nine participants were recruited, including five non-experts with no prior repair experience and four experts from different fields such as product design, AI, and electronics repair were involved (Table 1). Sixteen workshops were conducted: eight on repairing the Fairphone 5 screen and eight on repairing the FairBuds XL battery. These tasks were selected based on criteria such as required time to complete the repair, task complexity, and relevance to AI-guided support. During the workshops, participants interacted with AI-Fixer to complete the repair tasks (Figure 1). The tool provided step-by-step guidance via a chatbot interface. Participants were asked to fill out a worksheet to provide feedback based on their experience. Workshops for the Fairphone 5 screen replacement lasted approximately 20 to 40 minutes, while workshops for the FairBuds XL battery replacement took around 10 to 20 minutes. After each workshop, semi-structured interviews were conducted to gain deeper insights into participants' repair experiences. These interviews focused on their interaction with the tool, the repair process, and the overall outcome.

The data collected were analyzed to identify patterns and themes related to the tool's usability and effectiveness. Comparisons between expert and non-expert users highlighted differences in expectations and satisfaction. Key aspects included user confidence, and the perceived usefulness of AI-Fixer's features, such as instructions and interactivity.

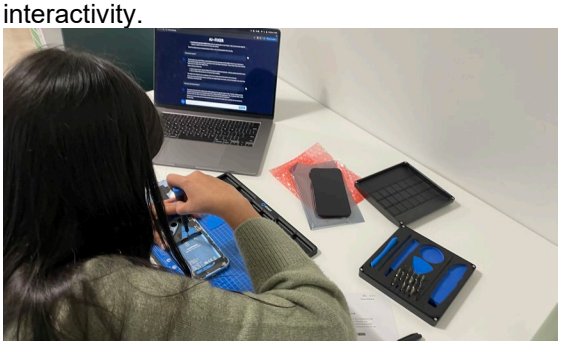


Figure 1. Participants interacted with AI-Fixer to complete the repair tasks.

Results

Co-design workshops and interviews provided valuable insights into the strengths and weaknesses of AI-Fixer, revealing differences in how expert and non-expert users interacted with the tool (Table 2).
Non-expert users found AI-Fixer to be a helpful entry point for repairing electronics. The tool's step-by-step guidance reduced the intimidation often associated with repairs and fostered confidence. For instance, Participant 1, described feeling empowered after completing a headphone repair, which motivated them to tackle a more complex phone repair.

However, non-expert users also encountered challenges. Reading the instructions and composing replies was sometimes tiring and complex, which led to confusion and disengagement. They requested multimodal support, including images and voice instructions as purely textual guidance was insufficient for tasks requiring precise identification of components, such as the cable connector or screws. Features like progress indicators (e.g., "Step 1 of 10") were suggested in the co-design process and the tool was updated based on these kinds of requests to help users better navigate the repair process.

Participants (P)		**Workshop with Fairphone 5**	**Workshop with Fairbuds XL**
P1	Non-expert	✓	✓
P2	Non-expert	✓	✓
P3	Non-expert	✓	✓
P4	Expert on AI	✓	✓
P5	Expert Product Designer	✓	**x**
P6	Non-expert	✓	✓
P7	Non-expert	✓	✓
P8	Expert on Repair	✓	✓
P9	Expert on Repair	**x**	✓

Table 1. Co-Design Workshops participants included five non-experts and four experts.

Aspect	**Strengths**	**Weaknesses**
Empowering Users	-Provides step-by-step instructions for non-expert users. -Builds confidence by allowing users to proceed at their own pace.	-Instructions can be tiring to read or complex. -More detailed instructions needed.
Accessible Guidance	-Real-time, interactive chatbot support reduces intimidation compared to repair manuals. -Enables clarification during steps, minimizing confusion.	-Repetitive and non-adaptive responses fail to address user-specific queries, frustrating users.
Enhancing Repairability	-Data collected identifies the challenges that users face during repair to improve repairability.	-Repair instructions require manual creation, making scalability challenging.
Visual Aids	-Multimodal guidance can enhance user understanding (potential to include images, diagrams, and videos).	-Currently lacks sufficient visuals, making tasks like identifying connectors or screws difficult.
User Trust	-Potential to build trust by delivering reliable guidance.	-Users may hesitate to rely on AI for complex tasks.
Compatibility Challenges	-Framework is flexible and adaptable to various repair tasks.	-Wide range of consumer electronics with varying repair requirements complicates achieving broad compatibility.
Environmental Impact	-Promotes sustainable practices by encouraging repair over replacement.	-Training and operating resource-intensive AI models increase energy consumption and carbon emissions.

Table 2. The strengths and weaknesses of AI-Fixer based on the co-design workshop and interview results are summarised.

Experts viewed AI-Fixer as a supplementary tool but were more critical of its usability. They valued concise, to-the-point instructions and found the lack of brevity in responses frustrating. Participant 4, an AI expert, highlighted the need for visualizations, while Participant 5 suggested integrating color-coded components to the design, such as screws, to simplify identification.

Another common critique was the tool's inability to adapt responses dynamically. Experts found repetitive answers unhelpful and emphasized the importance of context-sensitive interactivity. Despite these limitations, experts acknowledged AI-Fixer's potential to support non-experts when they get stuck during the repair process. They also valued the potential of this tool to provide data insights for improving product design. AI-Fixer's ability to collect repair data offers significant potential for improving product design. By identifying what goes right and what goes wrong while the users are fixing these products, the tool can guide designers and manufacturers in improving the repairability of products.

Acknowledgments

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References

Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N. (2018). Exploring how usage-focused business models enable circular economy through digital technologies. Sustainability, 10(3), 639. https://doi.org/10.3390/su10030639

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). The global e-waste monitor 2020. Quantities, flows, and the circular economy potential, 1-119. ISBN 9789280891140

Parajuly, K., Kuehr, R., Awasthi, A. K., Fitzpatrick, C., Lepawsky, J., Smith, E., Widmer, R., & Zeng, X. (2019). Future e-waste scenarios. https://wedocs.unep.org/bitstream/handle/20.500.11822/30809/FutEWSc.pdf?sequence=1&isAllowed=y

Sherpa, Y., & Sinha, D. (2021). Digital solutions for a circular electronics value chain: A thought paper for International E-Waste Day 2021. International Telecommunication Union (ITU), WEEE Forum, GSMA, & Sofies Group. https://weee-forum.org/wp-content/uploads/2021/10/Thought-Paper-2021.pdf

Sonego, M., Echeveste, M.E.S., & Debarba, H. G. (2022). Repair of electronic products: Consumer practices and institutional initiatives. Sustainable Production and Consumption, 30, 556-565. https://doi.org/10.1016/j.spc.2021.12.031

Terzioğlu, N., Brass, C., & Lockton, D. (2015). Understanding user motivations and drawbacks related to product repair. Sustainable Innovation 2015, 9-10. https://www.researchgate.net/profile/Nazli-Terzioglu/publication/294256488_Understanding_User_Motivations_and_Drawbacks_Related_to_Product_Repair/links/56bf27cb08aee5caccf4b556/Understanding-User-Motivations-and-Drawbacks-Related-to-Product-Repair.pdf

Terzioğlu, N. (2021). Repair motivation and barriers model: Investigating user perspectives related to product repair towards a circular economy. Journal of Cleaner Production, 289, 125644. https://doi.org/10.1016/j.jclepro.2020.125644

Vanden Berge, R., Magnier, L., & Mugge, R. (2023). Until death do us part? In-depth insights into Dutch consumers' considerations about product lifetimes and lifetime extension. Journal of Industrial Ecology, 27, 908-922. https://doi.org/10.1111/jiec.13372

Extended Abstract
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Designing Electronics for a Circular Economy: How to balance Repair and Recycling

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Keywords: Circular Economy; Design for Repair; Design for Recycling; Electronic Product Design; Resource Recovery.

Introduction

The short lifespans and rapid innovation cycles of electronic products result in the loss of valuable and critical resources (Bakker, Wang, Huisman, & den Hollander, 2014; Baldé et al., 2024). Strategies aimed at extending product lifetimes, such as design for repair, focus on improving the ease of manual disassembly (De Fazio, Bakker, Flipsen, & Balkenende, 2021). However, connections optimized for repairability can hinder the mechanical separation of materials during recycling. This highlights a critical trade-off: improving repairability can often conflict with recyclability, emphasizing the need for balanced design approaches that address both recovery goals.
Navigating these trade-offs requires a deeper understanding of how materials and connection types in electronics affect circular strategies. This research aims to investigate tensions between repairability and recyclability by analyzing a diverse set of electronic products and relating the findings to their design architecture. This study seeks to inform design strategies that optimize for both repairability and recyclability, thus prolonging product lifetime while minimizing resource losses at end-of-life.

Method

While repairability assessment has become mature over the past years and the effect of various connection types is well established (Flipsen, Depypere, Huisken, & Opsomer, 2019; Vanegas et al., 2018), the field of design for recycling remains less developed. To address this gap, our experimental setup prioritized recycling-focused investigations to evaluate how design choices influence material recovery outcomes.

The design architecture of electronic products varies significantly, which affects their end-of-life outcomes. To investigate the impact of design choices on recyclability, we analysed a selection of products – four smart TV models, a streetlamp and an office luminaire – chosen for their diverse design architecture and material compositions.
Our method combined manual disassembly analysis and destructive mechanical shredding tests to evaluate recyclability. Each product was disassembled to component level, with all parts documented in a Bill of Materials (BoM) that recorded their mass and material composition. All disassembly actions were noted, including tool type, applied force, fastener type, and fastener and component visibility. A disassembly map was created for each product following the procedure outlined in (De Fazio et al., 2021), providing insights on the products' architecture.

We assessed material liberation using a 4-shaft e-waste shredder, with experiments conducted at an E-waste recycling plant to ensure alignment with industry practices. The resulting fragments were hand-sorted to trace material flows and assess the separation of different connection types. Homogeneous fragments – composed of a single material – were sorted by material type, while heterogeneous fragments – containing multiple materials – were classified based on likely recycling stream destinations, informed by expert consultations. Further analysis quantified unbroken connections in heterogeneous fragments. This allowed us to identify the effect of product architecture features on recyclability and find tensions between design for repair and design for recycling.



a b c

Figure 1. Heterogeneous fragments from a shredded smart TV.
a: A piece of aluminum is still attached to part of the plastic housing because of an adhesive (material closure) used in the design.
b: A piece of plastic, steel and PCB are still connected because of an unliberated screw (force closure).
c: The metal insert (force closure) is still attached to the plastic housing.

Connections		Suitable for...	
Class	Connection type	Manual dis- and reassembly (for repair)	Mechanical disintegration (for recycling)
Form closure	Friction fit	✓	✓
	Hook	✓	✓
	Turn lock	✓	✓
	Click connection	✓	✓
Form & force closure	Fold lock	✓	~
	Side lock	✓	~
	Top lock	✓	~
Force closure	Snap fit	✓	✓
	Magnetic connection	✓	✓[a]
	Screw	✓	~
	Nut and bolt	✓	~
	Rivet	✗	~
	Folding	✗	~
	Crimping	✗	~
	Clinching	✗	~
	Heat staking	✗	~
Material closure	Pressure sensitive adhesives	✓	~
	Hot-melt adhesives	~	~
	Irreversible glue	✗	~
	Soldering	~	✗
	Welding	✗	✗
	2K molding	✗	✗
	Coatings	✗	✗

[a] Even though magnetic connections often break in a shredder, permanent magnets pose problems in the recycling process because they stick to ferrous fragments and to machines in the recycling line.

✓ Compatible
~ Design dependent
✗ Not compatible

Table 1. Evaluation of connection types regarding their suitability for manual dis- and reassembly and mechanical shredding, based on disassembly and shredding experiments. The table highlights the tensions between design choices for repairability and recyclability, providing insights into how different connection types perform in each recovery pathway.

Results and discussion

Disassembly revealed that the products contained non-recyclable materials such as coatings, plastics and rubbers, which reduced their theoretical recyclability to 70-95%. In addition, non-recyclable materials complicate material streams.

Repairability was visualised through disassembly maps, showing the ease of removing priority parts (i.e. those parts that are critical to the product's function and are known to be vulnerable) (De Fazio et al., 2021). Favorable connections for ease of disassembly are 'form closures', 'force closures' and reversible 'form and force' closures that can be easily accessed, as shown in table 1 (based on (Peeters et al., 2018; Vanegas et al., 2018)).

Shredding experiments provided valuable insights into the impact of different connections on material liberation. It revealed that some components, such as supportive steel structures in the back of some TV's, were so rigid that they could strain or even block the shredder, demonstrating a clear obstacle to effective recycling. In general, 'form closure' connections like friction fits and turn locks easily break down during shredding, while 'material closure' like glues, soldering and coatings remain connected (figure 1). For 'form and force' closures like fold locks, and 'force closures' like screws, rivets and crimping (figures 2 and 3), connection behaviour was less predictable. For example, screws separated cleanly in some products but remained embedded in others, likely due to variations in tolerances and material properties. Table 1 provides an overview of the likelihood of connection break-down during shredding.

While designing for disassembly often improves repairability, large-scale recycling mostly relies on shredding rather than manual disassembly. As a result, repair-friendly connections do not necessarily translate into better recyclability. At the same time, waste processing technologies continue to evolve, but instead of only expecting recycling to adapt to new designs, this study highlights the importance of designing with existing recycling infrastructure in mind. If a designer should prioritize repairability or recyclability depends on the product's End-of-Life scenario, requiring careful consideration of environmental impacts using Life Cycle Assessment and other decision-making tools.

Our findings identified tensions between repair and recycling, as many connections that facilitate repair might hamper recycling (Table 1). This shows the need for design approaches that consider both recyclability and repairability. Our results form the basis for a design guide to help designers addressing conflicts between recovery strategies and to improve simultaneously on repair and recyclability.

Acknowledgments

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References

Bakker, C., Wang, F., Huisman, J., & den Hollander, M. (2014). Products that go round: exploring product life extension through design. *Journal of Cleaner Production, 69*, 10-16. doi:10.1016/j.jclepro.2014.01.028

Baldé, C. P., Kuehr, R., Yamamoto, T., McDonald, R., D'Angelo, E., Althaf, S., . . . Wagner, M. (2024). *The Global E-waste Monitor 2024*. Retrieved from Geneva/Bonn:

De Fazio, F., Bakker, C., Flipsen, B., & Balkenende, R. (2021). The Disassembly Map: A new method to enhance design for product repairability. *Journal of Cleaner Production, 320*. doi:10.1016/j.jclepro.2021.128552

Flipsen, B., Depypere, M., Huisken, M., & Opsomer, T. (2019). *Smartphone Reparability Scoring: Assessing the Self-Repair Potential of Mobile ICT Devices*. Paper presented at the PLATE 2019, Berlin.

Peeters, J., Tecchio, P., Ardente, F., Vanegas, P., Coughlan, D., & Duflou, J. (2018). *eDIM: further development of the method to assess the ease of disassembly and reassembly of products: Application to notebook computers*. Retrieved from Luxembourg. ISBN: 978-92-79-73189-1

Vanegas, P., Peeters, J. R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., . . . Duflou, J. R. (2018). Ease of disassembly of products to support circular economy strategies. *Resources, Conservation & Recycling, 135*, 323-334. doi:10.1016/j.resconrec.2017.06.022

Extended Abstract
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The Importance of Reuse and Repair– A Call for Canadian Municipal Action to Promote Clothing Repair Events

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Keywords: Clothing; repair events; mending; municipal action; sustainability.

Introduction

The fashion industry persists as a major contributor to widespread environmental issues, including global CO_2 emissions, water overconsumption, pollution, and landfill accumulation (Niinimäki et al., 2020). These negative outcomes are a direct result of the 'fast fashion model', which encourages excessive consumption and waste due to the vast availability and short lifespan of cheaply produced, poor-quality garments (Linden, 2016). An estimated 1.1 million tonnes of textile waste is generated in Canada each year, resulting in a per capita average of 31.2 kg/year (Cheminfo Services Inc., 2022).

In Canada, household waste collection and disposal is the responsibility of municipal governments (Degenstein et al., 2021). Only recently have there been efforts to address the textile waste stream, with a few municipalities having implemented textile waste diversion programs (ECCC, 2024). Though municipal governments rely on industry and non-profit organisations to handle used clothing, a critical way to reduce initial waste is through active repair

Clothing repair events are a growing global initiative to address textile waste. They are organised, local community workshops that offer the materials, tools, and skilled volunteers to help people fix their damaged clothing and textile items (Repair Café, 2024). The act of mending diverts the clothing waste stream and prolongs garment life, supporting the idea of a circular economy (Diddi & Yan, 2019; Ellen MacArthur Foundation, 2013). Additionally, clothing repair events are an intervention for the general decline and loss of mending skills (McQueen et al., 2022). Participants can develop self-repair skills, build community connections, and promote environmentally sustainable habits with one another. This study has two main objectives: 1) to investigate how Canadian municipalities are providing their residents with information and support for dealing with unwanted textiles, with an emphasis on repair; and 2) to assess Canadians' awareness and access to community clothing repair events, by focusing on differences between attendees and non-attendees. Our goal is to identify gaps and opportunities for municipal action, in order to further encourage clothing repair event attendance.

Methods

A content analysis was conducted to explore how textile waste management information is communicated across 81 Canadian municipalities. These municipalities were identified following a Google search of Canadian urban and rural municipalities for some mention of textile waste where they had either an active textile diversion program or a municipal or community repair initiative. The evaluation of municipal websites followed criteria based on the waste hierarchy, focusing on textile diversion initiatives, citizen awareness and education, options for unwanted clothing, and general waste reduction plans. An official textile diversion or recycling program (TDRP) is defined as an initiative specifically labeled as such on a municipal website, or one that includes information aimed at reducing landfill waste.

An online survey was developed to evaluate Canadians who had and had not attended clothing repair events. Participants were recruited using convenience sampling methods, with a focus on disseminating the survey through social media platforms (e.g.,

Facebook, Instagram). Additionally, active Canadian repair groups were identified and contacted to help share standardized recruitment notices. The survey questions came from literature sources with established validated scales where possible, with adaptations when necessary. Question topics included clothing repair behaviours, previous clothing repair event attendance, and factors affecting the interest and ability to attend these events. All questions were closed-ended multiple choice, with forced-choice responses.

Findings

Municipal Textile Diversion/Recycling Programs

Out of the 81 municipalities, only 14 (17%) have official TDRP. All 14 municipalities included clothing donation as a core initiative; however, only 4 (28%) implemented additional initiatives beyond donation. Three municipalities provided information on waste reduction, with two of those highlighting reuse and repair strategies to further reduce waste. One municipality allowed residents to bring clothes to a recycling depot, but did not inform them about what happens to the clothing after it is dropped off.

Notably, only two textile diversion programs, located in Vancouver and Toronto, offered practical initiatives that actively involved citizens in clothing reuse and repair. In these cases, donation was positioned as a last resort rather than the primary solution. Toronto was particularly unique, as it was the only program to provide in-person, hands-on access to clothing repair services.

Community Repair Events Survey

A total of 582 valid responses were collected, of which107 participants had previously attended a clothing repair event, whereas 475 had not. Of the non-attendees, 39 participants indicated having previously attended a repair event for non-clothing/textile items, while the remaining 436 had never attended any type of repair event. When non-attendees were asked if they had heard about clothing repair events prior to the survey, 50.1% selected “no”.

Table 1 (see Appendix) shows agreement rating results for a series of statements on the ability to attend clothing repair events, based on various physical, psychological, and environmental factors. Independent sample t-tests for statements 1, 2, 5, and 9, relating to physical capabilities and digital/transportation means, revealed that there were no significant differences between attendees and non-attendees at a significance value of 0.001. However, differences were found for statements 3, 4, and 6- 8, corresponding to psychological factors of social anxiety and confidence, and the perception of repair event occurrences, items in need of repair, and time availability. Despite a low response rate for previous clothing repair event attendance, both participant groups displayed a relative ability to attend clothing repair events.

Discussion and Conclusions

Traditionally, textile waste collection within Canada has been inadequately managed, with municipalities relying heavily on business and charity donations (Weber et al., 2017). Despite various newer textile diversion initiatives implemented by Canadian municipalities, there exists a lack of transparency regarding if and how these programs are being executed; for the few that are explained, the municipalities resort to either donation or recycling programs. Although important, both methods have limitations. Clearing out closets and donating to charity can allay the guilt of buying more new clothes (Ha-Brookshire & Hodges, 2009), and unsold items in local retail outlets may end up exported to the global south. Most items that are immediately recycled undergo labour and resource intensive processes, to create non-clothing textiles for industrial purposes (Harmsen et al., 2021). In contrast, clothing repair facilitates reuse, reduces consumption, and minimizes environmental impacts by keeping clothing in the hands of the original owner (Levänen et al., 2021; Neto & Ferreira, 2021).

Although the decision to attend a clothing repair event ultimately depends on the individual, the reported ability to attend by both participant groups, in addition to a majority of non-attendees not having heard about such events before, indicate a need for municipalities to improve public awareness and outreach for these events. Garment reuse-repair should take priority over the current municipal diversion methods of donation and recycling, and municipal promotion for clothing repair events would likely lead to increased participation, contributing to greater fashion sustainability.

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References

Cheminfo Services Inc. (2022, May 31). *Characterizing Reuse, Recycling and Disposal of Textiles in Canada.* https://nactr.ca/wp-content/uploads/2022/07/Characterizing-Reuse-Recycling-andDisposal-of-Textiles-in-Canada.pdf

Degenstein, L. M., McQueen, R. H., & Krogman, N. T. (2021). 'What goes where'? Characterizing Edmonton's municipal clothing waste stream and consumer clothing disposal. *Journal of Cleaner Production*, *296*, 126516. https://doi.org/10.1016/j.jclepro.2021.126516

Diddi, S., & Yan, R. N. (2019). Consumer perceptions related to clothing repair and community mending events: A circular economy perspective. *Sustainability*, *11*(19), 5306. https://doi.org/10.3390/su11195306

Ellen MacArthur Foundation. (2013). *Towards the circular economy Vol. 1: an economic and business rationale for an accelerated transition.* https://www.ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition

Environment and Climate Change Canada (ECCC). (2024, July 8). *Addressing plastic waste and pollution from the textile and apparel sector: consultation document.* https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/consultations/roadmap-plastic-waste-pollution-textile-apparel-sector/proposed-roadmap-plastic-waste-pollution-textile-apparel-sector.html

Ha-Brookshire, J. E., & Hodges, N. N. (2009). Socially responsible consumer behavior?: Exploring used clothing donation behavior. *Clothing and Textiles Research Journal*, *27*(3), 179–196. https://doi.org/10.1177/0887302X08327199

Harmsen, P., Scheffer, M., & Bos, H. (2021). Textiles for Circular Fashion: The Logic behind Recycling Options. *Sustainability*, *13*(17), 9714. https://doi.org/10.3390/su13179714

Levänen, J., Uusitalo, V., Härri, A., Kareinen, E., & Linnanen, L. (2021). Innovative recycling or extended use? Comparing the global warming potential of different ownership and end-of-life scenarios for textiles. *Environmental Research Letters*, *16*(5), 054069. https://doi.org/10.1088/1748-9326/abfac3

Linden, A. R. (2016). An analysis of the fast fashion industry. *Senior Projects Fall 2016*. 30. https://digitalcommons.bard.edu/senproj_f2016/30

McQueen, R. H., Jain, A., McNeill, L. S., & Kozlowski, A. (2022). The role of resources in repair practice: Engagement with self, paid and unpaid clothing repair by young consumers. *Textile Research Journal*, *93*(3-4), 576-591. https://doi-org.login.ezproxy.library.ualberta.ca/10.1177/00405175221123067

Neto, A., & Ferreira, J. (2021). "I still love them and wear them"—Conflict occurrence and management in wearer-clothing relationships. *Sustainability*, *13*(23), Article 23. https://doi.org/10.3390/su132313054

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, *1*(4), 189-200. https://doi.org/10.1038/s43017-020-0039-9

Repair Café. (2024). *About.* Retrieved July 31, 2024, from https://www.repaircafe.org/en/about/

Weber, S., Lynes, J., & Young, S. B. (2017). Fashion interest as a driver for consumer textile waste management: Reuse, recycle or disposal. *International Journal of Consumer Studies*, *41*(2), 207–215. https://doi.org/10.1111/ijcs.12328

Appendix

Statement	Attendees	Non-Attendees
1. I believe I am physically capable of repairing clothes	6.39 ± 0.77[a]	6.31 ± 0.95[a]
2. I believe I am capable of learning and following clothing repair instructions	6.30 ± 0.83[a]	6.26 ± 0.93[a]
3. I would feel too socially anxious to attend a clothing repair event	2.62 ± 1.83[a]	3.39 ± 1.93[b]
4. I am confident that I could attend a clothing repair event if I wanted to	6.21 ± 0.96[a]	5.68 ± 1.32[b]
5. I have the means (e.g. working device, internet connection, social media) to become aware of clothing repair events near me	6.32 ± 0.99[a]	6.25 ± 0.93[a]
6. There are likely to be plenty of opportunities to attend a clothing repair event	4.87 ± 1.60[a]	4.00 ± 1.55[b]
7. I have clothing items that need repair	6.03 ± 1.20[a]	5.10 ± 1.75[b]
8. If I wanted to, I would have the time to attend a clothing repair event	5.69 ± 1.14[a]	5.13 ± 1.48[b]
9. If I wanted to, I would have the transportation means to attend a clothing repair event	6.10 ± 1.14[a]	6.04 ± 1.28[a]
Note: different super-scripted letters indicate a significant difference in agreement rating ($p \leq 0.001$)		

Table 1. Mean (± standard deviation) for statements regarding the ability to attend a clothing repair event based on a 7-point scale, where 1 = "strongly disagree" and 7 = "strongly agree" (Attendees *N = 107* ; Non-attendees *N = 475*).

Product Lifetime Modelling



Research paper
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Convenience as a Key Driver in Extending the Cumulative Lifespan of Furniture

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Keywords: Furniture; Product Longevity; Emotional Attachment; Value; Convenience.

Abstract
In response to environmental challenges and overconsumption, design strategies focusing on product longevity have emerged. While product longevity is partly determined by physical durability, it is also heavily influenced by the consumer. Therefore, understanding consumer attitudes toward product lifespans is essential for gaining insights into longevity. Specifically, this study investigates how consumers' valuation of furniture impacts its lifespan.

The findings are based on data from semi-structured interviews and a survey provided by AAU Design Lab, analyzed through reflexive thematic analysis. The study introduces two terms to further specify the understanding of product lifespan: individual ownership lifespan and cumulative lifespan.

The study found that emotional attachment is not necessarily essential for achieving prolonged cumulative lifespan of furniture, challenging existing strategies like design for attachment and emotional durability. While these strategies influence individual ownership lifespan, the findings in this paper suggest that convenience is the key driver in extending the cumulative lifespan of furniture by enabling its reuse through accessible disposal methods and platforms. Accordingly, putting a stronger focus on the systems and contexts in which products exist could play an important role in extending their lifetime.

As this is a preliminary study with limited data, these findings should be considered an interesting starting point for further investigation.

Introduction

Furniture is a constant presence in our lives, shaping the spaces where we live, work, and relax. Beyond its practical functions, it often reflects personal identity, social trends, and economic status (Almquist et al., 2016). Yet, while some furniture is cherished for years or even generations, other pieces are disposed of after a short time. A study revealed that 42% of products are discarded while still being fully functional (Haase & Laursen, 2022, p. 5). This raises the research question: *How does the consumers' valuation of furniture affect its lifespan?*

There is a common association that durable furniture is exclusively tied to high economic value, emotional significance, or premium materials (Cox et al., 2013, p. 25; Haase & Laursen, 2022, p. 33; Mugge et al., 2005, pp. 40–41). While these claims might be true, they overlook the complex ways people assign value to their belongings.

Through this study, we aim to explore the values that affect furniture lifespans and how. We will highlight how consumer attitudes and behaviors can redefine the understanding of "long-lasting" furniture, providing additional perspectives on consumer valuation and product longevity.

Theory

Product longevity

In their book "Designing for Longevity", Haase & Laursen (2022) describe product longevity in terms of products that:

- are **physically durable**
- provide **long-term value** for users (emotional durability)
- represent a **viable business**
- generate a **competitive advantage** for the company

They claim that these factors are equally important and must be present simultaneously to achieve product longevity (Haase & Laursen, 2022, p. 34).

Extensive theoretical research focuses on how designers can achieve physical durability to ensure long lasting products, emphasizing factors such as repairability, the use of high-quality materials, upgradability and modularity (Haase & Laursen, 2022, p. 33; Van Nes & Cramer, 2005, pp. 295–296).

Another key factor is emotional attachment, which plays a pivotal role in extending product lifespan by creating a bond between the consumer and the product (Chapman, 2015, p. 21; Mugge et al., 2005, pp. 40–41). This attachment typically occurs when the product provides enjoyment or pleasure, or holds a nostalgic value, such as inherited items (Frahm et al., 2022, p. 4; Mugge et al., 2005, p. 41). Emotional attachment can also arise from financial investment in a product (Cox et al., 2013, p. 25).

Existing literature on product longevity heavily emphasizes product-person relationships, adaptable constructions, and the use of durable materials (Mugge et al., 2005, p. 41; Van Nes & Cramer, 2005, pp. 295–296).This calls for further exploration of how the lifespans of furniture that lacks emotional durability are affected.

Methodology

Data Collection

This study is based on data collected from semi-structured interviews and a survey provided by AAU Design Lab.

Semi-Structured Interviews

Ten semi-structured interviews were conducted using a prepared interview guide, ensuring focus while allowing participants to share additional insights. The guide was based on “fast furniture” and the initial assumption that conscious consumers would feel guilty about frequently replacing functional furniture, particularly inexpensive pieces with low emotional attachment (Antonetti & Maklan, 2014; Burnett & Lunsford, 1994).

Interviews were conducted both in-person and online to accommodate participants' and researchers’ locations. The interviewees were selected through convenience sampling within social and professional networks of the researchers. All participants live in Denmark, where apartments are typically rented unfurnished, suggesting more frequent furniture replacement compared to furnished rentals.

Survey

A survey provided by AAU Design Lab was distributed to gather insights into consumers' personal belongings and the lifespans of these items. The survey asked participants to select a piece of furniture from their home and respond to questions about, among other things, its history, repair, attachment, and lifespan. Information about the data collected can be found in Table 1.

Due to a low response rate, the data from the survey was analysed qualitatively and incorporated into the analysis. As a result, this study should be seen as a preliminary exploration of the topic.

Method	Quantity	Data type and processing
Interviews	10 (in total 120 minutes)	Audio recordings, transcriptions, notes
Survey	9 answers	Multiple choice, written answers, pictures.

Table 1. Data collection overview

Data Analysis

Interview data was analysed using reflexive thematic analysis as outlined by Braun & Clarke (2019). This approach emphasizes a researcher-driven process for identifying, organizing, and interpreting patterns within qualitative data.

The process involved:

- Familiarization with the data: The researchers transcribed and read the interview transcripts to gain a comprehensive understanding of the participants’ experiences and perspectives on the topic and questions.
- Initial coding: The researchers coded the transcripts by tagging segments that reflected potential insights relevant to the research question.
- Clustering of codes into themes: Through an iterative process, codes were grouped into broader categories

to identify relevant themes across the data.

Each researcher was responsible for coding the interviews they had personally conducted, followed by a collaborative clustering of codes into themes across all interviews.

Results

The following presents the findings which emerged from analyzing the data collected.

While the themes of "fast furniture" and guilt served as the starting point for the research, new topics that had not been initially considered in forming the interview guide were uncovered during data analysis.

Prolonging product lifespan

The analysis revealed three main methods that consumers employ to dispose of their unwanted furniture:

Recycling: Taking furniture to a recycling station. Primarily for reuse and *not* material recovery, depending on the physical state of the furniture.

Curbside Disposal: Placing furniture on the street for others to pick up or as part of bulk waste collection.

Donating or Selling: Giving furniture away to friends or relatives or selling it through online platforms such as Facebook Marketplace or Den Blå Avis (a Danish re-selling platform between private citizens).

This illustrates that consumers are disposing of their furniture in ways that allow the items to remain accessible to others, providing an opportunity to extend their lifetime.

Initially, the analysis adopted the definition of *product lifetime* provided by Haase and Laursen. They describe it as "the active lifetime of a product or the product's 'service life' (i.e. its total period in use)." (Haase & Laursen, 2022, p. 33).

The disposal methods identified revealed a limitation in this product lifetime definition, since it does not distinguish between a product's lifespan with a single owner and its cumulative lifespan across various owners. As such, the terms individual ownership lifespan and cumulative lifespan were established and illustrated in Figure 1:

Individual ownership lifespan: The period a single consumer owns and uses a particular product before replacing, disposing or passing it on.

Cumulative lifespan: The total time a product remains in use across multiple owners or purposes, from initial acquisition to final disposal. Consequently, a product's cumulative lifespan can consist of multiple individual ownership lifespans.

One Man's Trash…

When examining why consumers discard their furniture, the analysis revealed that items are often disposed of when they no longer fulfill the consumer's needs or expectations. This aligns with Van Nes & Cramer's (2005) established motives for product replacement, which identify four primary reasons for furniture disposal: *Wear and tear*, *improved utility*, *improved expression*, and *new desires*.

These reasons for disposing of furniture all result in ending its individual ownership

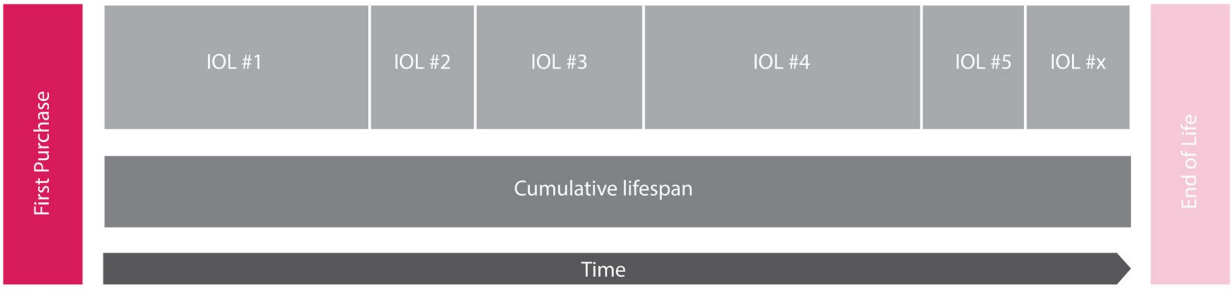


Figure 1. The relationship between individual ownership lifespan (IOL) and cumulative lifespan (CL).

lifespan. However, a product with no or limited value for the current owner can possibly provide value for another – one man's trash is another man's treasure. This is supported by the statement:

"[The last piece of furniture I got rid of was] my dining chairs, because they were falling apart… I gave them away via Facebook."

Even though the chairs had become physically obsolete for the owner, they still had enough value for another to come pick them up. When this is the case, and the product is passed on to the next, it will result in prolonging the cumulative lifespan of the product.

The Relationship Between Attachment and Product Lifespan

As presented in the theory section, emotional durability can play a key role in extending the cumulative lifespan of furniture longevity (Haase & Laursen, 2022, p. 34). On the contrary, another interview revealed that a low level of attachment to a piece of furniture does not necessarily impact its lifespan negatively:

"When I moved into [my apartment] I got a small cabinet under the sink and some curtains that the person who lived there before me had just left up. I think the person who lived there before them also had them hanging. And I've sold some of it to the next person who moved in after me. These are just cheap products that cover basic functional needs. They're so inexpensive that you don't form any attachment to them. If you had spent your own money on them, maybe you would have prioritized taking them with you."

This consumer passed on their furniture to which they felt little to no functional, emotional or monetary attachment. This insight presents an interesting perspective: Low-valued furniture can remain in use when it serves a basic function and is easily passed on. This suggests that a significant level of emotional attachment is not necessary for a piece of furniture to have a long cumulative lifespan.

Convenience in disposal

When disposing of furniture, several interviewees emphasized convenience as a crucial factor by using words like 'easy' and 'quick' and expressing feelings of satisfaction.

One interviewee shared, *"It made me very happy that someone came and helped me remove [the closet] so I wouldn't have to do it myself."*
This highlights how physical assistance in furniture disposal can significantly reduce the effort required, making the process more appealing.

Another interviewee described the speed of the process, stating, "*I can post it on Facebook, for example my old bed. Then somebody came and picked it up (…) after 15 minutes.*"
This response underscores how digital platforms enhance convenience in furniture disposal by facilitating quick, hassle-free transactions.

The interviewees expressed that they valued convenience not only in terms of time and physical labor, but also for its psychological impact. As one interviewee explained, *"I thought it was better to resell rather than throw it away, because the wardrobe wasn't that old.",* emphasizing that the consumer considers reselling the more ethical choice because the piece of furniture is still fully functional.

Another interviewee acknowledged the role of avoidance in decision-making: *"It would probably be easiest just to put the dresser somewhere. It might also be a bit of avoiding responsibility because then I don't have to decide to throw it away. Others can decide whether it can be used for something."*
This illustrates how convenience is intertwined with emotional and ethical considerations - leaving furniture available for others to take can serve to avoid the guilt of discarding functional items.

These four statements highlight the convenience of disposal methods like reselling or dumping furniture on the street, which allow consumers to

a) invest minimal effort in disposing of their furniture
b) avoid the emotional or ethical burdens of discarding items

This combination of avoidance and convenience lowers the efforts required to enable furniture reuse, ultimately creating opportunities for prolonging the cumulative lifespan of furniture.

This concept is both illustrated and supported by the rising popularity of ”byttebokse” (translated: ‘swap boxes’, Dons, 2024) that can be seen as a symptom of easy and convenient furniture salvaging and disposal, Figure 2. Here citizens can put products they no longer need in one of multiple boxes in the city center for others to pick up free of charge.



Figure 2. "Bytteboks" (‘swap box’) in Aalborg C.

Discussion

Emotional Attachment vs. Convenience in Prolonging Product Lifespan

It was found that a significant level of attachment is not always necessary to prolong the cumulative lifespan of furniture. This finding contrasts with the several strategies that have arisen to address the challenge of product obsolescence, including design for attachment and design for emotional durability (Chapman, 2015, p. 21; Mugge et al., 2005, pp. 40–41).

As further explained by Haase & Laursen: “The aim of all these strategies is to create an emotional bond between the user and the product, thereby making the user less likely to dispose of the product.” (Haase & Laursen, 2022, p. 11).

While the abovementioned viewpoints hold merit, their focus on emotional attachment as the primary driver for prolonging product life does not account for the cumulative lifespan of the product: Emotional attachment primarily affects the individual ownership lifespan of a product. Similarly, the following individual ownership lifespans cannot be expected to be long, as the product does not necessarily hold an emotional attachment to the new owners. Løvbak Berg & Hebrok (2024) highlight the effects of both physical and emotional durability for product lifetimes but note that all their investigated products, that consumers held onto, retained either their function, held up appearance, had material withstanding use, or provided comfort. This indicates that the cumulative lifespan would mainly be observed in products with high physical durability.

Besides the importance of physical durability (and emotional durability), an overlooked aspect in literature on product lifetimes is the convenience when consumers discard products. We suggest that convenience is the primary driver for prolonging the cumulative lifespan of furniture. In contrast to emotional attachment, which mainly impacts the individual ownership lifespan of a piece of furniture, convenience is the factor that drives its cumulative lifespan, allowing it to enter (and re-enter) the reuse cycle, ultimately prolonging its lifespan – given that the physical durability qualities highlighted by Løvbak Berg & Hebrok (2024) are still intact.

This insight could have a significant impact on the current understanding of product longevity, as the focus should not exclusively be on the product itself and its individual ownership lifespan, but also on the contexts and systems that support its reusability and facilitate the extension of its cumulative lifespan. The “Bytteboks” (‘swap box’) in Figure 2 can be seen as a strong example of designing a system that caters to the convenience of furniture disposal.

Societal Structure Leads to Frequent Furniture Replacement

The Danish context, where the interviews were conducted, supposedly influences the findings, particularly when comparing the Danish property market to other countries. A comparison with the Italian property market (Table 2) showed a remarkable difference in the share of furnished apartments.

	DK	IT
Share of furnished apartments	4 - 26%	66 - 90%

Table 2. Share of furnished apartments in Denmark and Italy.

This indicates a greater need for temporary furnishment in Denmark. Consequently, the demand for convenience becomes crucial, as tenants face shifting needs when moving into unfurnished properties.

Limitations

The sample size of interviewees and survey respondents was relatively small, which suggests the need for further investigations to verify the implications presented. For this reason, the study should be considered a preliminary study into the topic.

The interviewees were only able to confirm how they acquired their piece of furniture and how they disposed of it or planned to dispose of it. Therefore, the findings in this study are based solely on a segment of the furniture's cumulative lifespan, with the fate of the item after disposal remaining unknown, see Figure 3.

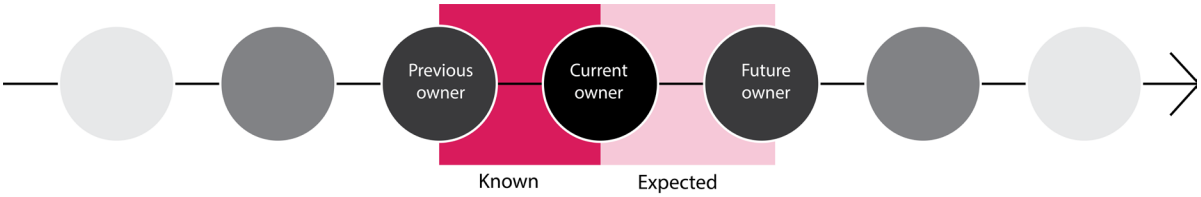


Figure 3. Data limitations in the study.

Conclusion

This study investigated how consumers' valuation of furniture impacts its lifespan. The study did so by collecting and subsequently analyzing data from semi-structured interviews and a survey provided by AAU Design Lab. The findings offer a more nuanced understanding of furniture lifespans through the introduction of two new terms: Individual ownership lifespan and cumulative lifespan. The former refers to the duration a single consumer retains a product, while the latter encompasses the total lifespan of a product across multiple ownership periods.

To answer the research question, *How does consumers' valuation of furniture affect its lifespan?* this study found that emotional attachment is not necessarily crucial for extending the cumulative lifespan of furniture. This challenges existing design strategies that emphasize emotional attachment and emotional durability as crucial drivers for product longevity. While these strategies may extend the individual ownership lifespan, they fail to consider the cumulative lifespans that depend on multiple users and rely on physical durability.

This study contributes to this by introducing convenience – both physical and emotional – as the key driver in extending the cumulative lifespan of furniture in the context of furniture disposal. Accessible disposal methods and platforms that support reuse are crucial for integrating products into reuse cycles, extending their cumulative lifespan. Considering convenience as a factor in future design processes or in systems targeting reuse could further promote sustainability.

Despite its contributions, this study has some limitations. While acknowledging these limitations, the insights presented in this paper contribute to a more nuanced understanding of product longevity and furniture reuse. By highlighting the importance of convenience, this study provides new insights into emotional attachment and consumer valuation.

To better understand the potential extension of the cumulative lifespan through multiple owners, further investigation is needed by tracing the entire journey of the furniture, from its initial purchase to its final disposal. Data collection from first purchase to final furniture disposal remains an important step in future research. Such studies could investigate how

long products remain in use, how frequently they are reused, and how many have had "previous lives" before reaching their end of use, further contributing to the understanding of product lifetimes

This could be aided with the coming EU Product Passport (European Commission 2024), which contains detailed lifecycle data to not only help consumers at the end-of-life stage, but also aid research like this – if the digital product passport will be able to be updated. For example, normalizing a usage history similar to used cars. The initial findings in this study could be further cemented by pursuing a life cycle assessment (LCA), partly supplemented with actual usage data to quantify the environmental benefits of long cumulative lifespans.

References

Antonetti, P. & Maklan, S. (2014) Exploring Guilt and Pride in the Context of Sustainability. Psychology & Marketing, 31(9), 717-735. https://doi.org/10.1002/mar.20730

Almquist, E., Senior, J., & Bloch, N. (2016, September). The Elements of Value: Measuring—And delivering—What consumers really want. *Harvard Business Review*, *Customer Strategy*. https://hbr.org/2016/09/the-elements-of-value

Antonetti, P., & Maklan, S. (2014). Exploring Postconsumption Guilt and Pride in the Context of Sustainability. *Psychology & Marketing*, *31*(9), 717–735. https://doi.org/10.1002/mar.20730

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Burnett, M. S., & Lunsford, D. A. (1994). Conceptualizing Guilt in the Consumer Decision-making Process. *Journal of Consumer Marketing*, *11*(3), 33–43. https://doi.org/10.1108/07363769410065454

Chapman, J. (2015). *Emotionally durable design: Objects, experiences and empathy* (Second edition). Routledge, Taylor & Francis Group.

Cox, J., Griffith, S., Giorgi, S., & King, G. (2013). Consumer understanding of product lifetimes. *Resources, Conservation and Recycling*, *79*, 21–29. https://doi.org/10.1016/j.resconrec.2013.05.003

Dons, A. S. (2024, August 11). *Nye byttebokse i tre bydele i Aalborg*. https://ligeher.nu/aalborg/nyheder/det-sker/byttebokse ne-rykker-endnu-taettere-paa-centrum/5184701

European Commission. (2024, March). *EU's Digital Product Passport: Advancing transparency and sustainability*. https://data.europa.eu/en/news-events/news/eus-digital-product-passport-advancing-transparency-and-sustainability

Frahm, L. B., Laursen, L. N., & Tollestrup, C. (2022). Categories and Design Properties of Inherited Long-Lasting Products. *Sustainability*, *14*(7), Article 7. https://doi.org/10.3390/su14073835

Haase, L. M., & Laursen, L. N. (2022). *Designing for Longevity: Expert Strategies for Creating Long-Lasting Products*. Routledge.

Løvbak Berg, L., & Hebrok, M. (2024). Holding on or letting go: Conflicting narratives of product longevity. *Resources, Conservation and Recycling*, *210*, 107834. https://doi.org/10.1016/j.resconrec.2024.107834

Mugge, R., Schoormans, J. P. L., & Schifferstein, H. N. J. (2005). Design Strategies to Postpone Consumers' Product Replacement: The Value of a Strong Person-Product Relationship. *The Design Journal*, *8*(2), 38–48. https://doi.org/10.2752/146069205789331637

Van Nes, N., & Cramer, J. (2005). Influencing product lifetime through product design. *Business Strategy and the Environment*, *14*(5), 286–299. https://doi.org/10.1002/bse.491

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Mind the gap: To what extent are Danish early adopters of science-based targets addressing impacts across their products´ life cycles?

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Keywords: Product life cycle; Scope 3; Value Chain; Science-based Targets; Absolute Sustainability.

Abstract: Value chain emissions constitute the largest share of most company's greenhouse gas (GHG) inventory, making their reduction essential for achieving science-based targets (SBTs) and supporting global climate goals. This study analyses the decarbonization efforts of six Danish early adopters of SBTs, focusing on their strategies to reduce emissions across product life cycles and value chains. Based on publicly disclosed data from company reports and responses to the CDP Climate Change Questionnaires, the findings reveal a primary focus on Scope 1 and 2 emissions, with limited efforts targeting value chain emissions (i.e., Scope 3) during the early years following target setting. The study highlights significant gaps between the reductions required to meet targets and the reported impact of current and planned strategies, with shortfalls ranging from 17% to 75% of current inventory levels. Additionally, the study highlights inconsistencies and gaps in company disclosures making it difficult to assess actual progress. To close these gaps, there is a need for more knowledge on how companies can accelerate value chain decarbonization - such as through circular economy strategies - and improved transparency in reporting. Enhanced corporate action and disclosure are critical to aligning with SBT commitments and ensuring meaningful climate progress.

Introduction

Companies play a critical role to mitigate climate change (Bjørn, Tilsted, et al., 2022; Krabbe et al., 2015; United Nations' High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities, 2023) by implementing strategies to enable operating within planetary boundaries (Moshrefi et al., 2020, 2021). The Science-Based Targets initiative (SBTi) offers a framework for aligning corporate strategies with environmental needs (SBTi, 2023b, 2024c), facilitating a shift from relative to absolute sustainability (Bjorn et al., 2020; Hauschild et al., 2020). This involves addressing direct emissions (Scope 1), indirect emissions from energy use (Scope 2), and value chain emissions (Scope 3) from product life cycles (Callahan et al., 2011). Despite significant momentum in companies setting science-based targets (SBTs), implementation lags behind (Aldy et al., 2023; Bjørn, Lloyd, et al., 2022; Day et al., 2023; Dietz et al., 2018), particularly for Scope 3 emissions (Giesekam et al., 2021; SBTi, 2023a). Upstream and downstream scope 3 emissions are defined by the impacts across the lifecycle of a product and dominate manufacturing company greenhouse gas (GHG) inventories (CDP, 2023b; SBTi, 2023a) and are crucial to address. Achieving SBTs is further challenged by companies' revenue growth plans, linked with increased production volumes. Circular economy strategies offer an opportunity for implementing comprehensive changes in Scope 3 (Marini et al., 2024; The Danish Business Authority et al., 2023; Zomer et al., 2022). For example, extending product life can reduce Scope 3 emissions in purchased goods and end-of-life treatment (Blomsma et al., 2019; Marini et al., 2024). However, companies struggle with selecting and detailing these approaches effectively to meet their climate goals (Moshrefi et al., 2020, 2021; The Danish Business Authority et al., 2023; Zomer et al., 2022).

Danish companies have been among the early adopters of SBTs (SBTi, 2024c; UN Global Compact Network Denmark, 2023). This study seeks to clarify the current state of corporate climate action among Danish early adopters by

analysing published data. Specifically, this research examines current and planned decarbonization strategies for Scope 3 and evaluates their potential impact on meeting SBTs. The research question guiding this study is: *What decarbonization strategies related to Scope 3 are currently being implemented by companies with science-based targets, what future strategies are planned, and how do these align with the required reductions to meet their targets?*

Methods

The research involved three steps: 1. Selecting relevant companies and analysing their GHG inventory levels, 2. identifying implemented decarbonization strategies, and 3. evaluating planned strategies in relation to their targets.

In step 1, the six Danish companies that had SBTi-validated targets for at least three years and publicly available data in emission and revenue changes were selected (SBTi, 2024c). Data was primarily sourced from company annual reports, which provided information on revenue trends and Scope 1, 2, and 3 emissions. Incomplete company data (e.g., not including all Scope 3 sub-categories covered by a target), was supplemented with CDP Climate Change Questionnaire responses (CDP, 2023a), a disclosure platform endorsed by SBTi (SBTi, 2024b).

In step 2, the decarbonization strategies of each company were analysed using disclosed data from the CDP Climate Change Questionnaire question C4.3b: "*Provide details on the initiatives implemented in the reporting year in the table below*". This question details initiatives implemented during the year, including their estimated CO_2e savings and related GHG Scopes. As the question was introduced in 2019, the analysis spanned 2019–2022 to ensure consistency. Strategies were categorized into two groups: (A) Scope 1 and 2 and (B) Scope 3, to clarify for the share of efforts targeting the value chain. Discrepancies between CDP disclosures and company reports for the same years were documented to identify potential inconsistencies in reported data.

In step 3, data on planned reduction initiatives was analysed to assess the comprehensiveness of each company's strategies for achieving near-term SBTs (i.e., 5-10 years from the date the target is submitted following science-based reduction pathways (SBTi, 2024b)). The analysis was made based on CDP question C4.3a "*Identify the total number of initiatives at each stage of development, and for those in the implementation stages, the estimated CO_2e savings*". An optimistic scenario was applied to evaluate the potential impact during the transition period, assuming all initiatives would achieve the planned effect from year one, relative to the timeline for each company's short-term target. To enable comparison with estimated future emissions savings, supplier and intensity targets were converted to absolute terms, following assumptions that will be further outlined in Section 3.

Results and Discussion

This section addresses the research question by introducing the studied SBT (section 3.1), examining implemented decarbonization strategies (section 3,2), evaluating planned future strategies (section 3.3) and discussing limitations in disclosed data (section 3.4).

Introduction and stock take of the early Danish SBT adopters

In 2017, Carlsberg Group became the first Danish company to publish SBTs approved by SBTi (SBTi, 2024c). Novo Nordisk followed in 2018, and in 2020, four additional Danish companies joined the initiative: Rockwool Group (Rockwool), the Lego Group (Lego), Vestas Wind Systems (Vestas) and the Velux Group (Velux) (SBTi, 2024c). These six Danish early SBT adopters are all product manufacturers, representing diverse sectors such as pharmaceuticals, consumer goods, food and beverages, building products, and machinery. Now, more than three years after setting targets, data from the six companies provide an opportunity to evaluate the effectiveness of their strategies in reducing GHG emissions across their value chains.

Figure 1 shows GHG inventory trends from target publication to the latest reporting year. It highlights trends in direct emissions from Scopes 1, 2 and 3 (Callahan et al., 2011; WRI et al., 2004).

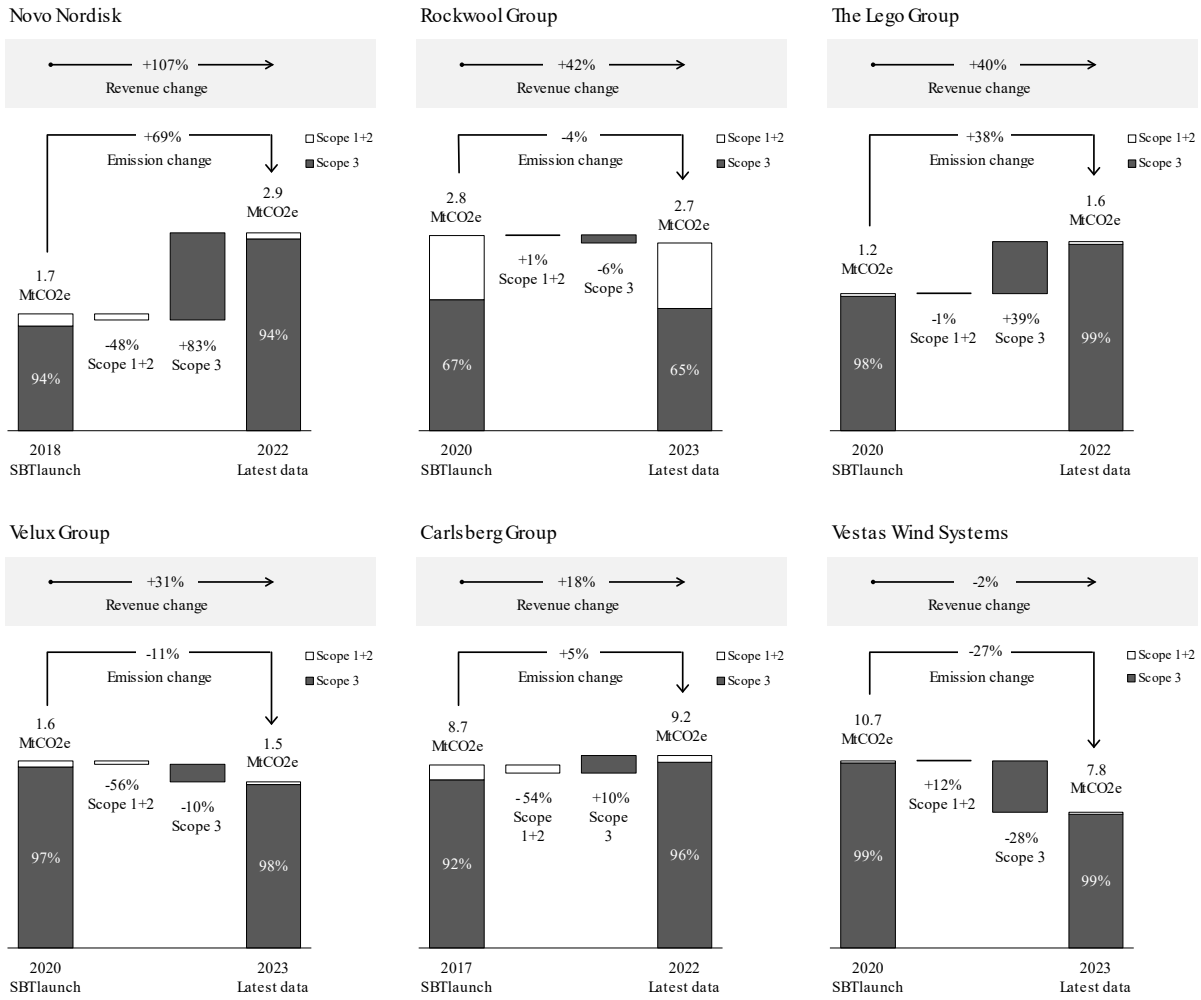


Figure 1. Emission development across GHG Scopes of the Danish early SBT adopters. *Emission data: Novo Emission data: Novo Nordisk and Carlsberg figures derive from CDP Climate Change Response Datasets (2018-2023) (CDP, 2023a) and figures for remaining companies stem from company sustainability reporting (Rockwool Group, 2024b; The Lego Group, 2021, 2023, 2024b; Velux Group, 2024a; Vestas Wind Systems, 2024b). Revenue data: Company annual reports (Carlsberg Group, 2024; Novo Nordisk, 2024; Rockwool Group, 2024a; The Lego Group, 2024a; Velux Group, 2024b; Vestas Wind Systems, 2024a).*

Scope 3, with dominate the six companies' inventories, comprising 67–99% of the emissions in the target year, remained largely unchanged. This observation aligns with studies emphasizing the substantial share of Scope 3 in most sectors, especially in manufacturing companies (CDP, 2022; Hertwich et al., 2018).

When analysing the development of the total company GHG inventories, only Vestas and Velux have reduced emissions since their SBTs were published. Rockwool's emissions have remained somewhat stable, while Carlsberg, Novo Nordisk, and Lego have all experienced increases in total emissions. Carlsberg's GHG inventory grew 5%, while Lego and Novo Nordisk grew 38% and 69%, respectively.

Examining what GHG Scopes drives the inventory development, increases in emissions for Carlsberg, Novo Nordisk, and Lego are solely driven by changes in Scope 3. While all three companies have reduced Scope 1 and 2 emissions, their Scope 3 emissions have increased—by 10% for Carlsberg, 38% for Lego, and 83% for Novo Nordisk. These increases align with sizable revenue growth during the same period, suggesting that higher sales volumes, likely tied to increased production, are driving up value chain emissions. Similarly, the decrease in Scope 3

emissions by Vestas is also tied to a reduction in revenue (although only minor) over the same period. Only Velux and Rockwool have markedly reduced their Scope 3 emissions despite revenue growth, indicating that they may have adopted effective decarbonization strategies.

This raises the question: What specific decarbonization strategies have these companies implemented to manage Scope 3 emissions, and how do these efforts align with the observed trends in their GHG inventories? Section 3.2 investigates the decarbonization strategies pursued by each company, focusing on the impact across their value chains.

Current decarbonization strategies across product life cycles

The analysis of the disclosed data, presented in Figure 2, finds that between 2019-2022, the six Danish companies concentrated primarily on reducing Scope 1 and 2 emissions, while taking relatively limited actions to address Scope 3, e.g. implement design strategies for minimizing the impact across the product life cycle. The vast majority of efforts address Scope 1 and 2 ranging from 89-100% of the estimated CO_2e savings over the four-year period. All companies disclose to have implemented low-carbon energy consumption initiatives, such as biogas, wind energy, solar panels, or entering power purchasing agreements for renewable energy. Additionally, energy efficiency improvements in building operations and production processes are common, including optimized facility management for heating and lighting, as well as production enhancements like process optimization, automation, and machinery upgrades. At the same time, initiatives targeting Scope 3 have been scarce. Four of the six companies—Novo Nordisk, Rockwool, Lego, and Velux—have not yet implemented initiatives addressing the life cycle of their products to decarbonize their value chains in Scope 3. Only Carlsberg and Vestas have addressed the value chain in their efforts, but these initiatives have had minimal impact compared to savings from other measures. Carlsberg reports that only 2% of its estimated CO_2e savings over the four-year period occurred in the value chain, specifically through material recycling. Vestas indicates that 11% of its reductions arrives from resource efficiency measures in the value chain, with no further disclosed details.

Decarbonization strategies			Estimated CO2e savings from 2019-2022 as diclosed to CDP, t. tonnes CO2e					
GHG scope	CDP initiative category	Details	Carlsberg	Novo Nordisk	Rockwool	Lego	Vestas	Velux (only 2021)
Emission savings occuring in Scope 1 and 2	Energy efficiency in buildings	Heating, Ventilation and Air Conditioning (HVAC)	0.5			0.4	3.8	
		Lightning			0.5	2.1	0.9	
		Insulation				0.2		
	Energy efficiency in production processes	Process optimization	26.7		16.7	0.2	0.1	
		Automation; Smart control system	1.7		1.1			
		Machine/equipment replacement			17.6	0.3		
		Electrification; Fuel switch			16.8	0.1		
		Other (compressed air, cooling technology etc.)	6.9	11.3	0.6	0.5	0.4	
	Low-carbon energy consumption	Biogas; Solid Biofuels	12.8				0.4	
		Wind			92.9		0.1	
		Solar PV					0.0	
		Other (Power Purchasing agreements)						45.0
	Low-carbon energy generation	Biogas; Solid Biofuels	0.9				0.4	
		Solar PV				5.3		
	Non-energy industrial process emissions	Substitution material with low financial impact.			6.1			
	Fugitive emissions reductions	-						
	Transportation	Company fleet vehicle replacement					0.5	
	Other, please specify	Energy savings programme	0.2	2.7				
Emission savings occuring in Scope 3	Transportation	-						
	Company policy or behavioural change	Resource efficiency					0.8	
	Waste reduction and material circularity	Product/component/material recycling	1.0					
	Other, please specify	-						
Total estimated CO2e savings from 2019-2022			50.5	14.0	152.2	9.1	7.4	45.0
%-share related to Scope 1 and 2			98%	100%	100%	100%	89%	100%
%-share related to Scope 3			2%	0%	0%	0%	11%	0%

Figure 2. Decarbonization strategies of the six first Danish SBT companies and their cumulative estimated CO_2e savings from 2019-2022 as disclosed to CDP. *Data: CDP Climate Change Response Datasets (2018-2023)* (CDP, 2023a)

Given the sizable proportion of Scope 3 emissions in corporate inventories compared to Scopes 1 and 2 (Figure 1), the lack of life cycle initiatives pose significant challenges for companies aiming to meet near-term targets (SBTi, 2023a). Energy efficiency measures, while important, are typically insufficient to achieve the reductions required to meet SBTs and often lead to increased consumption offsetting the intended emission reductions (Hauschild et al., 2017; Kara et al., 2018). Despite offering significant potential to address value chain emissions (Marini et al., 2024; The Danish Business Authority et al., 2023; Zomer et al., 2022), the implementation of circular economy strategies is often hindered by long timeframes and complex challenges (Bey et al., 2013; Geissdoerfer et al., 2023). The limited adoption of value chain initiatives could partly be explained by the extended lead times these strategies demand, leaving many still in the planning stage. To investigate this, Section 3.3 explores planned strategies and assesses their alignment with the reductions necessary to meet SBTs.

Future strategies and alignment with targeted reductions

In addition to strategies already implemented, the company's responses to the CDP's annual Climate Change Questionnaire also highlight emission reduction initiatives in different planning stages (question C4.3a). Although the specific strategies are not disclosed in detail, the responses categorize initiatives by maturity levels (i.e., "implementation commenced," "to be investigated," and "under investigation") and include an overall yearly CO_2e impact assessment for each stage.

Figure 3 compares the estimated total impacts of these disclosed future strategies with current emission inventory levels (Figure 1) and near-term targets, highlighting the gap towards achieving these targets. The analysis is based on two key assumptions:

1. *Immediate full impact of planned reduction initiatives.* The impacts were calculated under an optimistic scenario, assuming each initiative achieves full effectiveness immediately upon implementation from following year and until near-term target is reached. In reality, reductions will likely be lower, as many initiatives are still in the early phase - “to be investigated” - and because some initiatives will likely require time to reach full impact.

2. *Conversion of intensity and supplier engagement targets into absolute target levels.* To compare strategy impacts with inventory levels, intensity-based targets (Carlsberg and Vestas) and supplier engagement targets (Novo Nordisk) were converted into absolute terms. Near-term absolute target levels for intensity-based targets were assessed by projecting historical revenue trends from the base year to estimate production volumes for the target year. Since supplier engagement targets cannot directly be translated into an absolute measure, the 2030 target for Novo Nordisk was defined by assuming a linear reduction towards net-zero by 2045 — a target published in the company´s 2023 Annual Report but not currently approved by SBTi (Novo Nordisk, 2024; SBTi, 2024c).

Although these assumptions introduce a degree of uncertainty to the analysis, the overall conclusion is robust. The analysis shows that a substantial gap remains in meeting the near-term SBTs ranging from 17-75% of current GHG inventory levels across the studied companies. The estimated impacts of the currently planned strategies, according to disclosures, are modest for Rockwool and Lego (with 6% and 13% reductions respectively), and nearly negligible for Vestas, Carlsberg, and Novo Nordisk (with reductions of 1%, 1%, and 0%, respectively). These findings suggest that, despite several years into their climate transition efforts, these companies have yet to disclose sufficient strategies to meet their targets. Although the specific type of strategies being developed were not clarified in the disclosures, the small impact may indicate that currently planned reduction efforts are only to a small extent addressing the sizable emission in their value chains.

This raises the question of whether the shortfall is mainly due to inadequate current and planned strategies, or to disclosure limitations that fail to reflect actual company activities. This issue is discussed in Section 3.4.

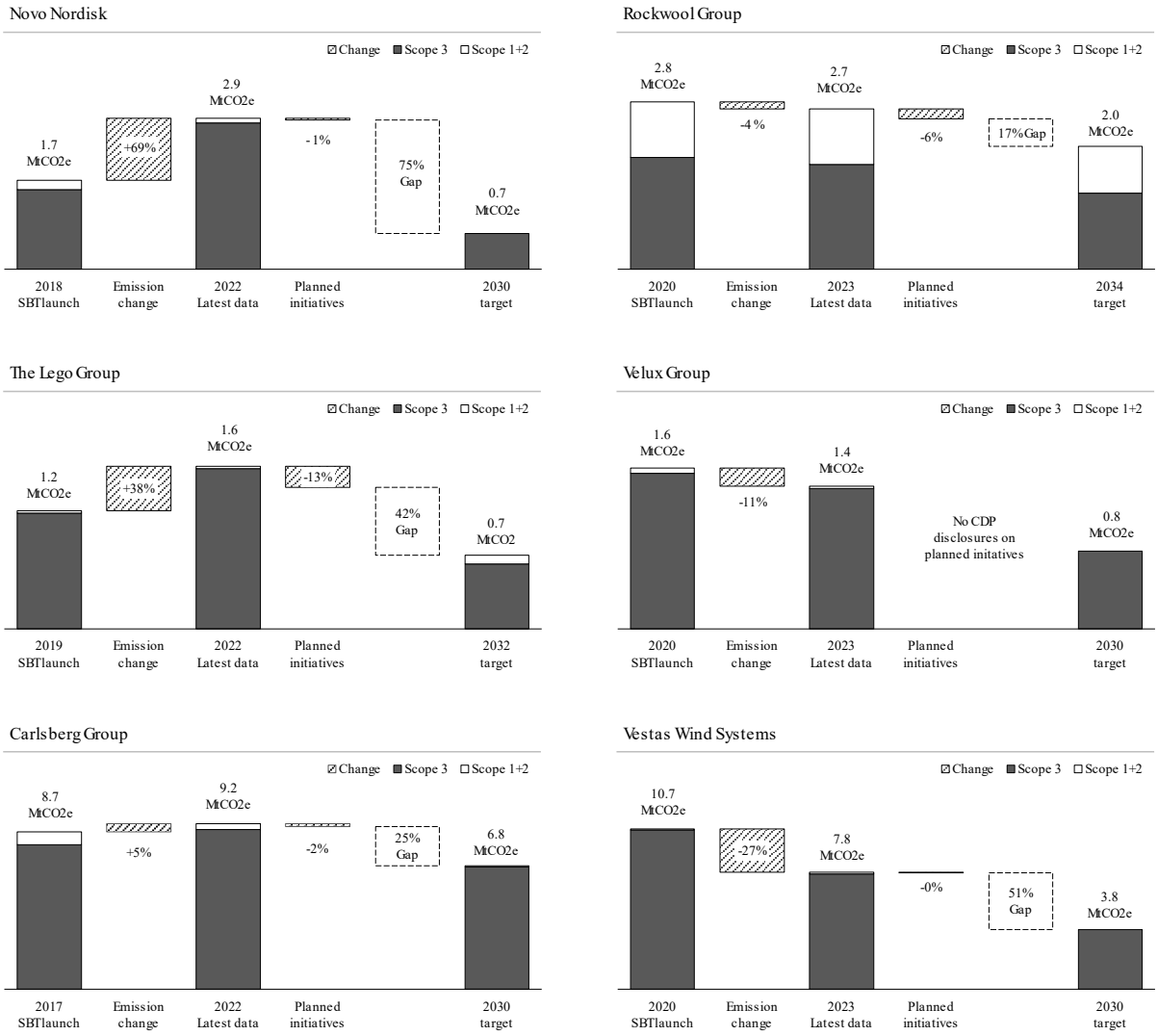


Figure 3. Comparison of estimated cumulative impacts of disclosed future strategies (planned initiatives) with current GHG inventory levels and near-term targets. *Emission data sources: Novo Nordisk and Carlsberg figures derive from CDP Climate Change Response Datasets (2018-2023) (CDP, 2023a) and figures for remaining companies stem from company sustainability reporting (Rockwool Group, 2024b; The Lego Group, 2021, 2023, 2024b; Velux Group, 2024a; Vestas Wind Systems, 2024b). Near-term target sources: SBTi webpage (SBTi, 2024c).*

Lack of action, deficient disclosure or both?

The data disclosed by the companies suggest trends but fall short of providing definitive conclusions due to possible limitations in the disclosures and deficiencies in the reported data. Firstly, many unanswered questions reveal significant gaps in the companies' responses to CDP's Climate Change Questionnaire. The most notable case is Rockwool, which left questions unanswered in 2019, 2020, and 2022, and offered only minimal reporting in 2021. Secondly, misalignment between reported emission trends over time (Figure 1) and disclosed actions (Figure 2) suggest that companies may not be reporting reduction initiatives comprehensively. The absence of Scope 3 initiatives is evident in the cases of Carlsberg, Novo Nordisk, and Lego, whose value chain emissions have also increased alongside revenue growth during their initial years with SBTs (Figure 1). In contrast, it remains unclear how Velux and Rockwool have reduced Scope 3 emissions despite revenue growth and without implementing value chain-specific strategies (Figure 2). While external factors such as energy grid changes, market dynamics, and value chain behaviour can influence GHG

inventories, these examples suggest a potential lack of transparency in disclosure. Thirdly, discrepancies between company reports and CDP disclosures (as also documented by other studies (Klaaßen et al., 2021)) suggest that additional emission reduction actions may exist even though they are not available in the CDP data. For example, Velux reports reductions achieved through factory electrification across four sites and the incorporation of non-virgin materials in its products within its annual reports; however, these details are not presented in the CDP disclosures (CDP, 2023a; Velux Group, 2024a). Similarly, Novo Nordisk's 2023 Annual Report highlights a major initiative requiring suppliers to transition to renewable energy and includes an assessment of its projected CO_2e impact. However, these details are absent from the company's disclosures on future initiatives in the CDP reporting (CDP, 2023a; Novo Nordisk, 2024).

These discrepancies between CDP data, achieved emission reductions, and figures reported in annual reports raise potential reliability issues suggesting that reporting may not fully represent actual actions. Possible reasons for these discrepancies include:

- **Challenges in quantifying future impact:** Companies may struggle to quantify the future impact of reduction strategies, which require aligning these strategies with revenue growth plans. This reflects findings from other studies, which highlight the current lack of methodologies for conducting future environmental impact assessments (de Bortoli et al., 2023; Moshrefi et al., 2022; SBTi, 2023a, 2024a).
- **Limitations in the disclosure standard:** The structure of the CDP questionnaire itself may also restrict comprehensive reporting. CDP categorizes initiatives into 9 main areas with 55 sub-categories, that are largely focused on Scope 1 and 2 emissions and offering limited options for Scope 3 specific actions (CDP, 2023a).
- **Internal reporting challenges:** Internal communication gaps may exist. For example, reporting teams might work separately from sustainability or R&D teams, limiting their ability to accurately translate strategic initiatives into required disclosures.

These limitations create uncertainty about data reliability, with the observed gaps of 17–75% between required emission reductions and reported impacts remaining ambiguous. It is unclear whether these discrepancies result from deficient reporting, insufficient actions, or both. The lack of transparency and clarity in companies' plans presents barriers to understand and verify progress toward climate goals. Without accurate tracking, companies have the flexibility to set SBTs without sufficient accountability, making it challenging to differentiate between those with robust transition strategies and those without - concerns echoed in several studies and frameworks (CDP, 2023b; Day et al., 2023; de Bortoli et al., 2023; Hans et al., 2023; Tilsted et al., 2023).

Conclusions

The study evaluates the decarbonization efforts of six Danish early adopters of SBTs, focusing on Scope 3 emissions across the life cycle. Publicly disclosed data from annual reports and CDP Climate Change Questionnaires show that while these companies actively reduce Scope 1 and 2 emissions, limited action is taken for Scope 3 reduction, despite its dominance in GHG inventories and direct link to revenue growth.

A significant gap between reductions required for near-term SBTs and the impact of disclosed future strategies is observed. Limited life cycle initiatives suggest companies are unlikely to meet climate goals without significantly strengthening efforts in this area. Additionally, incomplete reporting and inconsistencies between disclosed actions and reported reductions hinders assessing actual progress. This lack of clarity obscures whether gaps result from insufficient action, poor reporting, or both.

Closing the ambition-action gap requires companies to prioritize life cycle decarbonization through robust strategies, such as circular economy, addressing the entire value chain. Improved transparency via consistent reporting is essential for accurate progress tracking and accountability. Future research should explore barriers to implementing and disclosing life cycle initiatives, ensuring corporate actions align with SBT commitments and business growth plans.

References

Aldy, J. E., Bolton, P., Kacperczyk, M., & Halem, Z. M. (2023). Behind schedule: The corporate effort to fulfill climate obligations. *Journal of Applied Corporate Finance*, *35*(2), 26–34. doi: 10.1111/jacf.12560

Bey, N., Hauschild, M. Z., & McAloone, T. C. (2013). Drivers and barriers for implementation of environmental strategies in manufacturing companies. *CIRP Annals - Manufacturing Technology*, *62*(1), 43–46. doi: 10.1016/j.cirp.2013.03.001

Bjorn, A., Chandrakumar, C., Boulay, A. M., Doka, G., Fang, K., Gondran, N., Hauschild, M. Z., Kerkhof, A., King, H., Margni, M., McLaren, S., Mueller, C., Owsianiak, M., Peters, G., Roos, S., Sala, S., Sandin, G., Sim, S., Vargas-Gonzalez, M., & Ryberg, M. (2020). Review of life-cycle based methods for absolute environmental sustainability assessment and their applications. In Environmental Research Letters (Vol. 15, Issue 8). IOP Publishing Ltd. doi: 10.1088/1748-9326/ab89d7

Bjørn, A., Lloyd, S. M., Brander, M., & Matthews, H. D. (2022). Renewable energy certificates threaten the integrity of corporate science-based targets. *Nature Climate Change*, *12*(6), 539–546. doi: 10.1038/s41558-022-01379-5

Bjørn, A., Tilsted, J. P., Addas, A., & Lloyd, S. M. (2022). Can Science-Based Targets Make the Private Sector Paris-Aligned? A Review of the Emerging Evidence. *Current Climate Change Reports*, *8*(2), 53–69. doi: 10.1007/s40641-022-00182-w

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D. C. A., Hildenbrand, J., Kristinsdottir, A. R., Kristoffersen, E., Shabazi, S., Nielsen, K. D., Jönbrink, A.-K., Wiik, C., & McAloone, T. C. (2019). Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation. *Journal of Cleaner Production*, *241*. doi: 10.1016/j.jclepro.2019.118271

Callahan, W., James Fava, S. A., Wickwire, S., Sottong, J., Stanway, J., & Ballentine, M. (2011). *Corporate Value Chain (Scope 3) Accounting and Reporting Standard Supplement to the GHG Protocol Corporate Accounting and Reporting Standard GHG Protocol Team*.

Carlsberg Group. (2024). *Annual Report 2023*.

CDP. (2022). *CDP Technical Note: Relevance of Scope 3 Categories by Sector CDP Climate Change Questionnaire*.

CDP. (2023a). *CDP 2023 Climate Change Response Dataset*.

CDP. (2023b). *Global supply chain report 2022 - Scoping out: Tracking nature across the supply chain* .

Day, T., Mooldijk, S., Hans, F., Smit, S., Posada, E., Skribbe, R., Woollands, S., Fearnehough, H., Kuramichi, T., Warnecke, C., Kachi, A., & Höhne, N. (2023). *Corporate Climate Responsibility Monitor 2023: Assessing the transparency and integrity of companies' emission reduction and net-zero targets*.

de Bortoli, A., Bjørn, A., Saunier, F., & Margni, M. (2023). Planning sustainable carbon neutrality pathways: accounting challenges experienced by organizations and solutions from industrial ecology. *International Journal of Life Cycle Assessment*, *28*(7), 746–770. doi: 10.1007/s11367-023-02147-z

Dietz, S., Fruitiere, C., Garcia-Manas, C., Irwin, W., Rauis, B., & Sullivan, R. (2018). An assessment of climate action by high-carbon global corporations. In Nature Climate Change (Vol. 8, Issue 12, pp. 1072–1075). Nature Publishing Group. doi: 10.1038/s41558-018-0343-2

Geissdoerfer, M., Santa-Maria, T., Kirchherr, J., & Pelzeter, C. (2023). Drivers and barriers for circular business model innovation. *Business Strategy and the Environment*, *32*(6), 3814–3832. doi: 10.1002/bse.3339

Giesekam, J., Norman, J., Garvey, A., & Betts-Davies, S. (2021). Science-based targets: On target? *Sustainability (Switzerland)*, *13*(4), 1–20. doi: 10.3390/su13041657

Hans, F., Woollands, S., Day, T., & Höhne, N. (2023). *The corporate climate accountability loop: Introducing key functions of an accountability system for corporate climate action, and selected spotlights on how to improve the status quo*.

Hauschild, M. Z., Herrmann, C., & Kara, S. (2017). An Integrated Framework for Life Cycle Engineering. *Procedia CIRP*, *61*, 2–9. doi: 10.1016/j.procir.2016.11.257

Hauschild, M. Z., Kara, S., & Røpke, I. (2020). Absolute sustainability: Challenges to life cycle engineering. *CIRP Annals*, *69*(2), 533–553. doi: 10.1016/j.cirp.2020.05.004

Hertwich, E. G., & Wood, R. (2018). The growing importance of scope 3 greenhouse gas emissions from industry. *Environmental Research Letters*, *13*(10). doi: 10.1088/1748-9326/aae19a

Kara, S., Hauschild, M. Z., & Herrmann, C. (2018). Target-driven Life Cycle Engineering: Staying within the Planetary Boundaries. *Procedia CIRP*, *69*, 3–10. doi: 10.1016/j.procir.2017.11.142

Klaaßen, L., & Stoll, C. (2021). Harmonizing corporate carbon footprints. *Nature Communications*, *12*(1). doi: 10.1038/s41467-021-26349-x

Krabbe, O., Linthorst, G., Blok, K., Crijns-Graus, W., Van Vuuren, D. P., Höhne, N., Faria, P., Aden, N., & Pineda, A. C. (2015). Aligning corporate greenhouse-gas emissions

targets with climate goals. *Nature Climate Change*, *5*(12), 1057–1060. doi: 10.1038/nclimate2770

Marini, M., Pigosso, D. C. A., Pieroni, M., & McAloone, T. C. (2024). To what extent are circular economy strategies accounted in science-based targets for carbon emission reduction? *Computers and Industrial Engineering*. doi: 10.1016/j.cie.2024.110594

Moshrefi, S., Abdoli, S., Kara, S., & Hauschild, M. (2020). Product portfolio analysis towards operationalising science-based targets. *Procedia CIRP*, *90*, 377–382. doi: 10.1016/j.procir.2020.02.127

Moshrefi, S., Kara, S., & Hauschild, M. (2021). Eco-efficiency limits of product technologies towards achieving science-based targets. *Procedia CIRP*, *98*, 488–493. doi: 10.1016/j.procir.2021.01.139

Moshrefi, S., Kara, S., & Hauschild, M. (2022). A framework for future-oriented environmental impact assessment of companies considering Science-Based Targets. *Journal of Cleaner Production*, *373*. doi: 10.1016/j.jclepro.2022.133719

Novo Nordisk. (2024). *Annual Report 2023*.

Rockwool Group. (2024a). *ROCKWOOL Annual Report 2023*.

Rockwool Group. (2024b). *ROCKWOOL Sustainability Report 2023*.

SBTi. (2023a). *Catalyzing value chain decarbonization: Corporate survey results*.

SBTi. (2023b). *SBTi corporate net-zero standard*.

SBTi. (2024a). *SBTi Aligning Corporate Value Chains Scope 3 Discussion Paper*.

SBTi. (2024b). *Scence Based Targets initiative; Corporate Net-Zero Standard V1.2*.

SBTi. (2024c, November 12). *https://sciencebasedtargets.org/companies-taking-action*.

The Danish Business Authority, UN Global Compact Network Denmark, & Transition ApS. (2023). *Reducing scope 3 emissions through circular economy initiatives*.

The Lego Group. (2021). *GHG Report 2020*.

The Lego Group. (2023). *GHG Report 2022*.

The Lego Group. (2024a). *Annual Report 2023*.

The Lego Group. (2024b). *Sustainability Progress 2023*.

Tilsted, J. P., Palm, E., Bjørn, A., & Lund, J. F. (2023). Corporate climate futures in the making: Why we need research on the politics of Science-Based Targets. *Energy Research and Social Science*, *103*. doi: 10.1016/j.erss.2023.103229

UN Global Compact Network Denmark. (2023). *COMMITMENT TO THE SCIENCE BASED TARGETS INITIATIVE (SBTi) IN DENMARK A PROGRESS REPORT IN THE LEAD-UP TO COP28*.

United Nations' High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities. (2023). *Integrity Matters: Net Zero Commitments by Businesses, Financial Institutions, Cities and Regions*.

Velux Group. (2024a). *Sustainability Report 2023*.

Velux Group. (2024b). *Annual Report 2023*.

Vestas Wind Systems. (2024a). *Annual Report 2023*.

Vestas Wind Systems. (2024b). *Sustainability Report 2023*.

WRI, & WBCSD. (2004). *The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard*.

Zomer, T., McAloone, T. C., & Pigosso, D. C. A. (2022). To What Extent Is Circular Product Design Supporting Carbon Reduction Strategies? An Analysis of Nordic Manufacturing Firms within the Science-Based Targets Initiative. *Proceedings of the Design Society*, *2*, 1189–1198. doi: 10.1017/pds.2022.121

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Circularity Indicators for Packaging: A Literature Review and System-Based Classification

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Abstract: The transition to a Circular Economy (CE) in the packaging industry is vital to address growing environmental problems. Circularity indicators play a critical role in evaluating progress and guiding decision-making. However, existing indicators lack suitability for packaging and do not factor in the systemic considerations required for successful transition to CE. This study identified 21 circularity indicators relevant to packaging, critically assessing their: suitability for the packaging industry; and inclusion of systemic considerations across lifecycle stages such as sourcing, design and production, distribution, use, and end-of-life. Using a three-point scale (extensive inclusion, partial inclusion and none), the indicators are classified to establish the extent to which they consider systems, such as Packaging Characteristic, Infrastructure, Value and Regulation. The analysis highlights several gaps, including overemphasis on end-of-life systems, limited consideration of value for stakeholders, insufficient alignment with upstream systems, and inadequate consideration of regional infrastructure and regulation. The findings underline the need for future indicators to adopt a holistic approach, integrating diverse systems to enable effective CE strategy implementation. By highlighting these gaps, this research lays the groundwork for developing robust indicators that not only assess circularity but also guide the packaging industry toward a realistic implementation of CE strategies.

Introduction

Packaging refers to products used for the containment, protection, handling, delivery, and presentation of goods as they move from the manufacturer to the consumer (*Packaging*, 2025). While packaging is essential for safeguarding goods throughout their lifecycle, it is also a major contributor to environmental problems. Packaging waste, often ending up as litter or in landfills, not only harms the environment but also results in a considerable loss of valuable resources (Pongracz, 2007). This problem is driven by the current linear economy system of "take-make-dispose," which prioritises short-term use over long term resource conservation (Murray, 2017).

One emerging way to tackle this problem is to consider circular economy (CE) strategies, such as reduce, reuse, recycle etc. for designing packaging solutions (Kirchherr et al., 2017). The CE is a restorative and regenerative system in which resource input and waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2017). CE strategies are also advocated by legislations such as the new circular economy action plan, which aims to make packaging reusable and recyclable by 2030 (NCEAP, 2021). Additionally, the Packaging and Packaging Waste Regulations (PPWR) aims to promote CE strategies such as reduce and high-quality recycling (*PPWR*, 2022).

A system-based approach to CE transition

While the CE holds immense potential, its transition remains slow and inconsistent, with a significant gap between its conceptual promise and real-world implementation (Mubarik et al., 2024). Its implementation is impeded by numerous challenges and without addressing these, a true CE will remain unattainable (Velis, 2018). Existing literature highlights these challenges. Bressanelli et al. (2019), identified 24 challenges and categorised them into economic and financial viability, market and competition, product characteristics, standards and regulation, supply chain management, technology, and user behaviour. Similarly, Mubarik et al. (2024) categorised challenges into policy, economic incentives, consumer engagement, market dynamics, stakeholder engagement, operational, and logistics. While

these categorisations are insightful, fragmenting CE issues and treating them in isolation can hide their interdependencies (Iacovidou et al., 2021). For example, improving

recycling technology alone will not solve the problem of waste if collection and sorting systems are inadequate. Similarly, even if technology and supply chain inefficiencies are addressed, regulatory restrictions may still prevent recycled materials from entering regulated markets, such as food grade. Therefore, a systems-based approach is necessary to incorporate these interdependencies. Zeeuw Van Der Laan & Aurisicchio (2021) addressed this by classifying CE systems into principle, value, actor, data, infrastructure, and resource, emphasising that the integration of their elements is critical to overcoming systemic barriers. We suggest that these systems should be considered into the tools supporting the transition to a CE, enabling a more realistic assessment of CE strategies.

Circularity indicators for CE transition

Circularity indicators, especially micro-level indicators that assess the circularity of products, components, and materials (Kirchherr et al., 2017), are emerging as essential tools for evaluating and tracking progress. By measuring circularity, these tools inform the product design process and provide decision-makers with insights on how to redesign products to align with CE strategies. For example, the material circularity indicator (MCI) is the most commonly cited and used indicator (Vadoudi et al., 2022; Elia et al., 2017). It has been developed to measure how restorative flows are maximised and linear flows are minimised (EMF, 2021). However, the MCI has limitations in the packaging context. It allows users to input general recycling rate based on the material type (e.g. plastics, glass), while ignoring critical packaging characteristics such as shape, size, and colour, which significantly influence the recycling rates (CEFLEX, 2024). Moreover, the MCI does not account for local recycling infrastructure and regulations, both of which are critical in determining the feasibility of circularity strategies. Similarly, indicators designed for disassembly, such as Disassembly Effort Index (DEI), and Ease of disassembly (EDT) are unsuitable for packaging, as packaging is generally not designed for disassembly (Matos et al., 2024).

Packaging challenges hindering the adoption of circularity indicators can be summarised as follows:

- Short lifespan and single-use nature of packaging limits the suitability of indicators developed for durable products with longer lifecycles and strategies like repair or remanufacturing.
- Low material value of packaging materials, especially single-use plastics reduces economic incentives for recycling and reuse (Bening et al., 2021).
- Circularity indicators focusing primarily on isolated aspects of circularity rather than the broader interconnected systems that underpin circularity (Corona et al., 2019; Saidani et al., 2017).
- Material and design complexity existing in packaging, such as use of multilayered materials, adhesives, and additives, making it more difficult to recycle than monomaterial products (Walker et al., 2020).

Overall, the challenges highlight the pressing need for including systemic considerations in the formulation of micro-level circularity indicators to ensure their suitability to the packaging sector.

Aim of study

This study aims to identify existing micro-level indicators which are suitable for measuring packaging circularity and consider if the systems essential to the transition toward a CE are accounted for by such indicators. The research focuses on two key objectives:

- *Assess indicators' suitability for packaging*: Identify the circularity indicators which are specifically designed or adaptable to packaging-related CE strategies.
- *Classify indicators based on systemic considerations*: Analyse the extent to which these indicators include system considerations essential for circularity.

Methodology

This study uses comprehensive literature review and classification analysis to identify micro-level indicators and classify them based on their suitability for packaging and inclusion of systemic considerations.

Literature review:
General CE indicators search

The review followed a systematic approach to identify and analyse micro-level CE indicators. The process began with a broad literature search in databases such as Scopus and

Google Scholar using combinations of terms from this list: “micro", “product”, “circular economy", "circularity", "measure", "indicators", "indices", "index", and "metrics”. The results were restricted by the English language and year range from 2009 to the submitted date of this research.

We focused on review papers for their structured compilation of diverse sources. From these, we traced references to identify the original sources for each indicator mentioned and analysed them to ensure a comprehensive and accurate identification of existing micro-level indicators. From this initial search, 10 systematic review papers were identified (Corona et al., 2019; De Oliveira et al., 2021; De Pascale et al., 2021; Kristensen & Mosgaard, 2020; Matos et al., 2023; Moraga et al., 2019; Parchomenko et al., 2019; Roos Lindgreen et al., 2020; Saidani et al., 2019; Vural Gursel et al., 2023). These papers were selected for their structured evaluation of CE indicators across various domains. From these papers, 247 micro-level indicators were first identified. Afterwards, the identified indicators underwent a rigorous screening process based on the following exclusion criteria:

- *Duplicate Removal*: Duplicate indicators across different papers were removed.
- *Clarity*: Indicators lacking a clear methodology were excluded.
- *CE-Specific Relevance*: General sustainability indicators, such as those derived from Life Cycle Assessment (LCA), were omitted.
- *Packaging Suitability*: Indicators specific to processes like disassembly, refurbishing, and remanufacturing which are typically not relevant for packaging were removed.

This phase reduced the number of indicators from 247 to 18.

Packaging-Specific CE indicators search

To address the unique requirements of packaging circularity, an additional search using the keywords “packaging” “circularity", "measure", "indicators", "indices” “index", and "metrics” was conducted in Scopus and Google Scholar databases. The search identified 3 packaging-specific indicators; these include the Reusable Packaging in Circular Supply Chains (RPSC) (Betts et al., 2022), the Quality Model for Recycled Plastics (QMRP) (Golkaram et al., 2022a), and the Packaging Index (PIX) (Scagnetti et al., 2022). These 3 indicators,

along with the 18 identified from the general CE indicators search and screening, brought the total number of relevant CE indicators for packaging to **21**. The final list of 21 CE indicators is shown in (Table 1).

Indicator	**Authors**
Value-based resource efficiency (VRE)	(Di Maio et al., 2017)
Quality model for recycled plastics (QMRP)	(Golkaram et al., 2022b)
Packaging Index (PIX)	(Scagnetti et al., 2022)
Circular Economy Toolkit (CET)	(Bocken, N.M.P., 2013)
Circular Economy Index (CEI)	(Di Maio & Rem, 2015)
Product Circularity Indicator (PCI)	(Bracquené et al., 2020)
Recycling Desirability Index (RDI)	(Mohamed Sultan et al., 2017)
Reusable packaging in circular supply chains	(Betts et al., 2022)
Circularity Index (CI)	(Cullen, 2017)
Circular Design Guidelines (CDG)	(Bovea & Pérez-Belis, 2018)
Circularity Calculator (CC)	(IDEAL&COExplore, 2016)
Combination Matrix (CM)	(Figge et al., 2018)
Product Level Circularity Metric (PLCM)	(Linder et al., 2017)
Circular Economy Indicator Prototype (CEIP)	(Cayzer et al., 2017)
Material Circularity Indicator (MCI)	(EMF, 2021)
Circular economy performance indicator (CPI)	(Huysman et al., 2017)
End-of-life Index (-I)	(Lee et al., 2014)
In-Use occupation Indicator (IUOI)	(Moraga et al., 2020)
Reuse Potential Indicator (RPI)	(Park & Chertow, 2014)
Recyclability Benefit Rate (RBR)	(Huysveld et al., 2019)
Degree of material cycle closure (DOMC)	(Nelen et al., 2014)

Table 1 : CE Indicators identified from literature review

Systems-based classification to analyse indicators

Building on the broader classification by Zeeuw Van Der Laan & Aurisicchio (2021), this study proposes a system-based classification to analyse indicators focusing on four key systems: Packaging Characteristic (PC),

Infrastructure (I), Value (V), and Regulation (R). The systems and their definitions along with corresponding system elements are shown in (Table 2). With reference to the broader classification mentioned above, the PC system maps to Resource, the I system to Infrastructure, the V system to Value, and the R system to Principle. These four systems can feature across each of the five lifecycle stages, namely Source (S), Design and Production

(D&P), Distribution (Di), Use (U), and EOL. To evaluate the degree of consideration of these systems in the formulation of indicators, a classification criterion was developed based on inclusion of system elements at each lifecycle stage. The system elements (SE) at each lifecycle stage were extracted from the circular design guidelines (CEFLEX, 2024; RECOUP, 2024; Recyclass, 2024) and regulatory documents (e.g. *PPWR*, 2022).

Systems	**Definition**	**Lifecycle stage**	**System Elements**
Packaging Characteristic	The physical packaging that moves through various stages of the lifecycle.	S	Virgin, recycled, biological
		D&P	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
		Di	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
		U	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
		EOL	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
Infrastructure	The physical, technical, and organizational structures that support the circular flow of packaging.	S	Equipment for procuring raw materials and transport infrastructure
		D&P	Manufacturing equipment and filling lines
		Di	Transport vehicles
		U	Reverse logistics systems for reuse
		EOL	Regional kerbside collection bins, sorting, and recycling infrastructure
Value	Value is derived from services, transactions, and resource management between stakeholders	S	Raw materials cost
		D&P	Manufacturing cost, Labour cost, Filling cost
		Di	Transportation cost for distributors and retailers
		U	Packaging selling price
		EOL	Packaging Collection cost, sorting cost and Processing cost
Regulation	The legal frameworks, policies, standards, and enforcement mechanisms that guide and influence CE strategies.	S	Substances of concern, sustainable sourcing, and regenerative practices
		D&P	Provision for minimising packaging weight and volume to avoid overpackaging
		Di	Reuse transport packaging
		U	Compliance with food safety, chemical substance regulations, and information labelling requirements
		EOL	High-quality recycling and collection, recycling, and reuse targets, EPR costs

Table 2. CE Systems for Packaging

The indicators are categorised into three levels of systemic inclusion at each stage:

- **Extensive inclusion**: An indicator is classified with this label if it includes equal two or more than half of the mentioned system elements. If there is a single system element for a lifecycle stage, then inclusion of that will be considered as extensive.
- **Partial inclusion**: An indicator is classified with this label if it includes less than half of the mentioned system elements.
- **No inclusion**: An indicator is classified with this label if it includes none of the system elements.

For instance, with respect to the PC system:

- At the EOL stage, if an indicator includes only packaging material for calculating the recycling rate but excludes other critical elements like shape, size, and colour then it is classified as Partial inclusion**.**
- At the Source stage, if an indicator incorporates all material types (e.g., virgin, recycled, biological, reused) into its formulation, then it is classified as Extensive inclusion.
- At any stage, if an indicator includes no PC system elements in its formulation, then it is classified as No inclusion.

Similar classification logic applies uniformly to all other systems, ensuring a structured approach for analysing the indicators.

The indicators are also classified based on the CE business model embedded in their methodology. Two types of CE business models are used for classification. The first is *Single Use*, which focuses on improving circularity for the single lifetime of packaging by employing the CE principles of narrowing and closing resource loops. The second is *Reuse*, which focuses on improving circularity for multiple lifetimes of packaging by employing the CE principles of narrowing, closing, and slowing resource loops. (Bocken et al., 2016).

Results

The analysis of the indicators is presented in (Figure 1), where Extensive inclusion is depicted as green cells, Partial inclusion as yellow cells and No inclusion as empty cells.

S.No	CE Business model	CE principles	Indicator	Source				Design and Production				Distribution				Use				EOL				Number of systems
				PC	I	V	R	PC	I	V	R	PC	I	V	R	PC	I	V	R	PC	I	V	R	
1	Single use	Narrow	VRE																					8
2		Narrow	PLCM																					4
3		Narrow	CC																					4
4		Narrow	CEI																					4
5		Close	QMRP																					7
6		Close	RDI																					5
7		Close	CPI																					3
8		Close	RBR																					2
9		Close	DOMC																					2
10		Narrow, Close	PIX																					6
11	Reuse	Slow, Close	RPSC																					5
12		Slow, Close	PCI																					5
13		Slow, Close	CI																					5
14		Slow, Close	CDG																					4
15		Slow, Close	CM																					4
16		Slow, Close	RPI																					3
17		Slow, Close	EOL-I																					3
18		Slow, Close	MCI																					3
19		Narrow, Slow, Close	CET																					5
20		Narrow, Slow, Close	CEIP																					3
21		Narrow, Slow, Close	IUOI																					3

Figure 1 Classification Analysis of 21 Indicators Extensive Inclusion (■), Partial Inclusion (■), No inclusion (□)

Classification of the 21 circularity indicators reveals critical insights regarding their inclusion of systemic considerations across lifecycle stages. These insights are summarised below into three themes.

Lifecycle stage coverage

- Most indicators primarily focus on systems at the EOL, for example, PC at EOL is partially included by all the indicators. In contrast, focus on the upstream lifecycle stages of Source, Design and Production, Distribution, and Use is limited.

Number of systems considered

- None of the indicators considers all the four systems (PC, I, V, R) together at any specific lifecycle stage.
- Considering that each system can be accounted for in each lifecycle stage (4 system elements for 4 lifecycle stages which corresponds to a total of 16 system occurrences), the greatest number of systems included amount to 8 by the VRE indicator, with many indicators addressing fewer than 4 systems.
- Notably, VRE, PIX, PCI and MCI are the only indicators that address at least one system extensively.

System elements inclusion

- Packaging Characteristic: Most indicators include basic PC elements like material type, but only PCI and MCI extensively consider Source stage PC elements such as virgin, recycled, reuse, and bio-based content. At EOL, only PIX extensively includes all elements like shape, size, colour, adhesives, and labels
- Infrastructure: Few indicators include regional infrastructure elements. RDI and PIX partially address aspects like collection, sorting, and recycling.
- Value: Value elements are mostly considered at EOL, with limited inclusion across other lifecycle stages.
- Regulation: Regulatory elements are rarely included; only PIX considers packaging minimisation and QMRP promotes high-quality recycling in their methodology.

The classification results identified the following indicators as incorporating the greatest number of systemic considerations for given CE business models:

- Single use: VRE (narrow), PIX (narrow, close), QMRP (close)
- Reuse: RPSC (slow, close), CET (narrow, slow, close)

Given the CE business models currently employed by companies (single use or reuse), the above indicators provide a comprehensive approach for assessing circularity.

Discussion

This paper reviewed a large body of literature on CE indicators. In total, 21 indicators specific to packaging were identified addressing the need to move towards a sector-specific tool for measuring circularity in the industry. Indicators that employ CE strategies such as repair, refurbish, remanufacture, and repurpose were excluded.

The results of this research can help packaging designers identify indicators suitable for specific CE business models (single use or reuse) and CE principles (narrow, slow, close). Additionally, they allow packaging designers to determine the extent to which systemic considerations were included in an indicator's methodology. To the best of the author's knowledge, this is the first review study that classifies CE indicators based on systemic considerations, making it its most novel aspect. This differentiates this work from a recent review on packaging-specific CE indicators by Matos et al. (2024).

The results can also help packaging designers assess the comprehensiveness of different CE indicators. They also allow them to determine the level of input data required for circularity assessments, as a greater number of system elements considered by an indicator corresponds to a higher number of input parameters needed for the assessment.

The study also highlighted several key gaps in CE indicators, such as an overemphasis on EOL systems, insufficient coverage of systems in the early lifecycle stages, limited value inclusion, and a lack of alignment with regional infrastructure and regulation. For instance, while indicators like VRE, QMRP, and PIX show promise, they still fail to fully capture the systemic nature of CE by neglecting upstream stages, like infrastructure, and regulation. To overcome these limitations, future circularity indicators must ensure that systems are equally represented across all lifecycle stages, from source to EOL. Further, they should ensure the inclusion of all packaging characteristics system elements across lifecycle stages.

Indicators must be formulated to capture the value for all relevant stakeholders, including manufacturers, consumers, recyclers, etc. Indicators should also be adapted to reflect

regional differences in infrastructure, such as collection, sorting, and recycling capacities, to enhance practicality. Furthermore, indicators should be aligned with existing and emerging CE regulations. Additionally, further work on developing a comprehensive list of system elements for each lifecycle stage will provide more actionable strategies for developing new indicators.

Conclusion

The transition to a CE for packaging is a complex challenge that requires the consideration of systems such as Packaging Characteristic, Infrastructure, Value, and Regulation at various lifecycle stages. Circularity indicators play a critical role in evaluating progress and guiding decision-making. However, existing indicators show limited suitability for packaging and rarely account for the systems required for a successful transition to the CE. This study critically evaluated 21 CE indicators identified from existing literature, assessing their suitability for measuring packaging circularity and inclusion of systemic considerations across lifecycle stages. The analysis highlighted several strengths and limitations of existing CE indicators. The analysis also helped in deriving guidance for development of future circularity indicators.

References

Bening, C. R., Pruess, J. T., & Blum, N. U. (2021). Towards a circular plastics economy: Interacting barriers and contested solutions for flexible packaging recycling. *Journal of Cleaner Production*, *302*, 126966. https://doi.org/10.1016/j.jclepro.2021.126966

Betts, K., Gutierrez-Franco, E., & Ponce-Cueto, E. (2022). Key metrics to measure the performance and impact of reusable packaging in circular supply chains. *Frontiers in Sustainability*, *3*. https://doi.org/10.3389/frsus.2022.910215

Bocken, N. M. P., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bocken, N.M.P., E., J. (2013). *CE Toolkit*. Circulareconomytoolkit. http://circulareconomytoolkit.org/Assessmenttool.html

Bovea, M. D., & Pérez-Belis, V. (2018). Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment. *Journal of Environmental Management*, *228*, 483–494. https://doi.org/10.1016/j.jenvman.2018.08.014

Bracquené, E., Dewulf, W., & Duflou, J. R. (2020). Measuring the performance of more circular complex product supply chains. *Resources, Conservation and Recycling*, *154*, 104608. https://doi.org/10.1016/j.resconrec.2019.104608

Bressanelli, G., Perona, M., & Saccani, N. (2019). Challenges in supply chain redesign for the Circular Economy: A literature review and a multiple case study. *International Journal of Production Research*, *57*(23), 7395–7422. https://doi.org/10.1080/00207543.2018.1542176

Cayzer, S., Griffiths, P., & Beghetto, V. (2017). Design of indicators for measuring product performance in the circular economy. *International Journal of Sustainable Engineering*, *10*(4–5), 289–298. https://doi.org/10.1080/19397038.2017.1333543

CEFLEX. (2024). *Design Choices*. CEFLEX D4ACE. https://guidelines.ceflex.eu/guidelines/design-choices/

Corona, B., Shen, L., Reike, D., Rosales Carreón, J., & Worrell, E. (2019). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources, Conservation and Recycling*, *151*, 104498. https://doi.org/10.1016/j.resconrec.2019.104498

Cullen, J. M. (2017). Circular Economy: Theoretical Benchmark or Perpetual Motion Machine? *Journal of Industrial Ecology*, *21*(3), 483–486. https://doi.org/10.1111/jiec.12599

De Oliveira, C. T., Dantas, T. E. T., & Soares, S. R. (2021). Nano and micro level circular economy indicators: Assisting decision-makers in circularity assessments. *Sustainable Production and Consumption*, *26*, 455–468. https://doi.org/10.1016/j.spc.2020.11.024

De Pascale, A., Arbolino, R., Szopik-Depczyńska, K., Limosani, M., & Ioppolo, G. (2021). A systematic review for measuring circular economy: The 61 indicators. *Journal of Cleaner Production*, *281*, 124942. https://doi.org/10.1016/j.jclepro.2020.124942

Di Maio, F., & Rem, P. C. (2015). A Robust Indicator for Promoting Circular Economy through Recycling. *Journal of Environmental*

Protection, *06*(10), 1095–1104. https://doi.org/10.4236/jep.2015.610096

Di Maio, F., Rem, P. C., Baldé, K., & Polder, M. (2017). Measuring resource efficiency and circular economy: A market value approach. *Resources, Conservation and Recycling*, *122*, 163–171. https://doi.org/10.1016/j.resconrec.2017.02.009

Elia, V., Gnoni, M. G., & Tornese, F. (2017). Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production*, *142*, 2741–2751. https://doi.org/10.1016/j.jclepro.2016.10.196

EMF. (2021, July 14). *MCI*. https://www.ellenmacarthurfoundation.org/material-circularity-indicator

Figge, F., Thorpe, A. S., Givry, P., Canning, L., & Franklin-Johnson, E. (2018). Longevity and Circularity as Indicators of Eco-Efficient Resource Use in the Circular Economy. *Ecological Economics*, *150*, 297–306. https://doi.org/10.1016/j.ecolecon.2018.04.030

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Golkaram, M., Mehta, R., Taveau, M., Schwarz, A., Gankema, H., Urbanus, J. H., De Simon, L., Cakir-Benthem, S., & Van Harmelen, T. (2022a). Quality model for recycled plastics (QMRP): An indicator for holistic and consistent quality assessment of recycled plastics using product functionality and material properties. *Journal of Cleaner Production*, *362*, 132311. https://doi.org/10.1016/j.jclepro.2022.132311

Golkaram, M., Mehta, R., Taveau, M., Schwarz, A., Gankema, H., Urbanus, J. H., De Simon, L., Cakir-Benthem, S., & Van Harmelen, T. (2022b). Quality model for recycled plastics (QMRP): An indicator for holistic and consistent quality assessment of recycled plastics using product functionality and material properties. *Journal of Cleaner Production*, *362*, 132311. https://doi.org/10.1016/j.jclepro.2022.132311

Huysman, S., De Schaepmeester, J., Ragaert, K., Dewulf, J., & De Meester, S. (2017). Performance indicators for a circular economy: A case study on post-industrial plastic waste. *Resources, Conservation and Recycling*, *120*, 46–54. https://doi.org/10.1016/j.resconrec.2017.01.013

Huysveld, S., Hubo, S., Ragaert, K., & Dewulf, J. (2019). Advancing circular economy benefit indicators and application on open-loop recycling of mixed and contaminated plastic waste fractions. *Journal of Cleaner Production*, *211*, 1–13. https://doi.org/10.1016/j.jclepro.2018.11.110

Iacovidou, E., Hahladakis, J. N., & Purnell, P. (2021). A systems thinking approach to understanding the challenges of achieving the circular economy. *Environmental Science and Pollution Research*, *28*(19), 24785–24806. https://doi.org/10.1007/s11356-020-11725-9

IDEAL&COExplore. (2016). *Circularity calculator*. https://circularitycalculator.nl/#used

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kristensen, H. S., & Mosgaard, M. A. (2020). A review of micro level indicators for a circular economy – moving away from the three dimensions of sustainability? *Journal of Cleaner Production*, *243*, 118531. https://doi.org/10.1016/j.jclepro.2019.118531

Lee, H. M., Lu, W. F., & Song, B. (2014). A framework for assessing product End-Of-Life performance: Reviewing the state of the art and proposing an innovative approach using an End-of-Life Index. *Journal of Cleaner Production*, *66*, 355–371. https://doi.org/10.1016/j.jclepro.2013.11.001

Linder, M., Sarasini, S., & van Loon, P. (2017). A Metric for Quantifying Product-Level Circularity. *Journal of Industrial Ecology*, *21*(3), 545–558. https://doi.org/10.1111/jiec.12552

Matos, J., Martins, C. I., & Simoes, R. (2024). Circularity Micro-Indicators for Plastic Packaging and Their Relation to Circular Economy Principles and Design Tools. *Sustainability*, *16*(5), Article 5. https://doi.org/10.3390/su16052182

Matos, J., Martins, C., Simões, C. L., & Simoes, R. (2023). Comparative analysis of micro level indicators for evaluating the progress towards a circular economy. *Sustainable Production and Consumption*, *39*, 521–533. https://doi.org/10.1016/j.spc.2023.06.002

Mohamed Sultan, A. A., Lou, E., & Mativenga, P. T. (2017). What should be recycled: An integrated model for product recycling desirability. *Journal of Cleaner Production*, *154*, 51–60.

https://doi.org/10.1016/j.jclepro.2017.03.201

Moraga, G., Huysveld, S., De Meester, S., & Dewulf, J. (2020). Towards a circularity indicator to assess products' materials and lifetime: In-use occupation. *Procedia CIRP*, *90*, 10–13. https://doi.org/10.1016/j.procir.2020.01.085

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G. A., Alaerts, L., Van Acker, K., de Meester, S., & Dewulf, J. (2019). Circular economy indicators: What do they measure? *Resources, Conservation and Recycling*, *146*, 452–461. https://doi.org/10.1016/j.resconrec.2019.03.045

Mubarik, M. S., Kontoleon, A., & Shahbaz, M. (2024). Beyond the hurdles: Exploring policy obstacles in the path to circular economy adoption. *Journal of Environmental Management*, *370*, 122667. https://doi.org/10.1016/j.jenvman.2024.122667

Murray, A. (2017). *The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context*.

NCEAP. (2021). *New Circular Economy Action Plan*. https://www.europarl.europa.eu/doceo/document/TA-9-2021-0040_EN.html

Nelen, D., Manshoven, S., Peeters, J. R., Vanegas, P., D'Haese, N., & Vrancken, K. (2014). A multidimensional indicator set to assess the benefits of WEEE material recycling. *Journal of Cleaner Production*, *83*, 305–316. https://doi.org/10.1016/j.jclepro.2014.06.094

Packaging. (2025). [Term]. European Environment Agency. https://www.eea.europa.eu/help/glossary/eea-glossary/packaging

Packaging and packaging waste 94/62/EC. (2022, November 30). European Commision. https://eur-lex.europa.eu/resource.html?uri=cellar:de4f236d-7164-11ed-9887-01aa75ed71a1.0001.02/DOC_1&format=PDF

Parchomenko, A., Nelen, D., Gillabel, J., & Rechberger, H. (2019). Measuring the circular economy—A Multiple Correspondence Analysis of 63 metrics. *Journal of Cleaner Production*, *210*, 200–216. https://doi.org/10.1016/j.jclepro.2018.10.357

Park, J. Y., & Chertow, M. R. (2014). Establishing and testing the "reuse potential" indicator for managing wastes as resources. *Journal of Environmental Management*, *137*, 45–53. https://doi.org/10.1016/j.jenvman.2013.11.053

Pongracz, E. (2007). *CHAPTER 9 THE ENVIRONMENTAL IMPACTS OF PACKAGING*.

RECOUP. (2024). *RECOUP*. https://www.recoup.org

Recyclass. (2024). *Recyclass* [Computer software]. https://recyclass.eu

Roos Lindgreen, E., Salomone, R., & Reyes, T. (2020). A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level. *Sustainability*, *12*(12), Article 12. https://doi.org/10.3390/su12124973

Saidani, M., Yannou, B., Leroy, Y., & Cluzel, F. (2017). How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework. *Recycling*, *2*(1), Article 1. https://doi.org/10.3390/recycling2010006

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. *Journal of Cleaner Production*, *207*, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014

Scagnetti, C., Lorenz, M., Keller, J., & Albrecht, S. (2022). The Packaging Index (PIX)—A proposed methodology for packaging assessment and comparison. *E3S Web of Conferences*, *349*, 01002. https://doi.org/10.1051/e3sconf/202234901002

Vadoudi, K., Deckers, P., Demuytere, C., Askanian, H., & Verney, V. (2022). Comparing a material circularity indicator to life cycle assessment: The case of a three-layer plastic packaging. *Sustainable Production and Consumption*, *33*, 820–830. https://doi.org/10.1016/j.spc.2022.08.004

Velis, C. (2018). No circular economy if current systemic failures are not addressed. *Waste Management & Research*, *36*(9), 757–759. https://doi.org/10.1177/0734242X18799579

Vural Gursel, I., Elbersen, B., & Meesters, K. P. H. (2023). Monitoring circular biobased economy – Systematic review of circularity indicators at the micro level. *Resources, Conservation and Recycling*, *197*, 107104. https://doi.org/10.1016/j.resconrec.2023.107104

Walker, T. W., Frelka, N., Shen, Z., Chew, A. K., Banick, J., Grey, S., Kim, M. S., Dumesic, J. A., Van Lehn, R. C., & Huber, G. W. (2020). Recycling of multilayer plastic packaging materials by solvent-targeted recovery and precipitation. *Science Advances*, *6*(47), eaba7599. https://doi.org/10.1126/sciadv.aba7599

Zeeuw Van Der Laan, A., & Aurisicchio, M. (2021). *The Flow Mapper: A Tool to Model Solutions for the Circular Economy and Put Systems Thinking into Action*. University of Limerick. https://doi.org/10.31880/10344/10166

Extended Abstract
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Life cycle assessment (LCA) of remanufactured electrical and electronic products; a review of methodological choices

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Keywords: EEE; LCA; Circular Economy; Remanufacturing.

Introduction

Electrical and Electronic Equipment (EEE) is widely recognized for its substantial environmental impact, containing numerous toxic substances and contributes significantly to energy consumption in manufacturing and waste generation. This waste production is often driven by the continuous evolution of EEE in terms of new features and marketing strategies employed by companies to promote the perception that consumers must upgrade frequently to remain current, leading to premature obsolescence and shortened device lifespans (Neto and Bloemhof, 2009; Yuksek et al., 2023).

Circular economy (CE) approaches have emerged as essential strategies to address these pressing environmental issues (Ada, 2021; Andronicean, 2021). Within the CE framework, remanufacturing has gained prominence due to its potential to mitigate the environmental impacts associated with excess production of electronic equipment through product lifetime extension (Alkouh et al., 2023).

Remanufacturing involves restoring a used product to meet or exceed its original performance specifications and user expectations, accompanied by a warranty comparable to that of a newly manufactured product. The process includes multiple stages: collection, initial inspection and sorting, dismantling, cleaning, replacement of damaged parts, reassembly, upgrading, installation, and final testing (Gan et al., 2018).

To better understand the environmental advantages of product lifetime extension strategies like remanufacturing, it is crucial to evaluate environmental impacts through comprehensive assessment tools such as Life Cycle Assessment (LCA). LCA quantifies the environmental impacts of a product or service throughout its entire life cycle. By analyzing each stage, LCA helps identify areas where environmental burdens can be reduced, supports informed decision-making for product design improvements, and facilitates the comparison of different strategies aimed at extending product lifespan (Curran, 2015).

However, the LCA of remanufactured products remains a subject of debate, as the modelling choices used can significantly influence the results (Peters, 2016; Suhariyanto et al., 2017; Mann et al., 2022). Existing literature highlights a notable gap in research on this topic, particularly for EEE. To the best of our knowledge, our study is the first to critically review LCA studies based on remanufactured EEE.

This paper presents a literature review of studies on LCA of remanufactured EEE. The studies were analysed regarding the methodological aspects of LCA i.e. functional unit, system boundary, allocation method, inventory data, along with their results. It was examined whether they have provided a clear description of these and how these decisions influenced the LCA and its outcome. The results regarding the environmental impact of remanufactured EEE along with rebound effects were also analysed and reported. Additionally, recommendations were provided for future studies on LCA of remanufactured EEE.

Methodology

The literature review was conducted through an extensive search in scientific databases, specifically Scopus and Google Scholar for studies published between January 2000 and

November 2024. The search used the terms and their variants, “life cycle assessment” and “remanufacturing”, yielding a total of 166 results. These initial findings were rigorously screened to include only research papers that explicitly addressed remanufacturing at the end-of-life stage, while excluding studies that focused on other end-of-life strategies such as refurbishment and recycling.

The screening and selection process was performed following the Preferred Reporting Items of Systematic reviews and Meta-Analyses (PRISMA) as shown in figure 1.

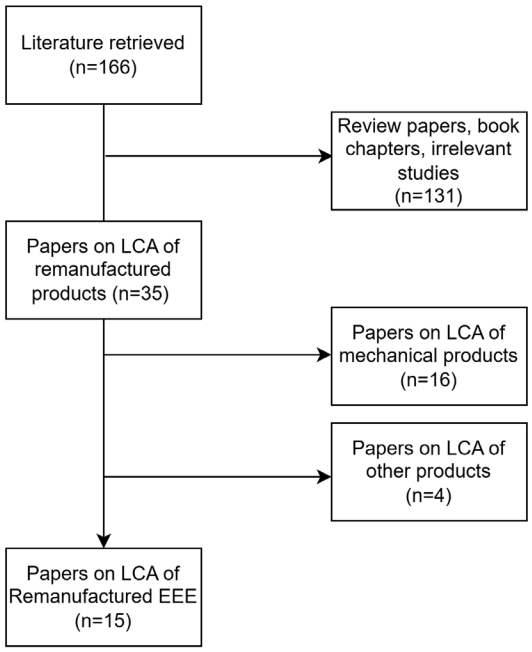


Figure 1. The screening approach of literature.

The literature review process identified 35 articles of LCA of remanufactured products. Of the 35, 16 articles pertained to mechanical products while 4 referred to other sectors, these were considered out of scope of this assessment. Finally, 15 articles on EEE were identified as the focus of the literature review in this study.

According to ISO 14044: 2006, it is crucial for LCAs to clearly state the goal and scope, functional unit, system boundary, inventory data, allocation and impact assessment method. Thus, these methodological aspects in the different LCAs were assessed.

Results and Discussion

The review of LCA studies on electrical and electronic equipment (EEE) showed that out of 15 studies, six did not clearly report key methodological aspects, such as the functional unit, system boundary, and allocation methods. Most studies relied on secondary or mixed data, particularly in the use phase, while few utilized primary data. Attributional modelling was employed in all studies except Wrålsen and O’Born (2023), which adopted a consequential approach.

The products reviewed for this study are mentioned in table 1. Electric bicycle motor, sparkplug and electrophysiology catheters are considered as electric products because they rely on electricity to perform their core functions.

	Product(s)	Authors
1	Laptop	Yuksek et al. (2023)
2	Computer	Fatimah & Biswas (2016)
3	Computer	Mann et al. (2022)
4	Phone	Neto and Bloemhof (2009)
5	Phone	Pamminger et al. (2021)
6	Phone and Refrigerator	Lu et al. (2017)
7	Portable power station	Yang S et al. (2024)
8	Li-ion battery	Wrålsen and O’Born (2023)
9	Electro-physiology catheters	Schulte et al. (2021)
10	Telecom equipment	Goldey et al. (2010)
11	Photocopier	Kerr and Ryan (2001)
12	Electric bicycle motor	Grosse Erdmann et al. (2023)
13	Sparkplug	Zhuang et al. (2023)
14	Li-ion battery	Yang H et al. (2024)
15	Coffee machine	Nikolic et al. (2024)

Table 1. Products and their corresponding authors of reviewed literature.

When assessing the environmental impacts of a product, it is essential to rely on accurate assumptions of its use. A product may have a higher environmental cost during manufacturing, but could compensate for this by offering significant energy savings during its operational life. However, if the use phase assumptions are incorrect or too generalized, it

can lead to inaccurate assessments (Sassanelli et al., 2020; Curran 2015).

All studies reviewed, except Lu et al. (2017) which assessed an obsolete refrigerator, reported that remanufacturing led to a significant reduction in GHG emissions, resource use, and energy consumption compared to conventional manufacturing. For instance, Yuksek et al. (2023) presented that the remanufacturing scenario resulted in 21 kg CO_2eq compared to 331 kg CO_2eq for conventional laptop manufacture through use of primary data.

A key challenge in LCA of remanufacturing is the allocation problem, typically addressed through either the cut-off approach or system expansion approach. Both methods comply with ISO 14044 standards, with the cut-off approach representing a "supporter" perspective and system expansion approach a "neutral" perspective on remanufacturing, as noted by Peters (2016). Most studies used the cut-off or supportive approach. Lastly, only as Wrålsen and O'Born (2023) and Neto and Bloemhof (2009) explored the potential rebound effects associated with remanufacturing.

The review offers several important recommendations to strengthen the rigour and depth of LCA in remanufacturing EEE. Key among these is the thorough application of established LCA standards to ensure transparency and reproducibility, allowing researchers to clearly specify and justify their methodological choices. Additionally, incorporating both supportive and neutral perspectives on remanufacturing either within the LCA or via sensitivity analysis can highlight how varying assumptions impact results, offering a more nuanced view of remanufacturing's effects.

The review also emphasizes the need for primary data, especially in the use phase, to reduce uncertainties associated with secondary data and enhance the precision of findings. Finally, it highlights the importance of addressing rebound effects, where resource efficiency gains may lead to increased consumption, thereby impacting the overall environmental benefits of remanufacturing.

Conclusions

The review highlights a pressing need for greater transparency and consistency in reporting functional units, system boundaries, inventory and allocation methods in LCA studies of remanufactured EEE. These methodological choices impact and influence LCA results, making clear and consistent reporting essential. The review also suggests that remanufacturing may offer substantial environmental benefits for EEE. Additionally, the recommendations provided aim to enhance the relevance and robustness of LCA findings for informed sustainability decision-making.

References

Ada, N., Kazançoğlu, Y., Sezer, M., Ede-Senturk, C., Ozer, I., & Ram, M. (2021). Analyzing barriers of circular food supply chains and proposing industry 4.0 solutions. *Sustainability*, *13*(12), 6812. https://doi.org/10.3390/su13126812

Alkouh, A., Keddar, K. A., & Alatefi, S. (2023). Remanufacturing of industrial electronics: A case study from the GCC region. *Electronics*, *12*(9), 1960. https://doi.org/10.3390/electronics12091960

Andronicеanu, A., Kinnunen, J., & Georgescu, I. (2021). Circular economy as a strategic option to promote sustainable economic growth and effective human development. *Journal of International Studies*, 14(1), 60-73. https://doi.org/10.14254/2071-8330.2021/14-1/4

Curran, M. A. (2015). *Life cycle assessment student handbook*. John Wiley & Sons.

Fatimah, Y. A., & Biswas, W. K. (2016). Sustainability assessment of remanufactured computers. *Procedia CIRP*, *40*, 150-155. https://doi.org/10.1016/j.procir.2016.01.087

Gan, S. S., Wahjudi, D., & Tanoto, Y. Y. (2018). The effect of product quality on the pricing of new and remanufactured short life-cycle product. In *IOP Conference Series: Materials Science and Engineering. 1*(12027). IOP Publishing. https://doi.org/10.1088/1757-899X/417/1/012027

Goldey, C. L., Kuester, E.-U., Mummert, R., Okrasinski, T. A., Olson, D., & Schaeffer, W. J. (2010). Lifecycle assessment of the environmental benefits of remanufactured telecommunications product within a "green" supply chain. *Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology*, 1–6.

https://doi.org/10.1109/ISSST.2010.5507761

Grosse Erdmann, J., Mahr, A., Derr, P., Walczak, P., & Koller, J. (2023). Comparative Life Cycle Assessment Of Conventionally Manufactured And Additive Remanufactured Electric Bicycle Motors. *ESSN: 2701-6277*, 903-913. https://doi.org/10.15488/15293

ISO (2006). *ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines.*

Kerr, W., & Ryan, C. (2001). *Eco-efficiency gains from remanufacturing A case study of photocopier remanufacturing at Fuji Xerox Australia*. https://doi.org/10.1016/S0959-6526(00)00032-9

Lu, B., Song, X., Yang, J., & Yang, D. (2017). Comparison on End-of-Life strategies of WEEE in China based on LCA. *Frontiers of Environmental Science & Engineering*, *11*(5), 7. https://doi.org/10.1007/s11783-017-0994-7

Mann, A., Saxena, P., Almanei, M., Okorie, O., & Salonitis, K. (2022). Environmental Impact Assessment of Different Strategies for the Remanufacturing of User Electronics. *Energies*, *15*(7), Article 7. https://doi.org/10.3390/en15072376

Neto, J. Q. F.; Bloemhof, J. M. (2009). *The Environmental Gains of Remanufacturing: Evidence from the Computer and Mobile Industry* (SSRN Scholarly Paper No. 1410467). Social Science Research Network.

Nikolic, M., Bergmann, G., Schelte, N., & Severengiz, S. (2024). Closing the loop of small WEEE–life cycle based approach for the evaluation of end-of-life strategies on the example of coffee machines. *Resources, Conservation & Recycling Advances*, 200220. https://doi.org/10.1016/j.rcradv.2024.200220

Pamminger, R., Glaser, S., & Wimmer, W. (2021). Modelling of different circular end-of-use scenarios for smartphones. *The International Journal of Life Cycle Assessment*, *26*(3), 470–482. https://doi.org/10.1007/s11367-021-01869-2

Peters, K. (2016). Methodological issues in life cycle assessment for remanufactured products: a critical review of existing studies and an illustrative case study. *Journal of Cleaner Production*, *126*, 21-37. https://doi.org/10.1016/j.jclepro.2016.03.050

Sassanelli, C., Urbinati, A., Rosa, P., Chiaroni, D., & Terzi, S. (2020). Addressing circular economy through design for X approaches: A systematic literature review. *Computers in industry*, *120*, 103245. https://doi.org/10.1016/j.compind.2020.103245

Schulte, A., Maga, D., & Thonemann, N. (2021). Combining Life Cycle Assessment and Circularity Assessment to Analyze Environmental Impacts of the Medical Remanufacturing of Electrophysiology Catheters. *Sustainability*, *13*(2), Article 2. https://doi.org/10.3390/su13020898

Suhariyanto, T. T., Wahab, D. A., & Rahman, M. N. Ab. (2017). Multi-Life Cycle Assessment for sustainable products: A systematic review. *Journal of Cleaner Production*, *165*, 677–696. https://doi.org/10.1016/j.jclepro.2017.07.123

Wrålsen, B., & O'Born, R. (2023). Use of life cycle assessment to evaluate circular economy business models in the case of Li-ion battery remanufacturing. *The International Journal of Life Cycle Assessment*, *28*(5), 554-565. https://doi.org/10.1007/s11367-023-02154-0

Yang, H., Hu, X., Zhang, G., Dou, B., Cui, G., Yang, Q., & Yan, X. (2024). Life cycle assessment of secondary use and physical recycling of lithium-ion batteries retired from electric vehicles in China. *Waste Management*, *178*, 168–175. https://doi.org/10.1016/j.wasman.2024.02.034

Yang, S. J., Hwang, Y. W., Kim, Y. W., Park, M. S., Nam, J. H., & Kang, H. Y. (2024). Environmental and Economic Benefits Induced by a Remanufactured Portable Power Station. *Energies*, *17*(4), Article 4. https://doi.org/10.3390/en17040793

Yuksek, Y. A., Haddad, Y., Pagone, E., Jagtap, S., Haskew, S., & Salonitis, K. (2023). Sustainability Assessment of Electronic Waste Remanufacturing: The Case of Laptop. *Procedia CIRP*, *116*, 378–383. https://doi.org/10.1016/j.procir.2023.02.064

Zhuang, X., Song, X., Yang, H., Zhao, D., Wu, W., & Zhao, J. (2023). The energy saving and GHG mitigation benefits assessment of product remanufacturing from a multi-life cycle perspective: A case study of spark plug. *Environmental Impact Assessment Review*, *99*, 107018. https://doi.org/10.1016/j.eiar.2022.107018

Extended Abstract
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Coupling LCA and product lifetime modeling to support repair & reuse: a case study in the WEEE sector

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Keywords: (W)EEE; repair; reuse; lifetime extension; LCA (Life Cycle Assessment)

ecosystem & the WEEE scheme

Representing about 5,000 Electrical and Electronic Equipment (EEE) producers, ecosystem is a Producer Responsibility Organization (PRO), i.e., a non-profit organization accredited by the French Public Authorities to organize and manage the collection, the repair, the reuse and the recycling of household and professional Waste of Electrical and Electronic Equipment (WEEE). Each year about 700,000 tons of e-waste is collected by ecosystem with 2% reuse, a trend that is expected to grow in the coming years to reduce the environmental footprint of the EEE sector.

Repair & reuse in the WEEE sector

The "Anti-waste law for a circular economy" enacted in France in 2020 led to the creation of two financial funds aiming at supporting stakeholders of the reuse and repair sectors to extend appliances' lifetimes (French Code of Environment, Art. L541-10-4 / Art. L541-10-5). Handed with historical partners Emmaüs and Envie, about 1 million household appliances were reused in 2023.

On the repair side, more than 100,000 repairs were realized in 2023 with the funds.

To enhance and to give value to these activities, ecosystem enlarged its expertise to quantify the environmental benefits from repair/reuse.

LCA to support repair and reuse

An LCA was conducted based on a substitution approach (Tecchio et al., 2016; Ardente et al, 2018; Fangeat, ADEME et al, 2022).

It is assumed in this work that the used product was either defective or a waste at the time ecosystem took a responsibility of if for extending its lifetime. Therefore, the product's first life is excluded from the scope.

Then, the functional unit is defined as per the following:

"Extending the lifetime of an electrical / electronical household appliance during X years instead of replacing it with a new equivalent one to be used the same way over the same period X."

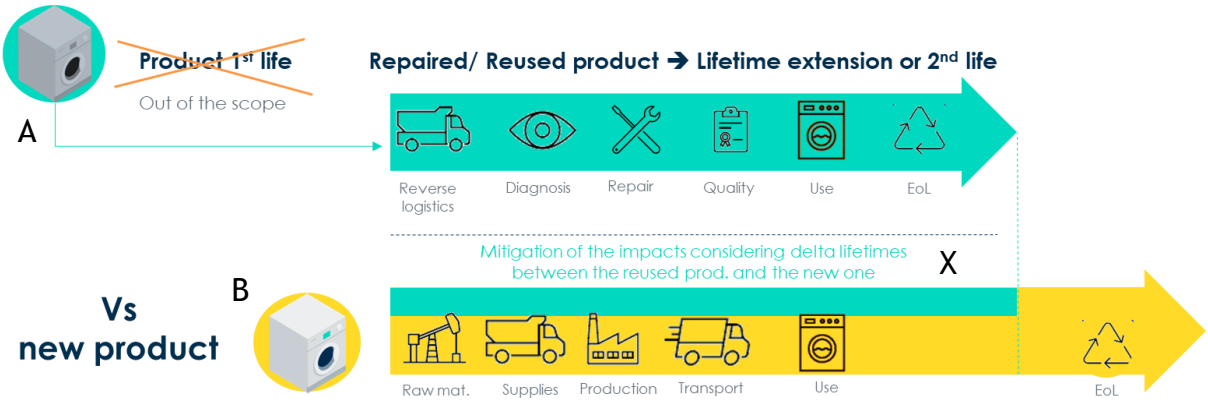


Figure 1. Visual approach of the environmental assessment of repair/reuse

The methodology remains identical for all household equipment, but a washing machine is chosen here as a study. A comparison is made between a first scenario considering a replacement of a washing machine (A) by a new one (B) and a second scenario where the washing machine (A) is extended by X years. A 10-year theoretical lifetime (TLT) is defined for the two scenarios, based on literature review and ecosystem's expertise on WEEE sampling.

Equation 1. Impact of 1st scenario (replace)

$$P_A + U_A \times LT_A + EoL_A + P_B \times \frac{X}{TLT} + U_B \times X + EoL_B \times \frac{X}{TLT}$$

Equation 2. Impacts of 2nd scenario (repair/reuse)

$$P_A + U_A \times (LT_A + X) + R_A + EoL_A$$

With:
P_A = Impacts of the production of appliance A
P_B = Impacts of the production of appliance B
U_A = Impacts of the use of appliance A
U_B = Impacts of the use of appliance B
EoL_A = Impacts of the end-of-life of appliance A
EoL_B = Impacts of the end-of-life of appliance B
TLT = Theoretical lifetime (assuming TLTA = TLTB)
LT_A = Lifetime of appliance A
X = Extended lifetime of appliance A

The assessment of the benefits is the difference between equation 1. and equation 2. described in equation 3.

Equation 3: Final assessment

$$\left[\frac{P_B}{TLT} + \frac{EoL_B}{TLT} + (U_B - U_A)\right] \times X - R_A$$

Two outcomes are possible:
1- The result is > 0, then it is relevant from an environmental standpoint to repair/reuse.
2- The result is < 0, then it is not relevant to repair/reuse. Another valorization shall be done by reusing spare parts and recycling.

This approach is relevant for setting an operational diagnosis to optimize the environmental benefits as part of an efficient circular economy strategy.

If the impacts modeling for repair can be different than reuse, both have shown that the assessment is very sensitive to the age of the washing machine, the need of spare parts for repair and reconditioning process and the lifetime extension as the key factor.

The delta of energy-consumption between the washing machine A and the new one B may also mitigate the benefits of repair/reuse particularly on fossil resources depletion.

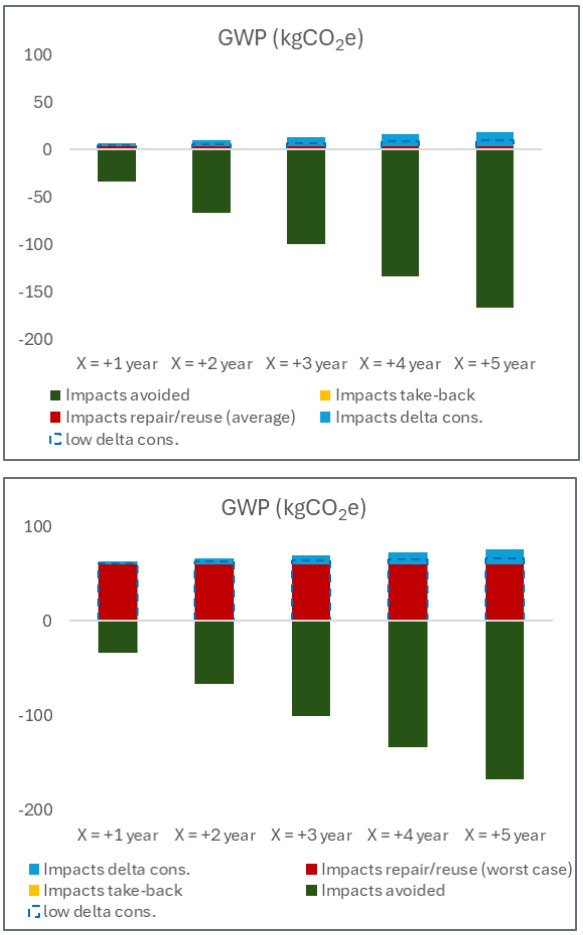


Figure 2. Results on climate change impact category (top = average scenario / bottom = spare part with high impact)

Overall, calculations have shown significant environmental benefits of repair / reuse, maximized with X.

Some isolated scenarios were considered when exploring the potential benefit of repair/reuse. As shown in Figure 2 the replacement of a spare with high impact will need to be compensated with more than two years' extension of product A. This emphasizes the need for secondary spare parts to minimize the impact.

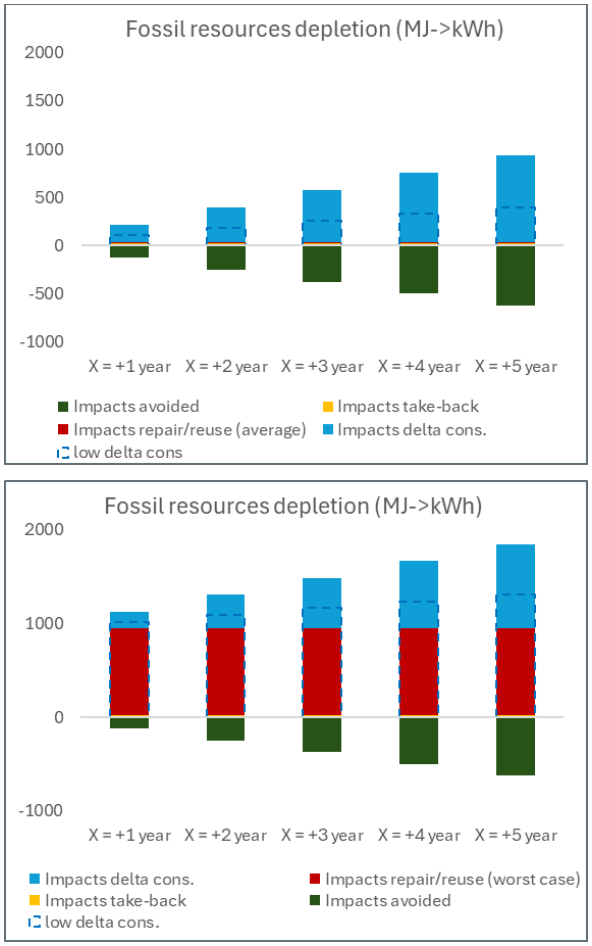


Figure 3. Results on fossil resources depletion impact category (top = average scenario / bottom = spare part with high impact)

The old washing machine may be less energy-efficient compared to the new one, and the environmental benefits from repair/reuse will also be limited as shown on Figure 3 looking at the fossil resources depletion impact category.

Using LCA to support a full diagnosis of the washing machine to repair/reuse considering its energy consumption linked to its age and its potential second life is key to deciding whether it is more viable to repair/reuse it or to send it to recycle.

Limits and perspectives

The environmental benefits of repair and reuse are mainly bonded to product lifetimes and particularly the lifetime extension as the major sensitive data and the first limit of the final assessment. This data remains in consumers' hands, which leads to high uncertainty about the results. To reduce this uncertainty, a refined data collection is currently carried out through several studies to address more the precisely the value of lifetime extension X**.**

A second limit is related to the TLT. If some assumptions can be made through literature and WEEE sampling, there is no consensus on the TLT value. Besides, using the number of years to define a product's lifespan may not reflect the same intensity usage from one consumer to another. This questions the functional unit when discussing the reuse of an electric drill used by a professional versus a non-professional user.

Finally, a third limit can be related to the 1st product's lifetime (ADEME, 2022). An allocation of the impact of the product A's 1st life can be considered when the repaired/reused product has not actually reached its TLT. Rebound effects of a second-hand market and product durability shall then be discussed.

References

Tecchio, Paolo & Mathieux, Fabrice & Ardente, Fulvio. (2016). Analysis of durability, reusability and reparability - Application to washing machines and dishwashers. 10.2788/630157.

Ardente, Fulvio & Talens Peiró, Laura & Mathieux, Fabrice & Polverini, Davide. (2018). Accounting for the environmental benefits of remanufactured products: Method and application. Journal of Cleaner Production. 198. 10.1016/j.jclepro.2018.07.012.

ADEME, RDC Environment, BV CODDE, 2017. Quantification de l'impact environnemental d'une action de réparation/réemploi/réutilisation.

Fangeat, ADEME et al, 2022. Evaluation de l'impact environnemental d'un ensemble de produits reconditionnés rapport final

ecosystem, 2024. Annual report 2023.

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Measuring the Impact of Smartphone Reuse Interventions on Consumer Choice and Product Lifetime – Preliminary Findings

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Keywords: circular consumption; consumer behavior; product reuse; effective interventions; environmental impacts.

Introduction

The smartphone market is experiencing dual trends: while new models continue to flood the market, the reuse sector is also growing rapidly. However, the circular economy of smartphones faces significant challenges. Many devices end up in a state of 'hibernation' - unused but stored away - or are prematurely discarded, disrupting the potential for efficient supply and demand in the second-hand market. Consumer acceptance of used devices and recirculation at end-of-use are crucial to ensure adequate supply and demand in this evolving market.

Previous work has shown that the reuse of smartphones extends their lifetime compared to linear use (Cooper et al. 2015, Amatuni et al. 2023), leading to a decrease in demand for new products and avoiding environmental impacts associated with new production (Clemm et al. 2023). Consequently, stimulating consumer behavior leading to increased engagement with second-hand markets is in line with the goals of the circular economy and global emission reduction targets. However, the effectiveness of reuse-promoting interventions and policies has, thus far, hardly been measured and understood. Mugge et al. (2017) reported that product-related interventions were most effective in increasing consumers' intention to purchase refurbished smartphones, including improved battery life and guaranteed software updates, indicating a need for continued performance. Bieser et al. (2022) considered all consumer decisions that affect smartphone lifetime, including purchase and end-of-use behavior. They identified 26 interventions without quantifying their effectiveness. Koide et al. (2023) proposed a method integrating consumer choice with product circulation modeling to assess the effectiveness of interventions for fostering the adoption of circular consumption, including reuse. Results were generated by adopting hypothetical scenarios and numerical examples only. Wilson et al. (2017) reported that mobile phones are hibernated for longer than they are actively used, emphasizing the need for interventions promoting circular consumption behavior.

This study aims to measure the potential of interventions aiming to promote product reuse. By evaluating the effects of interventions on consumer choice in markets, we strive to identify opportunities for extending smartphone lifespans and demonstrate their potential contributions to the circular economy.

Methods

The screening of literature indicated that previous studies did not account for actual consumer behavior as a baseline to measure the effectiveness of interventions. To address this gap, first, we collect consumer data on actual reported purchase and end-of-use (EoU) behavior as a baseline. Second, data on purchase and EoU intentions, assuming interventions for circularity, is collected. Third, we use this novel data as input into an existing market-level stock-and-flow model that describes the flow of new and second-hand (SH) products through a market and computes the required production of new devices to meet demand (Clemm et al., 2023). This allows us to evaluate the cumulative effects of specific product reuse-promoting interventions on consumer choice and the demand and supply of new and SH devices in a simulated market.

This study, therefore, approaches the question of which interventions are effective to induce desirable change in consumer behavior and production rates. Unlike studies focusing on individual consumption impacts, this study adopts a population-level perspective, accounting for diverse behaviors across the market.

For this preliminary analysis, two interventions were selected to assess their impacts and demonstrate the method: (1) an extended warranty on SH smartphones of three years, mitigating functionality concerns, and (2) a free data transfer and erasure service to facilitate the recirculation of devices at end-of-use (EoU), mitigating data privacy concerns. The interventions were selected to address barriers to both supply and demand of used smartphones. Surveys were conducted among the general population in the US.

The employed market model captures product flows from manufacturing to end-of-life, requiring empirical market data on product lifespans and consumer reuse propensity to simulate scenarios. Data on average use times of new and SH smartphones were sourced from Amatuni et al. (2023), while consumer preferences and behaviors were gathered via the online survey. The pilot survey collected 54 responses covering recent purchase and EoU decisions under current conditions (baseline scenario) and intended behaviors under the proposed interventions (hypothetical scenarios). The models' outputs for these scenarios were compared to estimate the interventions' potential impacts.

Results & discussion

The results reveal that under current conditions, about 14% of the respondents purchase SH devices, and the market-average total use time is 2.8 years. Introducing an extended warranty for SH devices could increase SH purchases to 22%, extend the average use time to 3.1 years, and reduce new production by 10% (Figure 1). In contrast, the free data transfer and erasure service showed no significant effect on consumer reuse behavior.

Additionally, the maximum potential of reuse-promoting measures was explored under an idealized scenario. This scenario assumed a technical limit of 5 years for smartphone use and a universal preference for obtaining and recirculating SH devices. Although new production is still needed to replenish retiring stocks in this scenario, the total production rate drops by 44%, with 60% of users opting for SH devices.

Conclusions & outlook

Our approach enables us to quantify how interventions for reuse, such as extended warranties, can influence market dynamics for new and second-hand products.

Future research includes several key improvements and expansions. A larger, more representative survey will strengthen the reliability of the findings. The scope of assessed interventions will be broadened to include measures such as product upgrades and trade-in programs. Additionally, we aim to analyze different geographical regions to enable cross-regional and -cultural comparisons. Another focus will be exploring how distinct consumer segments, based on their attitudes and perceptions of second-hand goods, respond to various interventions. This targeted approach will help identify the most effective measures for encouraging reuse and maximizing their impact.

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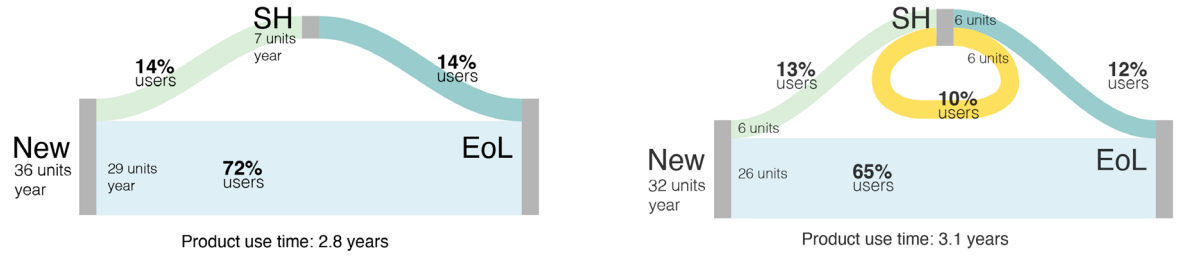


Figure 1. Sankey diagrams depicting the total demand for new smartphones and the flow between user types until products reach end-of-life (EoL) in a baseline scenario (left) and the scenario with extended product warranties (right) modeled for a market with a population of P = 100; SH = second-hand.

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References

Amatuni, L., Yamamoto, T., Baldé, C. P., Clemm, C., & Mogollón, J. M. (2023). Quantifying total lifetimes of consumer products: Stochastic modelling accounting for second-hand use and establishing an open-collaborative database. *Resources, Conservation, and Recycling*, *197*(107103), 107103. doi:10.1016/j.resconrec.2023.107103

Bieser, J. C. T., Blumer, Y., Burkhalter, L., Itten, R., Jobin, M., & Hilty, L. M. (2022). Consumer-oriented interventions to extend smartphones' service lifetime. *Cleaner and Responsible Consumption*, *7*(100074), 100074. doi:10.1016/j.clrc.2022.100074

Clemm, C., Amatuni, L., Mogollón, J. M., & Matsumoto, M. (2023). Modeling effects of smartphone reuse on market-level lifetime and environmental impacts informed by consumer survey data: Preliminary results. In K. Niinimäki & K. Cura (Eds.), *Product lifetimes and the environment (PLATE): Proceedings* (pp. 203–208). Espoo, Finland: Aalto University.

Cooper, D. R., & Gutowski, T. G. (2017). The environmental impacts of reuse: A review. *Journal of Industrial Ecology*, *21*(1), 38–56. doi:10.1111/jiec.12388

Koide, R., Yamamoto, H., Nansai, K., & Murakami, S. (2023). Agent-based model for assessment of multiple circular economy strategies: Quantifying product-service diffusion, circularity, and sustainability. *Resources, Conservation, and Recycling*, *199*(107216), 107216. doi:10.1016/j.resconrec.2023.107216

Mugge, R., Jockin, B., & Bocken, N. (2017). How to sell refurbished smartphones? An investigation of different customer groups and appropriate incentives. *Journal of Cleaner Production*, *147*, 284–296. doi:10.1016/j.jclepro.2017.01.111

Wilson, G. T., Smalley, G., Suckling, J. R., Lilley, D., Lee, J., & Mawle, R. (2017). The hibernating mobile phone: Dead storage as a barrier to efficient electronic waste recovery. *Waste Management (New York, N.Y.)*, *60*, 521–533. doi:10.1016/j.wasman.2016.12.023

Extended Abstract
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Exploring Lifetime Modeling Approaches in Life Cycle Assessment of Textiles and Footwear

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Keywords: Lifetime Modeling; Functional Unit (FU); LCA; Durability; Consumer Behavior.

Introduction

The European Union is prioritizing the development of sustainable production and consumption regulations (European Parliament, 2024), with the textile and footwear sector identified as a key focus due to its challenges, including those posed by fast fashion (Faraca G. et al., 2023). In this regard, the upcoming Product Environmental Footprint Category Rules for Apparel and Footwear will define guidelines for evaluating the potential environmental impacts of products in a comparable way.

In this context, Life Cycle Assessment (LCA) plays a crucial role. Indeed, a key factor in ensuring comparability of LCA studies is the functional unit (FU), which aims to define the product's specific function, quantify related flows, and assess the environmental profile. From an operational perspective, FU can be defined by answering four questions: What? How much? How well? How long? (European Parliament, 2024) When considering textiles and footwear products, the last two questions are challenging to represent, as they intrinsically depend on variables such as consumer behavior, product durability, and fashion trends (Laitala & Klepp, 2020). Consumer habits such as usage frequency, care practices, and disposal preferences significantly affect product lifespan. Similarly, the quality and durability of materials determine how long a product can last. Furthermore, rapidly changing fashion trends can shorten products' lifespan, as consumers may discard items that are no longer in style, even if still functional. To capture these aspects, Klepp et al. (2020) proposed to measure garment lifespan in terms of years, number of wears, cleaning cycles, and users. Consequently, the ideal FU should combine all these factors.

However, there is a lack of sufficient knowledge to effectively operationalize this approach and capture these highly variable aspects in LCA modeling. Consequently, this study aims to explore how product lifespan has been modeled in LCA studies of textile and footwear products to initiate a discussion on the most suited approach.

Methods

A literature search was conducted on Scopus, considering publications available up to November 2024, using the combination of keywords reported in Table 1. Our focus was on studies explicitly addressing LCA of textiles and footwear products, which included considerations on product lifetime.

Lifetime	Life Cycle Assessment	Product Category
life service		
service life	Environmental impact	Apparel
service of life	Environmental assessment	Footwear
duration of service	Environmental impact assessment	Textile
lifetime	Life cycle analysis	Cloth
lifespan	Life cycle assessment	Garment
product life	LCA	

Table 1: keywords and terms of literature search

The search yielded 104 articles, 17 of which deemed relevant based on explicit criteria: (i) inclusion of LCA for textiles or footwear, (ii) consideration of lifetime modeling, and (iii) accessibility of methodological details. Selected articles were categorized based on product(s) studied, system boundaries, FU, lifetime modeling approach, and lifetime estimation methods.

Preliminary results

The reviewed studies covered a wide range of products, primarily clothing items, with some studies addressing multiple products simultaneously. T-shirts were the most analyzed product (Amasawa et al., 2023; Farrant et al., 2010; Kjaer et al., 2016; Meng et al., 2024; Meyer et al., 2011; Periyasamy et al., 2017; Proske & Finkbeiner, 2020; Temizel-Sekeryan & Hicks, 2021), followed by trousers (Amasawa et al., 2023; Farrant et al., 2010; Kambanou et al., 2024; Luo et al., 2022; Periyasamy et al., 2017; Zamani et al., 2017) and jackets (André, 2024; Steinberger et al., 2009). Other products, such as shoes (Ferreira et al., 2020), shoe soles (Caraceni et al., 2024), socks (Meyer et al., 2011), dresses (Zamani et al., 2017), and sweaters (Wiedemann et al., 2020), were only reported once. We also included two non-apparel product studies that we deemed relevant: bedsheets (De Saxce et al., 2012) and silver-enabled textiles (Hicks & Theis, 2017). The studies operate within different system boundaries with cradle-to-grave being the most common (13 studies), followed by cradle-to-use (2) and reuse-focused modeling (2).

Concerning FU and lifetime modeling, various approaches were identified:

i) **Number of care cycles** - This approach estimates lifespan based on the number of washes, using values from literature and surveys. For example, t-shirts were modeled with a lifespan of 100 laundering cycles (Hicks et al., 2015; Temizel-Sekeryan & Hicks, 2021), while for jeans, two approaches were followed, one considering average yearly washing cycles (Periyasamy et al., 2017), and the other assuming various frequency and washing scenarios (Luo et al., 2022).

ii) **Combination of the number of wears and care cycles** - Here FU is defined as a function of the number of times a product is worn, often set to a single wear. In this context, care cycles scan product lifetime since they occur with a defined frequency. For example, Steinberger et al. (2009) modeled the lifecycle of a cotton t-shirt and a polyester jacket, considering as FU “100 days of a garment being worn”, which includes variable care cycles for the t-shirt (one every two wearings) and the jacket (three times a season). Zamani et al. (2017) and Sandin et al. (2019), when evaluating several garment types, considered FU of “one average use”.

iii) **Years of use** - In this method, lifetime is measured in years rather than specific usage cycles (Amasawa et al., 2023; André, 2024; Ferreira et al., 2020). Unlike previous approaches, here the use phase consists of many stages, where clothing is either worn, cleaned, or stored.

iv) **Durability-based lifetime estimation** - This approach models lifespan based on the product's intrinsic properties. De Saxce et al. (2012) and Caraceni et al. (2024) applied this method to bed sheets and footwear soles respectively, by conducting mechanical tests to establish durability parameters. This approach focuses on the product’s inherent characteristics (material quality, construction, and design), to estimate its potential lifespan and may be relevant, where durability and performance are key factors. However, it may not fully capture the impact of consumer behavior and usage patterns.

Conclusions

This study explores how the concept of product lifetime has been integrated into LCA studies for textile and footwear products. The complexity of this topic has so far prevented the development of a comprehensive model capable of simultaneously representing the number of wears, service lifespan, and durability features.

While there is substantial literature on consumer behavior, offering valuable data for LCA studies, approaches that define lifespan based on product durability remain underexplored. These durability-based models have the potential to evaluate products' lifespan by leveraging their intrinsic properties and product performance. Moreover, incorporating durability into LCA studies could facilitate the inclusion of product quality metrics, a critical issue for the apparel and footwear sector.

Future research should focus on harmonizing these models by integrating durability metrics with consumer data and developing standardized methodologies for lifetime modeling that improve accuracy and applicability in the textile and footwear sector. A proposal for recommendations will be formulated based on the type of products, FU, and goal of the LCA study.

References

Amasawa, E., Brydges, T., Henninger, C. E., & Kimita, K. (2023). Can rental platforms contribute to more sustainable fashion consumption? Evidence from a mixed-method study. *Cleaner and Responsible Consumption*, *8*(January), 100103. https://doi.org/10.1016/j.clrc.2023.100103

André, H. (2024). Opening the black box of the use phase in circular economy life cycle assessments: Environmental performance of shell jacket reuse. *Journal of Industrial Ecology*, *28*(3), 542–555. https://doi.org/10.1111/jiec.13475

Caraceni, F., Cordara, M., Caelli, C., Brondi, C., Airoldi, F., & Ballarino, A. (2024). Functional Unit definition in a circular economy perspective: Implication for LCA normalisation for a footwear outsole. *Procedia CIRP*, *122*, 737–742. https://doi.org/10.1016/j.procir.2024.01.103

De Saxce, M., Pesnel, S., & Perwuelz, A. (2012). LCA of bed sheets - Some relevant parameters for lifetime assessment. *Journal of Cleaner Production*, *37*, 221–228. https://doi.org/10.1016/j.jclepro.2012.07.012

European Parliament. (2024). *REGULATION (EU) 2024/1781 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. Establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2*.

Faraca G., Spiliotopoulos C., Ranea Palma A., Pérez-Camacho M.N., A. F., Bernad Beltran D., Lag Brotons A., Delre A., Pérez Arriba Z., Arcipowska A., La Placa M.G., Wolf O., Sanye Mengual E., Amadei A., Maury T., Ardente F., & Mathieux F. (2023). *Ecodesign for Sustainable Products Regulation - preliminary study on new product priorities*.

Farrant, L., Olsen, S. I., & Wangel, A. (2010). Environmental benefits from reusing clothes. *International Journal of Life Cycle Assessment*, *15*(7), 726–736. https://doi.org/10.1007/s11367-010-0197-y

Ferreira, M. J., Vera V., P., & Costa, P. (2020). LIFE GREENSHOES4ALL – FOOTWEAR ENVIRONMENTAL FOOTPRINT. *8th International Conference on Advanced Materials and Systems (ICAMS)*, 297–302. http://dx.doi.org/10.24264/icams-2020.IV.6

Hicks, A. L., Gilbertson, L. M., Yamani, J. S., Theis, T. L., & Zimmerman, J. B. (2015). Life Cycle Payback Estimates of Nanosilver Enabled Textiles under Different Silver Loading, Release, and Laundering Scenarios Informed by Literature Review. *Environmental Science and Technology*, *49*(13), 7529–7542. https://doi.org/10.1021/acs.est.5b01176

Hicks, A. L., & Theis, T. L. (2017). A comparative life cycle assessment of commercially available household silver-enabled polyester textiles. *International Journal of Life Cycle Assessment*, *22*(2), 256–265. https://doi.org/10.1007/s11367-016-1145-2

Kambanou, M. L., Matschewsky, J., & Carlson, A. (2024). Business models and product designs that prolong the lifetime of construction workwear: Success, failure and environmental impacts. *Resources, Conservation and Recycling*, *206*(April), 107602. https://doi.org/10.1016/j.resconrec.2024.107602

Kjaer, L. L., Pagoropoulos, A., Schmidt, J. H., & McAloone, T. C. (2016). Challenges when evaluating Product/Service-Systems through Life Cycle Assessment. *Journal of Cleaner Production*, *120*, 95–104. https://doi.org/10.1016/j.jclepro.2016.01.048

Klepp, I. G., Laitala, K., & Wiedemann, S. (2020). Clothing lifespans: What should be measured and how. *Sustainability (Switzerland)*, *12*(15), 1–21. https://doi.org/10.3390/su12156219

Laitala, K., & Klepp, I. G. (2020). What affects garment lifespans? International clothing practices based on a wardrobe survey in China, Germany, Japan, the UK, and the USA. *Sustainability (Switzerland)*, *12*(21), 1–47. https://doi.org/10.3390/su12219151

Luo, Y., Wu, X., & Ding, X. (2022). Carbon and water footprints assessment of cotton jeans using the method based on modularity: A full life cycle perspective. *Journal of Cleaner Production*, *332*(December 2021), 130042. https://doi.org/10.1016/j.jclepro.2021.130042

Meng, F., Brandão, M., & Cullen, J. M. (2024). Replacing Plastics with Alternatives Is Worse for Greenhouse Gas Emissions in Most Cases. *Environmental Science and Technology*, *58*(6), 2716–2727. https://doi.org/10.1021/acs.est.3c05191

Meyer, D. E., Curran, M. A., & Gonzalez, M. A. (2011). An examination of silver nanoparticles in socks using screening-level life cycle assessment. *Journal of Nanoparticle Research*, *13*(1), 147–156. https://doi.org/10.1007/s11051-010-0013-4

Periyasamy, A. P., Wiener, J., & Militky, J. (2017). Life-cycle assessment of denim. In *Sustainability in Denim*. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102043-2.00004-6

Proske, M., & Finkbeiner, M. (2020). Obsolescence in LCA–methodological challenges and solution approaches. *International Journal of Life Cycle Assessment*, *25*(3), 495–507. https://doi.org/10.1007/s11367-019-01710-x

Sandin, G., Roos, S., Spak, B., Zamani, B., & Peters, G. (2019). *Environmental assessment of Swedish clothing consumption* (Issue September). https://doi.org/10.13140/RG.2.2.30502.27205

Steinberger, J. K., Friot, D., Jolliet, O., & Erkman, S. (2009). A spatially explicit life cycle inventory of the global textile chain. *International Journal of Life Cycle Assessment*, *14*(5), 443–455. https://doi.org/10.1007/s11367-009-0078-4

Temizel-Sekeryan, S., & Hicks, A. L. (2021). Cradle-to-grave environmental impact assessment of silver enabled t-shirts: Do nano-specific impacts exceed non nano-specific emissions? *NanoImpact*, *22*(February), 100319. https://doi.org/10.1016/j.impact.2021.100319

Wiedemann, S. G., Biggs, L., Nebel, B., Bauch, K., Laitala, K., Klepp, I. G., Swan, P. G., & Watson, K. (2020). Environmental impacts associated with the production, use, and end-of-life of a woollen garment. *International Journal of Life Cycle Assessment*, *25*(8), 1486–1499. https://doi.org/10.1007/s11367-020-01766-0

Zamani, B., Sandin, G., & Peters, G. M. (2017). Life cycle assessment of clothing libraries: can collaborative consumption reduce the environmental impact of fast fashion? *Journal of Cleaner Production*, *162*, 1368–1375. https://doi.org/10.1016/j.jclepro.2017.06.128

Policies for Longer Lifetimes



Research paper
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Design for Traceability (DfT): How to enhance transparency and accountability by designing products and materials with features that allow their entire lifecycle to be tracked and documented?

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Keywords: Design for Traceability (DfT), Smart Identification Technologies (SIT), Digital Product Passports (DPP), Sustainable Lifecycle Management, Supply Chain Resilience.

Abstract: As global industries confront mounting complexity, regulatory mandates, and urgent sustainability targets, end-to-end transparency has become nonnegotiable. Design for Traceability (DfT) delivers a transformative blueprint—encoding traceability into the very DNA of products and materials. By harnessing Smart Identification Technologies (SIT)— including Radio-Frequency Identification (RFID), Near Field Communication (NFC), QR codes, IoT sensors, and blockchain—DfT establishes immutable "digital DNA," realized through interoperable Digital Product Passports (DPPs) and Material Passports (MPs). These passports grant real-time visibility, secure authentication, and frictionless data exchange, catalyzing circular resource loops while ensuring compliance with evolving regulations.The DfT framework is anchored by five interdependent pillars: *Lifecycle-Centric Design:* Embeds traceability at inception via modular architecture, durable materials, and design-for-disassembly, extending product life and simplifying end-of-life recovery. *Digital Traceability Infrastructure:* Constructs a secure, interoperable data ecosystem by integrating SIT and distributed ledger technology, enabling continuous monitoring, analytics, and decision support through DPP and MP integration. *Circular Business Models:*Transitions from one-time sales to service-based offerings, remanufacturing, and R-strategies (Reduce, Reuse, Recycle), unlocking new revenue streams and preserving asset value. *Stakeholder Collaboration:* Builds shared platforms and decentralized governance to unite manufacturers, regulators, consumers, and recyclers in transparent data-sharing networks, strengthening trust and supply-chain resilience. *Regulatory Alignment:* Integrates traceability into corporate strategy to anticipate stringent sustainability mandates, leveraging digital audits and transparent reporting for streamlined compliance. By interweaving these pillars, DfT empowers organizations to mitigate supply-chain risks, optimize resource utilization, and accelerate the shift toward a resilient, transparent circular economy. This holistic framework equips policymakers, industry leaders, and designers with actionable strategies to embed sustainability, accountability, and innovation at every stage of the product lifecycle.

Introduction

Traceability is a strategic enabler for managing complex global systems, offering precise tracking of products, components, and data to mitigate risks, ensure quality, and reinforce trust across supply chains (Guilherme Pulita, J., 2022; Ringsberg, H., 2014) . In food systems, it supports preparation, response, and recovery during recalls, while advanced digital platforms replace paper-based methods and facilitate vast data management. Current research frames traceability around four risk-focused pillars: logistics, information, production, and quality management [1].

Cutting-edge technologies are redefining traceability by enhancing transparency, security, and operational efficiency. Blockchain delivers tamper-proof, decentralized ledgers that fortify Enterprise Resource Planning (ERP) integrations for real-time, cost-effective traceability (Alwi, A., 2024; Kusnadi, A., 2023; Srivastava, A., 2022). IoT and RFID sensors enable end-to-end visibility—from livestock lifecycle tracking to smart-city data networks—and support critical material tracing (e.g., cobalt in manufacturing) (Dawood, M.N., 2024; Otte, S., Sufian, 2024).

Methodologically, traceability system design employs structured frameworks tailored by

scope, granularity, and integration level—distinguishing chain-wide from localized models in food supply chains (Guilherme Pulita, J., 2022; Ringsberg, H., 2014). Modified waterfall System Development Life Cycle (SDLC) approaches ensure compliance in sectors like halal meat and ceramics (Kusnadi, A., 2023; Barata, J., 2018; Kusnadi, A., 2024). Human-centered design, demonstrated in smart-city implementations, emphasizes "automatic and transparent" data capture to minimize disruption and maximize usability (Mora-Mora, H., 2015).

Emerging trends focus on sustainability integration. Research on Environmental, Social, and Governance (ESG) integration illustrates how coupling traceability with environmental, social, and governance criteria can bolster consumer trust, regulatory compliance, and ethical supply-chain practices (Putri, W.S., 2025). This convergence of traceability and sustainability principles promises to address mounting concerns over environmental impacts and global ethics in supply chains.

Towards a Comprehensive Traceability Framework

Effective traceability design demands integrated tech, organizational, and regulatory alignment. As transparency becomes essential, innovative frameworks address complex supply chain challenges. This study synthesizes current DfT research, detailing methodologies, sector applications, and emerging technologies for resilient, accountable, and sustainable systems.

Implementing circular strategy

Implementing a circular strategy in Design for Traceability (DfT) integrates circular economy principles to track products, parts, and materials throughout their lifecycle. This approach extends product lifespans by enabling reuse, repair, refurbishing, remanufacturing, and upgrading—pillars of a sustainable circular economy (Terzi, S., 2006; Mesa, J. A., 2023). Effective DfT incorporates lifecycle thinking through design for disassembly, sustainable material selection, and waste minimization. Technologies such as RFID, QR codes, and blockchain facilitate seamless lifecycle tracking. Circular business models—sharing, leasing, and product-as-a-service—further emphasize durability, repairability, and upgradeability (Mesa, J. A., 2023; Bandini, G., 2023). The article "Structuring Circular Objectives Design Strategies for the Circular Economy" presents a multi-hierarchical framework that maps design strategies to five circular objectives: maintenance/longevity, reuse, refurbishment, remanufacture, and recycling (Table 1). This framework guides managers and designers in creating traceable systems that support multiple product lifecycles (Franconi, A., 2022).

Patagonia embeds durability and maintenance into its design strategy, providing free DIY repair guides and affordable repairs at its Reno, NV center when self-repair isn't possible. Their 2011 "Don't Buy This Jacket" ad actively discouraged needless purchases. Through the Worn Wear program, Patagonia sells guaranteed, high-quality pre-owned garments and accepts trade-ins for store credit, thereby

Table 1 Circular objectives exemplification. © (Franconi, A., 2022).

Circular Objective	Description	Design Strategies
Maintenance / Longevity	Aims to extend product lifespan through maintenance, reducing resource depletion and obsolescence. Aligns with strategies for long-lasting, upgradable, or easily repairable products.	Reliability, maintainability, repairability, product-life extension.
Reuse	Enables products or components to be reused with minimal alteration, often in a new cycle. Focuses on retaining value and reducing waste generation.	Collaborative logistics, return incentives, robust and standardised design.
Refurbishing	Restores product functionality by reworking only failed parts. Enhances consumer acceptance through tested aesthetics and reliability.	Disassembly, reassembly, repair, reconditioning.
Remanufacturing	Fully restores products to like-new or better condition, integrating cleaning, inspection, and testing. Considered highly impactful for circular economy.	Disassembly, cleaning, inspection, reassembly, upgrading.
Recycling	Final strategy when reuse is unfeasible. Focuses on material recovery through careful sorting, processing, and design for disassembly.	Disassembly, sorting, consumer acceptance of recycled content.

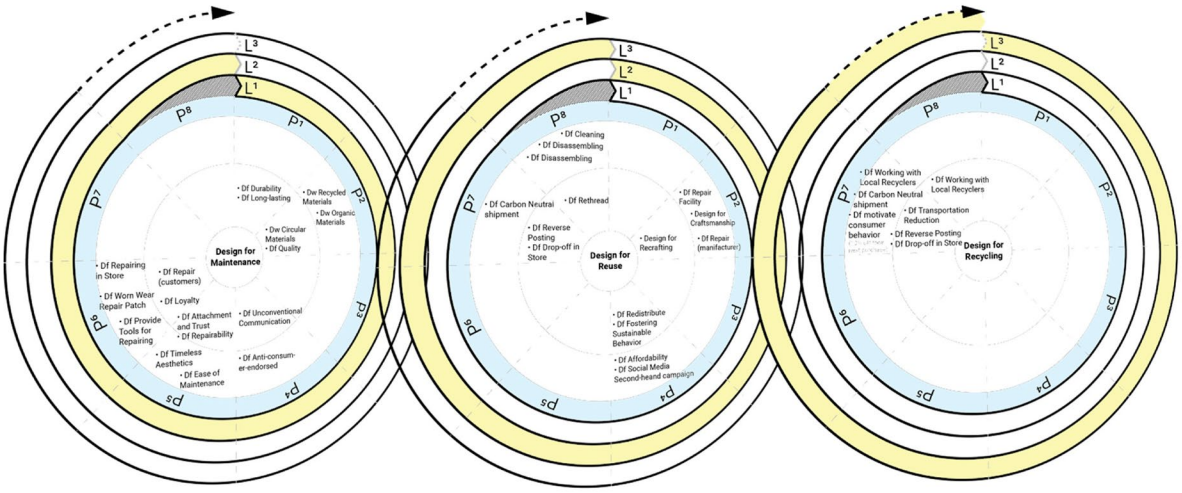


Figure 1 Patagonia case analysis. © (Franconi, A., 2022).

extending product lifespans. Items deemed irreparable are recycled—95 tons of clothing were processed into polyester fibers between 2005 and 2016—establishing a clear circular stage for each lifecycle phase (Bürklin, N., 2019; Rattalino, F., 2018). This blend of design for longevity, consumer engagement, and circular infrastructure exemplifies practical strategies for sustainability. The company has defined a specific circular stage for each life cycle, as depicted in Figure 1.

In terms of Design for Traceability, it is implied that understanding the journey of a product through its life cycle stages and being able to track and optimize this journey is crucial. This can lead to more sustainable and efficient use of resources, contributing to the goals of the circular economy (Franconi, A., 2022).

Here are some key points to consider when implementing a circular strategy in DfT:

Design for X (DFX) Tools

The 51-rule Design for Circularity and Durability (DFCD) guideline applies targeted DFX interventions—reuse, repair, refurbishing, remanufacturing, and recycling—to generate multiple lifecycle loops and extend product longevity (Bürklin, N., 2019). Its novelty lies in (i) defining dedicated circularity rules and (ii) organizing them by design stage. Derived from a literature review and mapping DFX rules to circular-economy strategies, DFCD delivers a structured framework that enables designers to embed both durability and circularity throughout product development, ensuring systematic, stage-specific guidance for sustainable, resilient design.

The article also presents a case study demonstrating the implementation and benefits of applying the DFCD guideline in practice. The article proposes an integrated DFX-based approach and design guidelines for the tricycle to help designers and companies incorporate circularity and durability into product design and development (Mesa, J. A., 2023). (Figure 2).

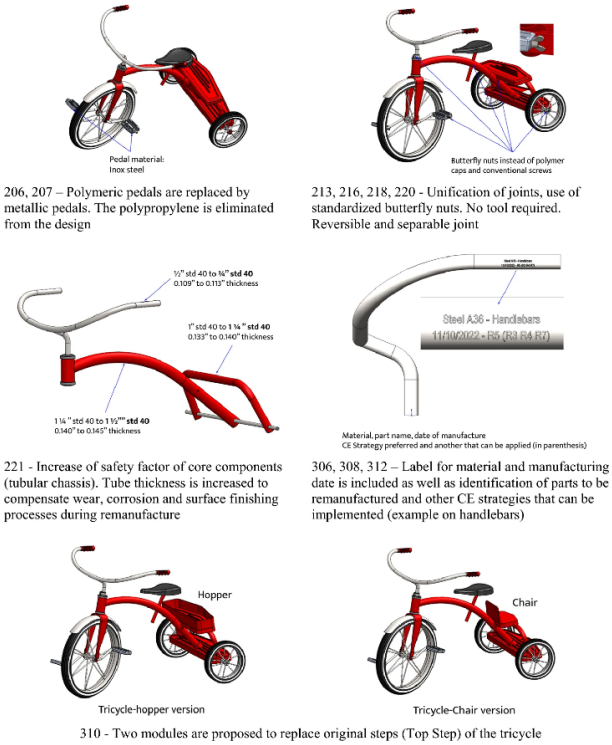


Figure 2. Modifcations using DFCD guidelines for Remanufacturing (R5)—embodiment and detailed design. © (Mesa, J. A., 2023).

Circular Economy (CE) Strategies Align design rules with Circular Economy R-strategies—Reduce, Reuse, Repair, Refurbish, Remanufacture, and Recycle—to slow and close the loop of products, parts, and materials (Davari, S., 2023). See Figure 3.

Traceability Framework
Develop a traceability framework that covers the main purposes of traceability enabling CE principles, the role of traceability across asset lifecycle stages, the type of data needed to support traceability, and the value of collaboration among industry stakeholders [18].

Lifecycle Information Management
Consider environmental, economic, societal, and technical impacts across the whole lifecycle, involving many considerations, disciplines, and indicators (Davari, S., 2023). (Figure 4).

Digital Threading
Digital threading enables tracing a product's development, identifying causal relationships between processes, and ensuring data consistency (Nowacki, S., 2023). It integrates data from diverse systems to create a unified digital representation, supporting collaboration and data-driven decisions (Domskienė, J., 2024). In the Circular Economy (CE), traceability is vital for tracking materials and products throughout their lifecycle. However, achieving traceability in the built asset industry is challenging due to complex projects and limited awareness of its benefits. In Canada, 27% of municipal waste comes from construction, with over 75% potentially recyclable, salvaged, or reused (Davari, S., 2023).



Figure 3. Key concepts related to traceability for sustainable development. © (Davari, S., 2023).

Smarter product use and manufacture	**R0**	**Refuse**	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	**Rethink**	Make product use more intensive (e.g. through sharing products or by putting multi-functional products on market).
	R2	**Reduce**	Increase efficiency in product manufacture or use by consuming fewer natural resources
Extend lifespan of product and its parts	**R3**	**Reuse**	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	**Repair**	Repair and maintenance of defective product so it can be used with its original function
	R5	**Refurbish**	Restore an old product and bring it up to date
	R6	**Remanufacture**	Use parts of discarded product in a new product with the same function
	R7	**Repurpose**	Use discarded products or its part in a new product with a different function
Useful application of materials	**R8**	**Recycle**	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	**Recovery**	Incineration of material with energy recovery

Figure 4. R-strategies in CE. © (Davari, S., 2023).

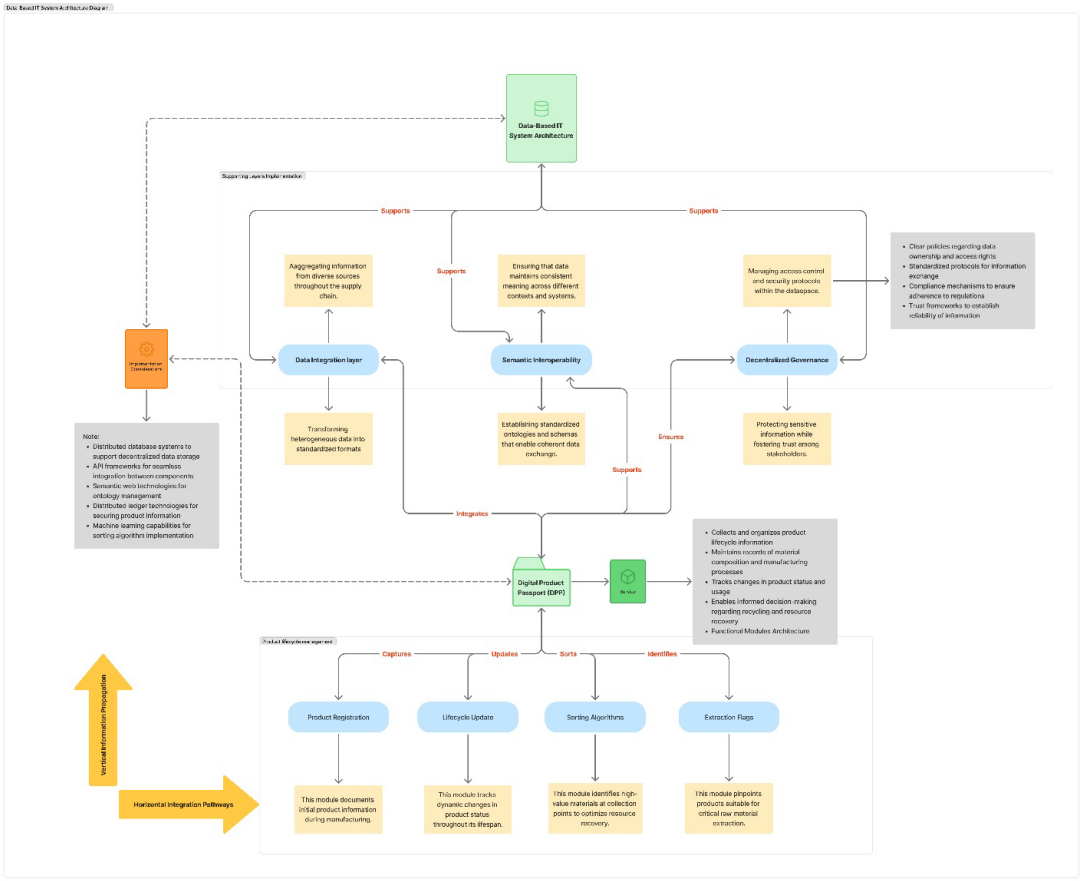


Figure 5. Visual Diagram for Dataspace-Based IT Systems Architecture with Digital Product Passport Modules. An enlarged version of the image is provided through [![Design-for-Traceability.jpg](https://i.postimg.cc/tJ5KmfNz/Design-for-Traceability.jpg)]

Modern Technology Enablers for Traceability

Smart Identification Technologies (SIT)

Smart tags integrate physical identifiers with digital systems to deliver secure, traceable product identities, enabling supply-chain visibility and circular economy goals. Blockchain integration and EU regulations like the Digital Product Passport initiative boost adoption. Embedded digital identities enhance transparency, sustainability, and end-of-life management while solving authentication and traceability challenges. Digital Product Passports (DPPs) are comprehensive digital documents that accompany products throughout their lifecycle, containing data on materials, manufacturing methods, distribution, environmental impacts, usage, and end-of-life stages (Nowacki, S., 2023). Introduced by the EU Green Deal to advance the circular economy, DPPs will be required for recyclable textiles by 2030, providing essential infrastructure for secure data collection and sharing across supply chains (Domskienė, J., 2024).

Dataspace-Based IT Systems Architecture

The following diagram presents an architecture that embeds Digital Product Passports (DPPs) into a dataspace-based IT system, enhancing transparency, circularity, and raw-material stewardship across product lifecycles. (Figure 5)

At its core, a **Dataspace-Based IT Architecture** serves as the network's brain, enabling bidirectional flows—from strategic decisions to operational tasks—and horizontal integration across systems. Three supporting layers enable functionality:

- **Data Integration Layer:** Aggregates heterogeneous supply chain data into standardized formats.
- **Semantic Interoperability:** Applies shared ontologies to ensure consistent data interpretation.

- **Decentralized Governance:** Manages access, security, and trust without centralized authority.

The **DPP node** acts as a digital twin, storing key lifecycle data to guide repair, recycling, or reuse. Its capabilities are extended by four **functional modules**:

- **Product Registration** (captures manufacturing details)
- **Lifecycle Updates** (records status changes)
- **Sorting Algorithms** (optimizes material recovery)
- **Extraction Flags** (identifies critical-material candidates)

Information flows vertically (architecture → layers → modules) and horizontally (across layers and modules), fostering coherent collaboration. **Implementation** relies on distributed databases, APIs, semantic web tools, and machine learning. **Governance and standards alignment** embed policies for data ownership, access rights, and interoperability, ensuring compliance and stakeholder trust.
Governance models support academic discussion on circular supply chains and critical-material management (Koppelaar, R. H., 2023). Smart tag–enabled digital identities facilitate secure authentication and anti counterfeiting (Falcone, A., 2021), full lifecycle traceability from raw material sourcing to recycling (Felicetti, C., 2023), and the capture of reuse, refurbishment, and recycling
data to drive circular economy initiatives (Voulgaridis, K., 2023).

Successful deployment depends on coordinated participation by manufacturers, distributors, consumers, and recyclers within a unified digital ecosystem.

Smart Tag Technologies for Digital Product Identity

Implementing digital product identities relies on diverse smart tag technologies—RFID, NFC, QR codes, and PUF tags—each tailored to specific roles within the digital identity ecosystem (Benčić, F. M., 2019).

RFID: Comprising microchips and antennas, RFID tags enable contactless, bulk reading and are available in passive, semi passive, and active formats with varying read ranges and memory capacities (Sudhakaran, S., 2024). Widely used in retail inventory, smart checkout, and industrial logistics, they significantly enhance traceability and operational efficiency (Gowtham, R., 2024; Chen, Z., 2024).

NFC: Building on RFID principles, NFC tags facilitate secure, short range interactions via smartphones, supporting consumer engagement, authentication, and seamless payment integration (Benčić, F. M., 2019).

QR Codes: As cost effective optical identifiers, QR codes require only a smartphone camera for scanning, making them ideal for early Digital Product Passport (DPP) deployment in cost sensitive sectors like textiles (Domskienė, J., 2024). Laser engraved 2D barcodes further improve durability and tamper resistance for long lifecycle products (Hakola, L., Hakola, E., 2024).

Physically Unclonable Function (PUF) tags: Leveraging random hardware variations, PUF tags generate unforgeable “digital fingerprints,” offering high security authentication for valuable goods (Falcone, A., 2021; Felicetti, C., 2023).
Selecting the optimal tag balances cost, durability, security, and user interaction. Comparative studies in reusable packaging demonstrate that properly protected RFID, NFC, and laser engraved codes withstand repeated washing and heat exposure (Hakola, L., Hakola, E., 2024).
Moreover, anchoring tag data in blockchain or distributed ledger technologies creates tamper evident records, underpinning DPPs and material passports for circular resource recovery (Benčić, F. M., 2019). By enabling automated lifecycle updates, predictive analytics, and stakeholder collaboration, smart tags form the backbone of resilient, transparent supply chain ecosystems aligned with circular economy goals.

Materials passports (MPs)

Digital Product Passports (DPPs) are dynamic tools that document material properties across lifecycles, enabling reuse, recycling, and resource efficiency in construction, manufacturing, and agriculture (Abedi, F., 2024). Powered by blockchain and QR codes, they transform static records into shareable digital platforms. Central to the EU Green Deal’s circular economy, DPPs face interoperability and standardization challenges

but benefit from emerging legal frameworks and structured data governance (Piétron, D., 2023; Kasimatis, C.N., 2024).
Material Passports similarly track materials throughout a product's lifecycle, crucial in construction—responsible for nearly 40% of global CO_2 emissions—by bridging data gaps from production to end-of-life and guiding retrofit versus demolition decisions (Abedi, F., 2024; Kasimatis, C.N., 2024). They capture composition, origin, and environmental product declarations (EPDs) (Wang, L., 2024), though aligning multiple passport formats remains a sector-wide challenge.
Here are some examples of MPs:

Buildings As Material Banks (BAMB)
BAMB organizes material and product data across hierarchical levels—properties, certifications, logistics—and offers a digital platform linking building components to market values, effectively turning structures into material banks.

3XN Architects
This passport framework guides the collection of circular-economy data at each building lifecycle stage. It connects technical and functional specifications to a centralized database, ensuring full traceability of components.

Madaster
Madaster structures MP data by building layers (structure, skin, services) and integrates circularity indicators to quantify virgin, recycled, reused, and renewable materials. Its cloud platform interfaces with BIM models, allowing users to generate bespoke passports for buildings or elements (Davari, S., 2023).
These MP initiatives exemplify how standardized, interoperable digital passports can transform material management into a measurable, market-driven circular economy. (Figure 6)

Blockchain Integration for Enhanced Security and Trust
Integrating blockchain with smart tags advances digital product identity systems by enhancing data integrity, trust, and decentralized verification (Felicetti, C., 2023). Blockchain's distributed ledger ensures transparent, tamper-proof tracking, while smart tags establish physical-digital linkages. Ethereum-based tools like Distributed Ledger

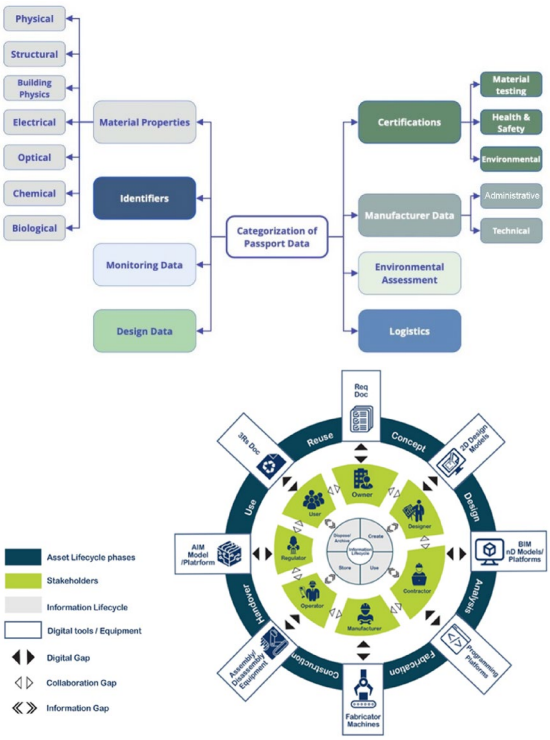


Figure 6. From up to down: Categorization of MP data & Overview of current gaps in asset lifecycle phases. © (Davari, S., 2023).

Technology (DLT) DL-Tags allow consensus across stakeholders without central control (Benčić, F. M., 2019). Smart contracts automate authentication, ownership transfer, and access control, reducing fraud and human error (Falcone, A., 2021; Abedi, F., 2024). Combined with PUF tags and elliptic curve cryptography (ECC), blockchain strengthens anti-counterfeiting efforts (Falcone, A., 2021; Benčić, F. M., 2019). Privacy-focused cryptographic methods safeguard sensitive data while enabling traceability (Benčić, F. M., 2019). Together, these technologies offer secure, decentralized, and privacy-preserving systems for managing identities in complex global supply chains.

IOTA's Distributed Ledger Technology
IOTA's distributed ledger technology offers a scalable, fee-less solution for tracking materials throughout product lifecycles, enhancing traceability, compliance, and sustainability in circular economy applications. Its Tangle architecture—a Directed Acyclic Graph (DAG)—supports parallel, miner-free transaction validation, ideal for IoT-enabled Digital Product Passports (DPPs). Unlike blockchain, each transaction validates two

previous ones, leveraging a Markov Chain Monte Carlo algorithm and lightweight proof-of-work for confirmation (Leivadaros, S., 2021). Transactions accrue cumulative weight, replacing traditional mining consensus, enabling energy-efficient, real-time validation. This architecture addresses key challenges in interoperability and secure data exchange, positioning IOTA as a foundational technology for decentralized and transparent digital product identity systems.

Digital Product Passports (DPP): Tracking Materials Across Lifecycles

IOTA's Digital Product Passport (DPP) prototypes leverage distributed ledger technology to ensure immutable, traceable, and transparent product records across all lifecycle stages. Recognized by the European Union, DPPs are pivotal to circular economy goals, enabling interoperable data exchange among stakeholders. These passports document materials across four lifecycle phases: (1) raw material acquisition, (2) production with component-level identification, (3) usage tracking (repairs, upgrades, ownership changes), and (4) end-of-life processing (recycling, disposal) (Blockchain News. (n.d.)., IOTA Foundation. (n.d.)).

Sector Applications

In electronics, IOTA collaborated with the Technical University of Catalonia to prototype a DPP from production to recycling (IOTA Foundation. (n.d.)). Automotive battery tracking is supported via a partnership with Eviden (EV Magazine. (n.d.)), while pharmaceutical traceability is enhanced through authentication and cold-chain monitoring (Suhail, S., 2019). IOTA has also worked with TradeMark East Africa (TMEA) to digitize Kenyan exports, utilizing EPCIS 2.0 to streamline cross-border trade documentation (ScyllaDB. (2023, February 9).

Technical Architecture

IOTA integrates lightweight IoT nodes for decentralized data issuance and secure transaction validation through proof-of-work. Full nodes validate transactions, while a central coordinator confirms milestone checkpoints (recycling, disposal) (Blockchain News. (n.d.)., IOTA Foundation. (n.d.), EV Magazine. (n.d.)). The architecture supports real-time data integrity and scalability for IoT ecosystems.

Benefits and Challenges

IOTA offers feeless microtransactions, high scalability (Leivadaros, S., 2021), immutable product records, and strong alignment with circular economy practices (Blockchain News. (n.d.)., IOTA Foundation. (n.d.)). However, challenges remain in IoT device security (Leivadaros, S., 2021), integration with legacy systems, and achieving broad standardization despite EPCIS 2.0 adoption (ScyllaDB. (2023, February 9).

Sectoral Applications of Material Passports (MPs) & Digital Product Passports (DDP)

Material Passports in Construction and Building Materials

Material passports are emerging as critical tools in the construction industry, addressing the sector's substantial resource use and environmental impact. By documenting comprehensive material data, they enable reuse and recycling at a building's end-of-life phase (Costa, A.R., 2024). In Turkey, BIM-integrated studies demonstrate how material passports improve lifecycle tracking, boost recovery rates, and reduce construction waste (Toprakli, A.Y., 2024). Their relevance spans both new and renovated structures, preserving vital material data across long building lifespans and project stakeholder turnover (Incorvaja, D., 2022; Byers, B.S., 2023).

Material Passports in CDW Management

In Construction and Demolition Waste (CDW) management, passports address data fragmentation. Platforms such as Madaster, Concular, and CB'23 provide standardized templates to enhance traceability and facilitate high-value material recovery (Honic, M., 2024).

From Data Templates to Passports & Enabling Business Models

The shift from static data templates to advanced material and digital product passports (DPPs) marks a critical advancement in construction and demolition waste (CDW) management. These tools ensure standardized, lifecycle-based documentation of material composition, origin, and reuse potential, enhancing data consistency and stakeholder interoperability. Technologies such as blockchain and QR codes enable real-time traceability, despite ongoing challenges in

capturing dynamic performance data (Aryblia, M., 2023). Emerging platforms exemplify scalable business models: Madaster increases material residual value by 15–25% (Honic, M., 2024), Concular facilitates reuse of up to 80% of demolition waste, and CB'23 promotes broad adoption through open-source material passport frameworks.

Impact on Circular Economy Goals

Passports support over 90% reuse of materials like steel and concrete, aligning with circular economy objectives. They help quantify embedded carbon, aiding the EU's target of 55% emissions reduction by 2030. Platforms such as Concular facilitate secondary material markets and challenge traditional linear supply chains (Honic, M., 2024; Aryblia, M., 2023).

Digital Material Banks for Circular Construction

Despite the EU's 70% CDW reuse target, actual reuse remains at ~50%, with just 3% upcycled. Digital Material Banks (DMBs) provide cloud-based inventories of reusable components. A post-earthquake Italian case study showed selective demolition and digital tools enhance recovery and carbon savings (Cocco, P.L., 2023).

Cross-Jurisdictional Trading of Construction Materials

The article proposes a blockchain-based framework using non-fungible tokens (NFTs) to improve cross-jurisdictional trading of construction waste materials (CWM) and reduce information asymmetry. It introduces a Waste Material Passport (WMP) system where each material is tokenized into a unique NFT to prevent duplication, enhance transparency, and ensure secure, immutable transaction records. Blockchain's distributed ledger and decentralized consensus mechanisms boost authentication and trading efficiency. A prototype and case study validated the approach, showing that blockchain and NFT integration significantly improve trust, traceability, and efficiency in CWM transactions (Wu, L., 2023). This supports broader adoption of Material and Digital Product Passports in construction.

DPPs in the Fashion Industry

DPPs address fashion's environmental impact—projected to contribute 26% of global GHG emissions by 2050—by enhancing supply chain transparency and supporting ethical sourcing. They help brands comply with sustainability regulations and meet eco-conscious consumer expectations. A case study of a sustainable fashion SME shows that collaborative innovation and digital twin adoption enable even small firms to implement DPPs (Re, N.U., 2024). Moreover, DPPs may reshape trademark law by redefining authenticity through digital records, reducing reliance on traditional brand identifiers (Gösken, C., 2025).

DPPs in Electronics and E-waste Management

DPPs hold significant promise in electronics manufacturing by extending product lifetimes and improving e-waste management. In one case, DPPs enabled assessment of washing machines for reuse and refurbishment by providing lifecycle data on durability, repairability, and upgrade potential (Stiksma, F., 2024). Another case from plastics recycling—relevant to electronics—traced the transformation of 486.7 kg of bottle caps into 363.2 kg of products using R-Cycle's DPP system based on GS1 standards (Rumetshofer, T., 2024). The initiative underscores the importance of standardized datasets and infrastructure, while highlighting challenges in balancing transparency with protection of proprietary data—crucial for electronics sector DPP deployment.

DPPs are emerging as transformative tools in electronics manufacturing, fostering supply chain transparency and sustainable production. By embedding lifecycle data, environmental and social indicators, and absolute sustainability metrics (Psarommatis, F., 2024; Panza, L., 2023), DPPs support informed decision-making and resource efficiency. Implemented through cyber-physical systems and the Asset Administration Shell (AAS) framework (Kühn, M., 2025), they enable traceability and secure data sharing via blockchain (Kim, M.J., 2025). Applications in sectors such as electronics and batteries (e.g., the EU battery passport) illustrate their scalability (Kühn, M., 2025). Strategic gains include improved stakeholder trust, competitive advantage (Haase, L.M., 2025), and adaptive capacity in industrial ecosystems through federated learning and orchestration mechanisms (Kim, M.J., 2025; Jensen, S.F., 2024).

Applications in Agriculture and Food Systems

Digital Product Passports (DPPs) enhance agricultural traceability by providing immutable records of inputs, methods, and origins—supporting organic certification and the EU Green Deal (Abedi, F., 2024). Dynamic DPPs for organic and geographically indicated foods update in real time to improve auditability and fraud prevention, requiring stakeholder collaboration and regulatory compliance (Lekawska-Andrinopoulou, L., 2024). IoT integration fortifies supply chains via real-time monitoring and data sharing, while blockchain ensures transparency from farm to table (Kale, M.D., 2023). Combined with Material Passports (MPs), DPPs offer a digital framework that delivers verifiable data on resource use and environmental impact to advance circular economy objectives and food safety, guiding stakeholders in sustainable, data-driven agricultural practices.

Robust technical infrastructure leverages blockchain, IoT, and federated learning (Kim, M.J., 2025) via frameworks like the Asset Administration Shell (Kühn, M., 2025) and cyber-physical systems (Rumetshofer, T., 2024). Strong data governance ensures high-quality, validated, and privacy-compliant information flows. Product tracing integrates QR/RFID, smart contracts, and real-time logging for full traceability. Sustainability is assessed through life cycle analysis, planetary boundaries (Panza, L., 2023), and circularity metrics (Fassio, F., 2023). Stakeholder engagement, seamless value chain integration, and rigorous regulatory compliance ensure system-wide adoption, resilience, and credibility.

Design for Traceability Framework

The framework promotes transparency and accountability by integrating circular economy principles, advanced digital technologies, and collaborative strategies. It encompasses five pillars: Lifecycle-Centric Design, Digital Traceability Infrastructure, Circular Business Models, Stakeholder Collaboration, and Regulatory Alignment, ensuring sustainability, traceability, and compliance across product and material lifecycles.

The DfT framework embeds traceability across lifecycles through five pillars: lifecycle-centric design, digital infrastructure, circular models, collaboration, and regulation. It begins with modular, durable design using DFCD tools and BIM for long-term decisions. RFID, NFC, and IOTA's blockchain-enabled DPPs support data interoperability, while IoT and BIM monitor material performance. Circular business models like leasing and remanufacturing leverage AI and digital twins. Public-private collaboration, IOTA's marketplace, and BIM promote secure, transparent data sharing. Regulatory alignment with EU DPP policies ensures compliance (Table 2 and Table 3). DfT enhances longevity, resource optimization, and circularity by enabling end-to-end transparency and building consumer trust, Figure 7.

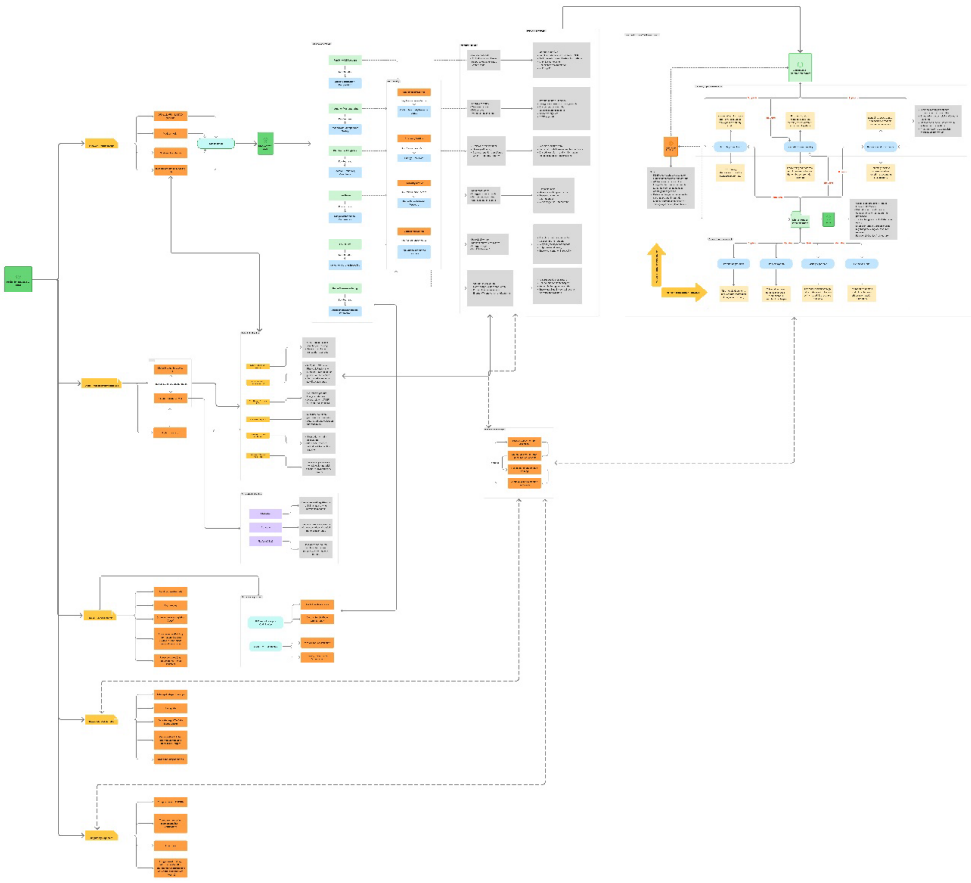


Figure 7 Visual Representation of the Framework. An enlarged version of the image is provided through [![Design-for-Traceability.jpg](https://i.postimg.cc/tJ5KmfNz/Design-for-Traceability.jpg)](https://postimg.cc/YLvDvdV4)

Table of the Framework

Table 2. Design for Traceability Framework: Pillars for Sustainable Integration.

Pillar	Key Strategies	Expected Outcomes
Lifecycle-Centric Design	Modular design, sustainable materials, DFX tools, *Building Information Modeling (BIM)*	Longer product lifecycles, efficient recycling, detailed lifecycle data for built assets (Standardized labeling)
Digital Traceability Infrastructure	Smart tags (RFID, QR, NFC, BUF), blockchain-enabled DPPs, dataspace IT systems, sensor networks, *IOTA Technology*, *IOTA Streams*	Real-time tracking, immutable records, enhanced decision-making, continuous monitoring of product performance, secure data validation
Circular Business Models	Service-based models, reuse programs, R-strategies, optimized reverse logistics (*IOTA*), adaptive reuse (*Building Information Modeling (BIM)* with *IOTA-based material passports*)	Waste reduction, new revenue streams, stronger consumer trust, optimized resource use through adaptive reuse
Stakeholder Collaboration	Public-private partnerships, living labs, cross-industry consortia, data sharing (*IOTA Data Marketplace*), collaborative *Building Information Modeling (BIM)* (*IOTA Tangle*)	Accelerated adoption, harmonized standards, improved stakeholder engagement and data sharing
Regulatory Alignment	Compliance with EU DPPs, transparent reporting mechanisms (*IOTA verification*), incentives, integration of *Building Information Modeling (BIM)* standards into building codes (*IOTA DLT for data integrity*)	Regulatory compliance, competitive advantage, broader adoption of traceability, enhanced sustainability in the built environment

Lifecycle Integration Layers Framework for Design for Traceability

These tables (Table 2 and 3) provide a structured, systematic, and technology-driven approach to lifecycle integration for traceability, ensuring sustainability, accountability, and efficiency throughout the entire product lifecycle.

Table 3 Design for Traceability Framework: Pillars for Sustainable Integration.

Lifecycle Stage	Traceability Mechanisms	Data Elements Captured	Key Metrics Tracked	Relevant Strategies
Raw Material Sourcing	-Geo-tagged sourcing certificates on blockchain (IOTA) -DPP initialization -NFC tagging at source -BIM for material specification & standardized labeling -PUF-based material authentication	- Material origin (GPS) - Supplier certifications (Fair Trade, FSC) - Environmental impact & extraction methods - Chemical composition - Compliance documentation - NFC Tag ID	- Carbon footprint - Ethical labor compliance - Resource depletion rates - Water usage	- Lifecycle-Centric Design (Sustainable Material Selection) - Digital Traceability (Blockchain, DPP, NFC, PUF) - Regulatory Compliance
Production/Manufacturing	- NFC/RFID smart tagging - DPP updates with real-time manufacturing data - Digital Twin integration - DFCD tools - BIM for process visualization & quality control - PUF for component authenticity	- Production date & location - Energy, water usage & waste generation - Component serial numbers - ML insights - Worker safety data - DFCD application	- Energy efficiency - Waste reduction - Defect rates - Worker safety incidents	- Modular & Lifecycle-Centric Design - Digital Threading (Smart tags, Digital Twin, PUF) - Circular Business Models (Remanufacturing design)
Distribution & Logistics	- IoT-enabled GPS tracking - Blockchain/IOTA supply-chain mapping - NFC scanning at custody transfer - BIM for route & storage modeling - PUF tagging for tamper-evident transit packs	- Real-time location data - Transport mode & environmental conditions - Custody transfer & routing info - Transportation carbon emissions	- Emissions per shipment - Delivery efficiency - Storage condition compliance - Chain-of-custody integrity	- Digital Traceability Infrastructure (Blockchain, IoT, PUF) - Stakeholder Collaboration (Supply-Chain Integration) - Regulatory Compliance
Use Phase	- IoT-enabled usage monitoring - NFC/QR-enabled DPP access for maintenance & repair - Predictive analytics - BIM-driven maintenance scheduling - PUF on high-value parts for service authenticity	- Usage statistics - Maintenance & repair history - Energy consumption - User feedback - Sensor logs & IoT interactions	- Repair frequency - Energy efficiency trends - Component wear rates - User satisfaction scores	- Lifecycle-Centric Design (Maintenance-focused) - Circular Business Models (Service-based) - Digital Traceability (IoT, DPP, PUF)
End-of-Life (Collection, Sorting, Recycling)	- DPP for disassembly & recovery info - Smart tags for sorting - Blockchain/IOTA for recycling docs - BIM for end-of-life facility planning	- Complete material composition - Disassembly instructions - Recycling facility & sorting data - Output material quality	- Recyclability rate - Material recovery efficiency - Energy savings - Landfill diversion %	- Lifecycle-Centric Design (Recyclability-focused) - Circular Business Models (R-strategies) - Digital Traceability (Smart tags, Blockchain, PUF)

	- PUF for material batch verification	- Energy consumption in recycling		
Reuse / Remanufacturing	- DPP-based product history tracking - Smart tags for component ID - Quality assessment - BIM-supported remanufacturing planning - PUF to certify remanufactured components	- Full product lifecycle history - Component condition analysis - Remanufacturing process data - Energy use & quality control records - Warranty renewal data	- Component reuse rate - Cost savings vs. new production - Product lifespan extension - Remanufacturing energy efficiency	- Lifecycle-Centric Design (Remanufacturing-focused) - Circular Business Models (Reuse programs) - Digital Traceability (DPP, NFC, Blockchain, PUF)

Conclusion

Embracing the Traceable Future – DfT as the Cornerstone of a Sustainable and Accountable Circular Economy

Design for Traceability (DfT) is embedded in the DNA of products and materials as “digital DNA”, making it a crucial pillar for a sustainable, accountable circular economy. It integrates Circular Economy (CE) principles, shifting from "take-make-dispose" models to optimize resource use, reduce waste, and increase consumer trust. Through tools like Design for X (DFX) and SIT, DfT enables informed decisions and minimizes environmental impact.

A multi-hierarchical framework aligns strategies with circular goals, as demonstrated by Patagonia’s focus on durability and reuse. DfT requires collaboration among designers, manufacturers, and consumers, supported by Digital Product Passports (DPPs) that provide product data, including origins and end-of-life options.

Key to DfT’s success is cross-disciplinary collaboration, standardization, transparency incentives, and empowering consumers. Advanced technologies like, AI, and digital twins enhance security and optimize resource allocation, enabling a closed-loop system. In conclusion, DfT is the catalyst for embedding sustainability and longevity in the product lifecycle.

References

Guilherme Pulita, J., Canesin, H., Lima de Oliveira, L., Lago da Silva, A., & Roberta Pereira, C. (2022). The Role of Traceability in Food Recall Management: A Systematic Literature Review. *Revista Gestão da Produção Operações e Sistemas*. https://doi.org/10.15675/gepros.v17i2.2881

Ringsberg, H. (2014). Perspectives on food traceability: A systematic literature review. *Supply Chain Management*, 19, 558-576. https://doi.org/10.1108/SCM-01-2014-0026

Alwi, A., Sasongko, N.A., Suprapto, Suryana, Y., & Subagyo, H. (2024). Blockchain and big data integration design for traceability and carbon footprint management in the fishery supply chain. *Egyptian Informatics Journal*. https://doi.org/10.1016/j.eij.2024.100481

Kusnadi, A., Arkeman, Y., Syamsu, K., & Wijaya, S.H. (2023). Designing Halal Product Traceability System using UML and Integration of Blockchain with ERP. *Jurnal Ilmiah Teknologi Sistem Informasi.* DOI: 10.26594/register.v9i1.3045

Srivastava, A., & Dashora, K. (2022). Application of blockchain technology for agrifood supply chain management: a systematic literature review on benefits and challenges. *Benchmarking: An International Journal*. https://doi.org/10.1108/BIJ-08-2021-0495

Dawood, M.N., Adile, M., Fahidhil, E., Hassan, A.R., Shukur Ali, H.M., Noori, M., & Adnan, M.M. (2024). Design of Traceability Platform for Animal Husbandry Products Supply Chain Based on RFID Internet of Things. 2024 International Conference on Smart Systems for Electrical, Electronics, Communication and Computer Engineering (ICSSEECC), 701-706. https://doi.org/10.1109/ICSSEECC61126.2024.10649535

Mora-Mora, H., Gilart-Iglesias, V., Gil, D., & Sirvent-Llamas, A. (2015). A Computational Architecture Based on RFID Sensors for Traceability in Smart Cities. Sensors (Basel, Switzerland), 15(6), 13591–13626. https://doi.org/10.3390/s150613591

Otte, S., Sufian, N.N., Schabel, S., & Fleischer, J. (2024). Identification of Relevant Parameters for Traceability in the Continuous Mixing Process in Battery Cell Production. *Energy Technology.* https://doi.org/10.1002/ente.202400493

Barata, J., Cunha, P.R., Gonnagar, A.S., & Mendes, M. (2018). Product Traceability in Ceramic Industry 4.0: A Design Approach and Cloud-Based MES Prototype.

https://doi.org/10.1007/978-3-319-74817-7_12

Kusnadi, A., Arkeman, Y., Syamsu, K., & Hartono Wijaya, S. (2024). Assurance of Halal Beef Products Using a Traceability System in Enterprise Resource Planning Applications. IOP Conference Series: Earth and Environmental Science, 1358. DOI 10.1088/1755-1315/1358/1/012020

Putri, W.S. (2025). The Impact of Sustainable Sourcing on Halal Certification: A Literature Review on Ethical and Environmental Concerns. *Journal of Halal Review*. https://doi.org/10.70764/gdpu-jhr.2025.1(1)-05

Terzi, S., Cassina, J., & Panetto, H. (2006). Development of a metamodel to foster interoperability along the product lifecycle traceability. In *Interoperability of Enterprise Software and Applications* (pp. 1-11). London: Springer London. http://dx.doi.org/10.1007/1-84628-152-0_1

Mesa, J. A. (2023). Design for circularity and durability: an integrated approach from DFX guidelines. Research in *Engineering Design*, 34(4), 443-460. https://doi.org/10.1007/s00163-023-00419-1

Bandini, G., Buffi, A., Caposciutti, G., Marracci, M., & Tellini, B. (2023, June). An RFID System Enabling Battery Lifecycle Traceability. In 2023 IEEE International Workshop on Metrology for Automotive (MetroAutomotive) (pp. 46-50). IEEE. 10.1109/MetroAutomotive57488.2023.10219134

Franconi, A., Ceschin, F., & Peck, D. (2022). Structuring Circular Objectives and Design Strategies for the Circular Economy: A Multi-Hierarchical Theoretical Framework. *Sustainability*, 14(15), 9298. https://doi.org/10.3390/su14159298

Bürklin, N. (2019). Worn Wear: Better than New—How Patagonia's Social Marketing Campaign Enhances Consumers' Responsible Behavior. *Social Marketing in Action: Cases from Around the World*, 187-201. https://doi.org/10.1007/978-3-030-13020-6_12

Rattalino, F. (2018). Circular advantage anyone? Sustainability-driven innovation and circularity at Patagonia, Inc. *Thunderbird International Business Review*, 60(5), 747-755. https://doi.org/10.1002/tie.21917

Davari, S., Jaberi, M., Yousfi, A., & Poirier, E. (2023). A traceability framework to enable circularity in the built environment. *Sustainability*, 15(10), 8278. https://doi.org/10.3390/su15108278

Nowacki, S., Sisik, G. M., & Angelopoulos, C. M. (2023, June). Digital product passports: Use cases framework and technical architecture using DLT and smart contracts. In 2023 19th International Conference on Distributed Computing in Smart Systems and the Internet of Things (DCOSS-IoT) (pp. 373-380). IEEE. DOI: 10.1109/DCOSS-IoT58021.2023.00067

Domskienė, J., & Gaidule, E. (2024). An overview of technological challenges in implementing the digital product passport in the textile and clothing industry. *AUTEX Research Journal*, 24(1), 20240002. doi.org/10.1515/aut-2024-0002

Koppelaar, R. H., Pamidi, S., Hajósi, E., Herreras, L., Leroy, P., Jung, H. Y., ... & Fontana, A. (2023). A digital product passport for critical raw materials reuse and recycling. *Sustainability*, 15(2), 1405. https://doi.org/10.3390/su15021405

Falcone, A., Felicetti, C., Garro, A., Rullo, A., & Saccà, D. (2021, August). PUF-based smart tags for supply chain management. In Proceedings of the 16th International Conference on Availability, Reliability and Security (pp. 1-7). https://doi.org/10.1145/3465481.3469195

Felicetti, C., Guzzo, A., Manco, G., Pasqua, F., Ritacco, E., Rullo, A., & Saccà, D. (2023, October). Deep learning/puf-based item identification for supply chain management in a distributed ledger framework. In 2023 Fifth International Conference on Blockchain Computing and Applications (BCCA) (pp. 28-35). IEEE. DOI: 10.1109/BCCA58897.2023.10338853

Voulgaridis, K., Lagkas, T., Karampatzakis, D., Argyriou, V., & Sarigiannidis, P. (2023, June). Realizing Digital Product Passports with Crowdsourcing Principles: The Case of Sustainable Smart Grids. In 2023 19th International Conference on Distributed Computing in Smart Systems and the Internet of Things (DCOSS-IoT) (pp. 381-388). IEEE. DOI: 10.1109/DCOSS-IoT58021.2023.00068

Benčić, F. M., Skočir, P., & Žarko, I. P. (2019). DL-Tags: DLT and smart tags for decentralized, privacy-preserving, and verifiable supply chain management. IEEE access, 7, 46198-46209. DOI: 10.1109/ACCESS.2019.2909170

Sudhakaran, S., Maheswari, R., & Kanchana Devi, V. (2024). An improvised analysis of smart data for IoT-based railway system using RFID. *Journal for Control, Measurement, Electronics, Computing and Communications*, 65(1), 361-372. https://doi.org/10.1080/00051144.2023.2295141

Gowtham, R., Vaishnavi, V., Suhas, P., Chethan, S., & Geetha, D. (2024, July). Integration of RFID-Enabled Smart Shopping Carts for Real-Time Product Scanning and Billing using Arduino and React Framework. In 2024 Second International Conference on

Advances in Information Technology (ICAIT) (Vol. 1, pp. 1-6). IEEE. DOI: 10.1109/ICAIT61638.2024.10690604

Chen, Z., Jiang, H., You, J., Wang, X., & Sun, P. Z. (2024). RFID lightweight authentication mechanism for smart factories based on blockchain. *IEEE Journal of Radio Frequency Identification*, 8, 19-30. DOI: 10.1109/JRFID.2024.3356194

Hakola, L., Hakola, E., Palola, S., Tenhunen-Lunkka, A., & Lahtinen, J. (2024). Durable and sustainable smart tags for identity management and condition monitoring: Case study for reusable packaging and recyclable data carriers. *Packaging Technology and Science*, 37(2), 107-121. https://doi.org/10.1002/pts.2781

Costa, A.R. (2024). A roadmap to accelerate material reuse in construction and use materials passports. *Sustainable Construction Materials and Technologies (SCMT)*. DOI: 10.18552/2024/SCMT/402

Piétron, D., Staab, P., & Hofmann, F. (2023). Digital circular ecosystems: A data governance approach. GAIA - Ecological Perspectives for Science and Society. http://dx.doi.org/10.14512/gaia.32.S1.7

Topraklı, A.Y. (2024). Enabling circularity in Turkish construction: a case of BIM-based material management utilizing material passports. *Smart and Sustainable Built Environment*. https://doi.org/10.1108/SASBE-05-2024-0199

Abedi, F., Saari, U.A., & Hakola, L. (2024). Implementation and Adoption of Digital Product Passports: A Systematic Literature Review. 2024 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC), 1-9. DOI: 10.1109/ICE/ITMC61926.2024.10794320

Kasimatis, C.N., Apostolou, D., Efthimiadou, A., & Mentzas, G. (2024). Agricultural Product Traceability Using Blockchain-Based Digital Product Passports. 2024 15th International Conference on Information, Intelligence, Systems & Applications (IISA), 1-8. DOI: 10.1109/IISA62523.2024.10786712

Wang, L., Jing, Z., Li, Z., & Yu, H. (2024). A Traceability Approach for Agarwood Based on Distributed Identity and Smart Contracts. 2024 International Conference on Intelligent Algorithms for Computational Intelligence Systems (IACIS), 1-6. DOI: 10.1109/IACIS61494.2024.10722022

Incorvaja, D., Celik, Y., Petri, I., & Rana, O.F. (2022). Circular Economy and Construction Supply Chains. 2022 IEEE/ACM International Conference on Big Data Computing, Applications and Technologies (BDCAT), 92-99. DOI: 10.1109/BDCAT56447.2022.00019

Byers, B.S., & De Wolf, C. (2023). QR Code-Based Material Passports for Component Reuse Across Life Cycle Stages in Small-Scale Construction. *Circular Economy,* Vol. 1(1). https://doi.org/10.3929/ethz-b-000634760

Aryblia, M., Sarantinoudis, N., Tsinarakis, G.J., & Arampatzis, G. (2023). Enabling sustainability and resilience in industries through the value chains' circularity and digitalisation. Global NEST International Conference on Environmental Science & Technology. https://doi.org/10.30955/gnc2023.00568

Cocco, P.L., & Ruggiero, R.W. (2023). From rubbles to digital material bank. A digital methodology for construction and demolition waste management in post-disaster areas. *Environmental Research and Technology*. https://doi.org/10.35208/ert.1290843

Wu, L., Lu, W., Peng, Z., & Webster, C.J. (2023). A blockchain non-fungible token-enabled 'passport' for construction waste material cross-jurisdictional trading. *Automation in Construction*. https://doi.org/10.1016/j.autcon.2023.104783

Re, N.U., Ghezzi, A., Rangone, A., & Gottari, G. (2024). Managing Open Twin Transition in SMEs: a Case Study in Fashion Industry. European Conference on Innovation and Entrepreneurship. https://doi.org/10.34190/ecie.19.1.2794

Gösken, C. (2025). Fashioning Authenticity: How Digital Roduct Passports Could Shape the Future of trademark Law. *Journal of Intellectual Property Law and Practice*. https://doi.org/10.1093/jiplp/jpae121

Stiksma, F., Sinderen, M.V., & Moreira, J.L. (2024). Value Assessment of Consumer Electronics with Digital Product Passports: A Case Study of Lifetime Extension Assessment of Disposed Washing Machines. *IEEE International Enterprise Distributed Object Computing Conference*. https://doi.org/10.1007/978-3-031-78338-8_5

Rumetshofer, T., Straka, K., & Fischer, J. (2024). How the Digital Product Passport Can Lead the Plastics Industry towards a Circular Economy-A Case Study from Bottle Caps to Frisbees. *Polymers*, 16(10), 1420. https://doi.org/10.3390/polym16101420

Psarommatis, F., & May, G. (2024). Digital Product Passport: A Pathway to Circularity and Sustainability in Modern Manufacturing. *Sustainability*. https://doi.org/10.3390/su16010396

Panza, L., Bruno, G., & Lombardi, F. (2023). Integrating Absolute Sustainability and Social Sustainability in the Digital Product Passport to Promote Industry 5.0. *Sustainability*. https://doi.org/10.3390/su151612552

Kühn, M., Baumann, M., Volz, F., & Stojanović, L. (2025). Digital Product Passport Design Supporting the Circular Economy Based on the Asset Administration Shell. *Sustainability*. https://doi.org/10.3390/su17030969

Haase, L.M., Lythje, L.S., Skouboe, E.B., & Petersen, M.L. (2025). More Than Legislation: The Strategic Benefits and Incentives for Companies to Implement the Digital Product Passport. *Circular Economy*. https://doi.org/10.55845/CAXG2280

Kim, M.J., Han, C.H., Park, K.J., Moon, J.S., & Um, J. (2025). A Blockchain-Based Digital Product Passport System Providing a Federated Learning Environment for Collaboration Between Recycling Centers and Manufacturers to Enable Recycling Automation. *Sustainability*. https://doi.org/10.3390/su17062679

Jensen, S.F., Kristensen, J.H., Christensen, A., & Waehrens, B.V. (2024). An ecosystem orchestration framework for the design of digital product passports in a circular economy. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.3868

Lekawska-Andrinopoulou, L., Tsiakou, D., Chatzioannou, K., Tsimiklis, G., & Amditis, A.J. (2024). Towards dynamic digital product passport: The approach for food sector. E3S Web of Conferences. https://doi.org/10.1051/e3sconf/202458508001

Kale, M.D., & Rathod, P.S. (2023). Agriculture Food Supply Chain Management System based on BlockChain and IOT. *International Journal of Advanced Research in Science, Communication and Technology*. https://doi.org/10.3390/agriculture12010040

Leivadaros, S., Kornaros, G., & Coppola, M. (2021, May). Secure asset tracking in manufacturing through employing iota distributed ledger technology. In 2021 IEEE/ACM 21st International Symposium on Cluster, Cloud and Internet Computing (CCGrid) (pp. 754-761). IEEE. DOI: 10.1109/CCGrid51090.2021.00091

Blockchain News. (n.d.). IOTA digital product passports for electronics. Retrieved April 19, 2025, from https://blockchain.news/news/iota-digital-product-passports-electronics

IOTA Foundation. (n.d.). DPP for electronics: IOTA's digital product passport. Retrieved April 19, 2025, from https://blog.iota.org/dpp-for-electronics-iota/

EV Magazine. (n.d.). IOTA Eviden launches digital passport solution. Retrieved April 19, 2025, from https://evmagazine.com/articles/iota-eviden-launch-digital-passport-solution

Suhail, S., Pandey, S., & Hong, C.S. (2019). A Provenance-based Solution for Tracking Sensor Data in the Pharmaceutical Supply Chain.

ScyllaDB. (2023, February 9). *How IOTA uses distributed ledgers and ScyllaDB for supply chain digitization*. Retrieved April 19, 2025, from https://www.scylladb.com/2023/02/09/how-iota-uses-distributed-ledgers-and-scylladb-for-supply-chain-digitization/

Fassio, F., & Chirilli, C. (2023). The Circular Economy and the Food System: A Review of Principal Measuring Tools. *Sustainability* 15(13), 10179. https://doi.org/10.3390/su151310179

Honic, M., Magalhães, P.M., Van den Bosch, P. (2024). From Data Templates to Material Passports and Digital Product Passports. In: De Wolf, C., Çetin, S., Bocken, N.M.P. (eds) A Circular Built Environment in the Digital Age. Circular Economy and *Sustainability*. Springer, Cham. https://doi.org/10.1007/978-3-031-39675-5_5.

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European Policy Strategies for Textile Product Life Extension: Current Implementation and Challenges

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Keywords: Regulations; Legal Framework; Eco-Design; Extended Producer Responsibility; Fashion

Abstract: European policies are evolving to extend the lifespan of textiles and reduce waste, but challenges remain in implementation. This study examines how policies have shifted from voluntary measures before 2020 to stricter regulations, such as the Eco-design for Sustainable Products Regulation and Extended Producer Responsibility schemes. While these policies aim to make textiles more durable, most still focus on managing waste rather than preventing it. A key challenge is the lack of repair infrastructure and inconsistent enforcement across countries. Additionally, current policies sometimes prioritize recyclability over longevity, which can lead to unintended consequences like shorter product lifespans. Policies must better support durability through financial incentives, clearer design standards, and better enforcement to make a real impact. Investing in repair and reuse infrastructure alongside recycling efforts will be essential for creating a genuinely circular textile economy.

Introduction

The expanding textile sector increases access to affordable clothing, drives material innovation, and creates jobs globally. However, this growth has significant environmental and social impacts. The industry contributes 3% to 10% of global greenhouse gas emissions, 9% of ocean microplastic pollution, and consumes nearly 215 trillion liters of water annually (United Nations Environment Programme, 2023). Competitive pricing often undermines fair wages and safe working conditions (EEA, 2022).

With post-consumer textile waste (PCTW) expected to rise by 60% by 2050 (Salmenperä, 2023), transitioning from a linear economy to a circular economy is essential. CE replaces the 'end-of-life' concept with reducing, reusing, recycling, and recovering materials (Kirchherr et al., 2017). It can function through various value retention loops, as shown in Figure 1, though the industry prioritizes recycling over reuse, repair, and durability.

Several European countries have enacted policies to extend textile product life by promoting repairability, durability, and responsible end-of-life recycling. The Eco-design for Sustainable Products Regulation (ESPR) establishes binding requirements for durability, repairability, and recyclability, ensuring textiles are designed for longevity. Extended Producer Responsibility (EPR) schemes shift waste management responsibility to producers, incentivizing recovery, reuse, and recycling.

This paper examines European policies and their evolution over the past two decades, focusing on how they extend the lifespan of textile products and the challenges in achieving a circular economy.

Methodology

This paper qualitatively reviews textile waste prevention and management policies, covering clean, pre-consumer, and post-consumer waste. Management strategies aim to reduce waste in production, processing, and post-consumer phases through optimized raw material use, promoting durability, repair, reuse, and improved waste collection and recycling. A quantitative assessment of policy impacts was not conducted because many initiatives were not fully implemented. Policies were identified through desktop research and literature reviews using Web of Science and Google Scholar, excluding indirectly linked proposals such as microplastic filtration regulations. Table 1 (see appendix) lists the reviewed policies.

Policies were classified by focus: strategies (general frameworks), legal frameworks (legally

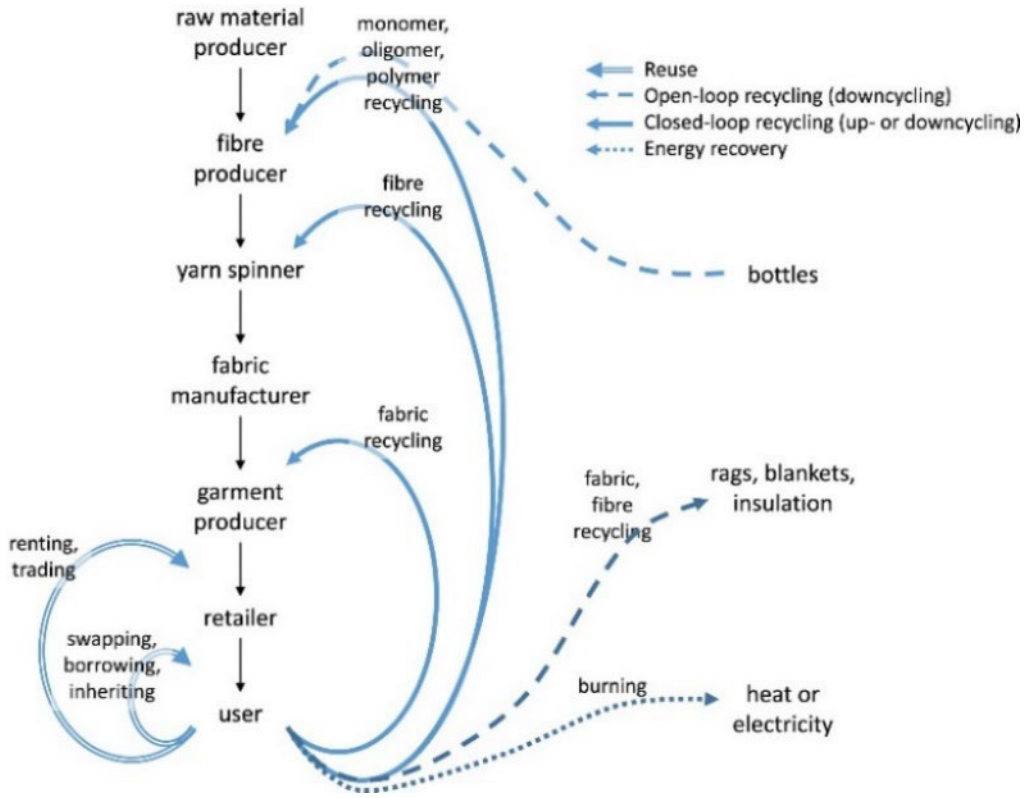


Figure 1. Circular activities within the textile value chain (Source: Sandin and Peters (2018))

binding with penalties), and incentives (financial or non-compulsory encouragement).

To assess effectiveness, policies were categorized by intensity: low-intensity (general guidelines), moderate-intensity (non-mandatory targets), and high-intensity (mandatory measures like eco-design mandates).

Policies were mapped to life cycle stages:

- Beginning of life – Promoting eco-design, durability, and sustainable production.
- Use phase – Supporting repair schemes, resale, and consumer engagement.
- End-of-life management – Regulations for collection, redistribution, recycling.

The analysis evaluates the scope, effectiveness, and enforcement of policies, mainly whether fewer high-intensity policies yield better results than numerous low-intensity measures.

Results and discussion

Type and intensity of polices

Classifying policies from Table 1 based on targets shows that high-intensity policies (6 cases) include EPR schemes, bans on destroying unsold goods, environmental labeling, and the EU's ESPR. These policies impose binding obligations on businesses and enforce accountability. Moderate-intensity policies (7 cases) involve national strategies, waste prevention plans, and voluntary commitments. While influential, they rely more on industry cooperation and policy guidance than strict enforcement. Low-intensity policies (2 cases) focus on financial incentives such as VAT reductions, which encourage sustainable behaviors without mandating them.

The timeline of policies shows a clear progression from voluntary and incentive-based approaches to regulatory enforcement. Apart from France's EPR in 2007, there were no legal frameworks pre-2020, with most policies being non-binding strategies and incentives to encourage sustainable practices without strict enforcement. At this stage, governments prioritized awareness-building and financial incentives over-regulation, reflecting an initial, business-friendly approach to sustainability, promoting voluntary participation, and providing a nudge to consumers toward circularity. Incentive-based approaches were common, offering tax reductions and financial support for repairs and donations. For example, Sweden's VAT Reduction on Repairs (2016) lowered the tax rate on repair services. Belgium's VAT

Exemption on Unsold Non-Food Products (2019) encouraged companies to donate rather than discard goods. These policies had low intensity because they relied on voluntary adoption rather than mandates. Some moderate-intensity strategies emerged during this period, such as Luxembourg's Textile Collection and Charity Reuse System (2017) and Czechia's Waste Act (2019), which set national targets for waste reduction but lacked stringent enforcement mechanisms.

Post-2020, the focus shifted toward high-intensity policies related to product design and material sustainability that could prevent waste before it occurs. Governments introduced stronger regulatory measures such as France's Anti-Waste Law (2020), the Netherlands' EPR (2023), and the EU's ESPR (2024). These policies impose mandatory targets, transparency requirements, and producer accountability. Additionally, high-intensity legal frameworks such as the Unfair Commercial Practices Directive (2024) mandate consumer transparency regarding durability and recyclability, signaling a move away from greenwashing and toward enforceable sustainability claims. France took a leading role, introducing the Anti-Waste and Circular Economy Law (2020), which banned the destruction of unsold goods, with financial penalties for non-compliance. Latvia and the Netherlands also established EPR frameworks, making textile producers responsible for waste management. Incentives have more targeted and high impact, such as France's Repair Fund (2022) and Austria's Repair Bonus (2022), which directly subsidized repair costs rather than offering broad tax reductions. Strategies also matured into enforceable national action plans. For instance, Denmark's Action Plan for Circular Economy (2023) introduced municipal obligations for textile sorting, and Finland mandated separate textile waste collection (2023), moving from general waste management to specific, measurable targets. At this stage, countries moved from encouraging circular practices to requiring them, demonstrating policy tightening and a stronger regulatory push for sustainability. This trend suggests a policy tightening over time, where governments first encourage best practices before making them mandatory.

Mapping policies based on product life stage

Based on the policies in Table 1, the European countries target textile waste management across various life cycle stages, mainly focusing on end-of-life and use phases. For instance, strategies like Denmark and Austria's "Action Plan for Circular Economy," Finland's "Textile Waste Separate Collection," and Latvia's National Waste Prevention Program show a recognition that circularity is not just about recycling but extending product lifecycles, promoting reuse, and repairing textiles during their use phase (Milios, 2018). A consistent goal across several initiatives is setting textile recycling targets (Puglia et al., 2024), particularly in the Netherlands and Czechia. These ambitious targets aim for fibre-to-fibre recycling or high percentages of textile waste to be recycled by 2025 and beyond. This reflects growing pressure to create closed-loop systems that reduce reliance on virgin resources. Countries like France, the Netherlands, and Latvia have adopted EPR schemes that require producers to take responsibility for the entire lifecycle of textiles, from production through to disposal and recycling, which implies designing products that are not only long-lasting but also easier to recycle, which may involve a shift in manufacturing processes and supplier relationships.

Incentives like Austria's "Repair Bonus Incentive," Sweden's VAT reduction on repair, Belgium's VAT exemptions on donated goods, and France's Repair Fund demonstrate a common strategy of encouraging the repair and reuse of textiles and also signal a shift towards encouraging a more responsible consumer mindset, where donations and second-hand usage are promoted over the purchase of new products. The rise of environmental labeling is also an apparent move to engage and educate consumers about the environmental impact of products to shift consumer behavior towards more sustainable choices. For instance, the environmental labeling in France's Climate & Resilience Law emphasizes transparency, making the environmental impacts of textiles more visible to consumers, which can influence purchasing behavior.

From Table 1, it is also evident that fewer countries target the beginning of life phases such as design and manufacturing. For instance, the Netherlands' "National Circular Economy Programme" mandates sustainable

materials and recycling at the design stage, reflecting a holistic view of circularity. These policies generally rely on setting mandatory standards for textile production, waste management, and recycling to ensure the industry adheres to specific, enforceable targets. However, the shift toward eco-design regulations suggests a growing recognition of the importance of sustainable materials and product longevity.

Challenges with policy targets and implementation

Standardized definitions and policy alignment: A major challenge in extending textile product lifespan is the lack of standardized definitions for key circularity concepts like durability, repairability, and recyclability. Inconsistent policy enforcement and industry compliance stem from a lack of harmonized understanding across the EU. Textile stakeholders stress the importance of clear distinctions between closed-loop and open-loop recycling, upcycling, and downcycling to ensure policies truly support product longevity, not just waste diversion (Textile Recycling Excellence Project, 2025). Additionally, current eco-design requirements that favor mono-material compositions for recyclability may unintentionally compromise durability and functionality, showing the need for balanced regulations prioritizing recyclability and long-term product use.

Circularity in design and manufacturing: The ESPR is key in shaping sustainable textile design, mandating durability, repairability, and reduced environmental impact. However, policies enforcing recycled content quotas must also consider material longevity to prevent unintended product degradation. Without this balance, efforts to create circular textiles may lead to shorter product lifespans, undermining sustainability goals (Textile Recycling Excellence Project, 2025).

A similar challenge exists within EPR schemes, which often prioritize end-of-life collection over extending product usability. Shared EPR costs among producers further reduce incentives for individual brands to invest in durability. To address this, eco-modulation fees could reward longevity, as seen in France's financial penalties for non-compliance and The Netherlands' ambitious reuse targets. However, for real impact, policies must promote recycling and enforce durability standards to ensure long-lasting, sustainable textiles.

Challenges in infrastructure and textile recycling's role in longevity: A significant barrier to textile longevity is the lack of large-scale repair and reuse infrastructure. Current waste management emphasizes recycling targets without adequately supporting textile reuse and repair. Although bans on textile waste destruction aim to keep materials in circulation, textiles may still become waste without investment in refurbishment and second-hand markets (Charnley et al., 2024). Additionally, the high cost of recycled fibers discourages textile-to-textile recycling, which could extend product life by converting old textiles into high-quality new ones (McKinsey & Company, 2022). Financial incentives for recycled fibers could enhance circularity. National laws like Finland's textile waste collection law and Denmark's circular economy strategies are promising, but their impact relies on broader policies that promote product life extension before recycling.

Repairability, Durability, and Extended Product Lifespan: One of the most direct policy levers for extending textile product lifespan is incentivizing repair and reuse. Current industry practices often prioritize cost efficiency over repair-friendly design, making it difficult for consumers to keep products in use longer (Korsunova et al., 2023). Policies promoting modular design, standardized replacement components, and third-party repair integration could significantly prolong textile usability. Policymakers could also consider subsidies or tax reductions for repairable textile designs, similar to existing initiatives in the electronics sector.

Several high-intensity policies encourage repairability, such as Austria's Repair Bonus Incentive, Sweden's VAT reduction on repairs, and France's Repair Fund. These initiatives demonstrate the effectiveness of financial incentives in encouraging consumer participation. However, their impact could be broadened beyond consumers to industry obligations, ensuring that brands integrate repairability features into product design from the outset.

Despite these initiatives, the voluntary nature of many consumer-driven policies limits their effectiveness. Stronger policy mandates for durability assessments, standardized repairability scoring, and manufacturer accountability could significantly shift industry norms toward longer-lasting products.

Another challenge is the lack of reliable data on product durability and consumer usage patterns, making it difficult to assess and extend product lifetimes (Textile Recycling Excellence Project, 2025). A standardized durability assessment framework could enhance transparency, allowing brands to communicate product longevity metrics and reinforcing consumer trust in sustainable purchasing decisions.

Addressing gaps in standardized definitions, design incentives, infrastructure investment, and repairability mandates is critical to ensuring that policies effectively promote longer-lasting textiles rather than just reducing textile waste. By shifting policy intensity toward durability and reuse, the EU can strengthen textile circularity while ensuring products stay used for as long as possible.

Conclusion and future outlook for the circular textile economy

The overview of policies shows that the European textile sector could be moving from waste management toward sustainable production and circularity, with increasing legal enforcement over time. Countries first introduce voluntary measures and financial incentives before enforcing stricter regulations, particularly in higher-income nations. However, end-of-life waste remains the primary focus, with design-stage interventions still emerging. Future policy developments will likely involve more stringent eco-design requirements, extended producer responsibility, and material transparency mandates to create a genuinely circular textile economy. Regulatory efforts by European countries are trying to ensure that textile products can last longer without compromising their usability and recyclability, and simplifying these frameworks and ensuring transparency will be critical to their long-term success.

Achieving systemic change requires improved policy coherence, investment in infrastructure, and more vigorous enforcement mechanisms. First, this can be done by strengthening enforcement mechanisms for high-intensity policies to ensure uniform compliance across member states. Second, increasing investment in recycling and repair infrastructure ensures that EU policies are supported by the physical and organizational capacity to implement them effectively. Third, consumer incentives and engagement should be enhanced by integrating repair services into mainstream retail practices and aligning policies with circular economy principles. Fourth, providing regulatory stability by establishing precise long-term policy trajectories that allow businesses to plan and innovate confidently

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References

BMUV Germany. (2020). *Die Obhutspflicht im Kreislaufwirtschaftsgesetz*. https://www.bmuv.de/themen/kreislaufwirtschaft/abfallpolitik/uebersicht-kreislaufwirtschaftsgesetz

Department for Environment Food & Rural Affairs. (2023). *The waste prevention programme for England: Maximising Resources, Minimising Waste*. https://www.gov.uk/government/publications/waste-prevention-programme-for-england-maximising-resources-minimising-waste/the-waste-prevention-programme-for-england-maximising-resources-minimising-waste#:~:text=Our%20aim%3A%20to%20support%20our,a%20profitable%20textile%20recycling%20industry.

EEA. (2022). *Textiles and the environment: the role of design in Europe's circular economy*. E. E. Agency. https://www.eea.europa.eu/publications/textiles-and-the-environment-the/textiles-and-the-environment-the

REACH Regulation, (2021). https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en

Federal Ministry Republic of Austria. (2020). *The Austrian Circular Economy Strategy Austria on the path to a sustainable and circular society*. https://www.bmk.gv.at/en/topics/climate-environment/waste-resource-management/ces.html

Government of the Netherlands. (2020). *Policy programme for circular textile 2020-2025*. https://www.government.nl/documents/parliamentary-documents/2020/04/14/policy-programme-for-circular-textile-2020-2025

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221-232.

https://doi.org/https://doi.org/10.1016/j.resconrec.2017.09.005

Lizenzero. (2024). *Textile EPR in Europe: an opportunity for a greener future in fashion*. https://www.lizenzero.eu/en/blog/textile-epr-in-europe-an-opportunity-for-a-greener-future-in-fashion/#:~:text=Introduction%20of%20the%20textile%20EPR%20in%20Latvia&text=The%20amendment%20to%20the%20law,fees%20to%20an%20EPR%20system.

Lüttin, L. (2024a). *France's Climate and Resilience Law for Fashion & Textile Companies*. https://www.carbonfact.com/blog/policy/france-climate-and-resilience-law#:~:text=Labeling%20requirements%3A%20At%20the%20time,impact%20on%20biodiversity%2C%20and%20the

Lüttin, L. (2024b, 05/12/2024). Full overview of the EU textile strategy and regulations. https://www.carbonfact.com/blog/policy/eu-regulations-for-textile-brands

Ministry of Environment of Denmark. (2021). *Action plan for Circular Economy* https://ddrn.dk/wp-content/uploads/2024/01/alle-faktaark-1.pdf

MoSARDR Latvia. (2021). *Minister Plešs: State waste management plan will ensure the development of the sector*. Ministry of Smart Administration and Regional Development Republic of Latvia. https://www.varam.gov.lv/en/article/minister-pless-state-waste-management-plan-will-ensure-development-sector?utm_source=https%3A%2F%2Fwww.google.com%2F

Müncheberg, M. (2024). *New EU rules for sustainable consumer behavior, the repair bonus is already available now*. https://www.sea-help.eu/en/news-general/eu-repair-bonus-replacement/#:~:text=In%20Austria%20is%20already%20further,of%20200%20euros)%20for%20their

Puglia, M., Parker, L., Clube, R. K. M., Demirel, P., & Aurisicchio, M. (2024). The circular policy canvas: Mapping the European Union's policies for a sustainable fashion textiles industry. *Resources, Conservation and Recycling*, *204*, 107459. https://doi.org/https://doi.org/10.1016/j.resconrec.2024.107459

ReFashion. (2021, 05/12/2024). The Repair Fund newest obligations. https://refashion.fr/pro/en/repair-fund-newest-obligations

Roberts, H., Milios, L., Mont, O., & Dalhammar, C. (2023). Product destruction: Exploring unsustainable production-consumption systems and appropriate policy responses. *SUSTAINABLE PRODUCTION AND CONSUMPTION*, *35*, 300-312. https://doi.org/https://doi.org/10.1016/j.spc.2022.11.009

Salmenperä, H. (2023). Governing the Transition to Circularity of Textiles – Finnish Companies' Expectations of Interventions for Change. *Circular Economy and Sustainability*, *3*(4), 1747-1767. https://doi.org/10.1007/s43615-022-00238-x

Sandin, G., & Peters, G. M. (2018). Environmental impact of textile reuse and recycling – A review. *JOURNAL OF CLEANER PRODUCTION*, *184*, 353-365. https://doi.org/10.1016/j.jclepro.2018.02.266

Smejkalová, V., Šomplák, R., & Pluskal, J. (2024). Modelling the impact of legislative interventions on future waste production within territorial division. *Clean Technologies and Environmental Policy*. https://doi.org/10.1007/s10098-024-02903-1

United Nations Environment Programme. (2023). *Sustainability and Circularity in the Textile Value Chain: A Global Roadmap*.

Ville De Luxembourg. (2022). *Clothing and Textile*. https://www.vdl.lu/en/living/your-home/waste-collection-and-sorting/type-waste/clothing-and-textiles

Zero Waste Europe. (2022). *The Finnish law on textile waste separate collection and implementation pilots*. https://zerowasteeurope.eu/library/the-finnish-law-on-textile-waste-separate-collection-and-implementation-pilots/

Appendix

Table 1. Policies promoting extended product lifetime in the EU and individual member states (Abbreviations: Beginning-of-Life (BoL), End-of-Life (EoL), Use Phase (UP))

Name	Country	Description	BoL	UP	EoL	Type	Year	Intensity	Source
Action Plan for Circular Economy	Austria	Transitioning to a circular economy for textiles focuses on extending product life, promoting reuse, and increasing circular material use.	×	✓	✓	Strategy	2021	Moderate	(Federal Ministry Republic of Austria, 2020)
Repair Bonus Incentive	Austria	Refund citizens up to 50% of repair costs (up to €200)	×	✓	×	Incentive	2022	High	(Müncheberg, 2024)
VAT exemption on unsold non-food products	Belgium	VAT Reduction on donated products	×	×	✓	Incentive	2019	Low	(Roberts et al., 2023)
541/2020 Coll. on Waste (Waste Act)	Czechia	Czechia aims to recycle 55% of municipal waste by 2025, 60% by 2030, and 65% by 2035.	×	×	✓	Strategy	2019	Moderate	(Smejkalová et al., 2024)
Action Plan for Circular Economy	Denmark	Encourage textile sorting from waste for reuse or recycling, managed by local municipalities.	×	✓	✓	Strategy	2023	Moderate	(Ministry of Environment of Denmark, 2021)
Finnish Law on Textile Waste Separate Collection	Finland	Collect textiles for reuse and recycle non-reusable waste.	×	×	✓	Strategy	2023	Moderate	(Zero Waste Europe, 2022)
Extended Producer Responsibility (EPR)	France	Minimize textile waste via recycling, reuse, and sustainable materials from producers.	×	×	✓	Legal Framework	2007	High	(Roberts et al., 2023)
Anti-Waste and Circular Economy Law	France	Ban on destroying unsold goods; non-compliance incurs up to 15,000 EUR penalty.	✓	✓	✓	Legal Framework	2020	High	(Roberts et al., 2023)
French Climate & Resilience Law – Environmental Labelling for Products	France	Mandatory environmental labeling for textiles and footwear shows impacts like greenhouse gas emissions and resource use, ensuring consumer transparency.	✓	✓	✓	Legal Framework	2023	High	(Lüttin, 2024a)
Repair Fund	France	Up to 20% discounts on out-of-warranty repairs, financed through EPR fees.	×	✓	✓	Incentive	2022	High	(ReFashion, 2021)
"Duty of Care" under the Circular Economy Act	Germany	Prioritize waste prevention to support circular economy goals.	✓	✓	✓	Strategy	2020	Moderate	(BMUV Germany, 2020)
National Waste Prevention Program	Latvia	Integrate waste prevention for textiles through reuse, repair, and circular strategies, supporting textile and footwear repair.	×	✓	✓	Strategy	2021	Moderate	(MoSARDR Latvia, 2021)
Producer Responsibility Scheme for Textiles and Footwear	Latvia	Enhance textile recycling, promote eco-friendly manufacturing, and develop recycling infrastructure.	×	×	✓	Legal Framework	2023	High	(Lizenzero, 2024)

Name	Country	Description	BoL	UP	EoL	Type	Year	Intensity	Source
Textile Collection and Charity Reuse System	Luxembourg	Collect textiles for charity and enhance reuse.	×	×	✓	Strategy	2017	Moderate	(Ville De Luxembourg, 2022)
VAT Reduction on Repair	Sweden	Reduced VAT (6% in 2022) for minor bicycle, clothing, and shoe repairs.	×	✓	×	Incentive	2016	Low	(Puglia et al., 2024)
EPR	The Netherlands	At least 50% of textiles must be recycled or reused by 2025, reaching 75% by 2030. Fiber-to-fiber recycling must reach 25% by 2025 and 33% by 2030.	×	×	✓	Legal Framework	2023	High	(Government of the Netherlands, 2020)
National Circular Economy Programme	The Netherlands	Use 50% sustainable textiles by 2025 and recycle 100% non-reusable textiles by 2030.	✓	×	✓	Strategy	2023	High	(Government of the Netherlands, 2020)
Textiles 2030: UK Sustainable Textile Action Plan	The United Kingdom	Cut carbon and water footprints in textiles by 50% and 30% by 2030 through circular business models.	✓	×	✓	Incentive	2021	Moderate	(Department for Environment Food & Rural Affairs, 2023)
Circular Fashion Program	The United Kingdom	A £15 million fund aims to enhance circularity in fashion and textiles, emphasizing sorting, recycling, innovation, and research to adopt scalable models by 2032.	×	×	✓	Strategy	2022	Moderate	(Department for Environment Food & Rural Affairs, 2023)
Interdisciplinary Textiles Circularity Centre	The United Kingdom	A £5.4 million initiative to enhance innovation in renewable textile materials, focusing on post-consumer products and household waste feedstock.	✓	×	✓	Strategy	2022	High	(Department for Environment Food & Rural Affairs, 2023)
Eco-design for Sustainable Products Regulation	The EU	Framework for eco-design requirements to enhance product durability, repairability, recyclability, and manage hazardous chemicals.	✓	×	✓	Legal Framework	2024	High	(Lüttin, 2024b)
Waste Framework Directive	The EU	Establishes waste management definitions, requires member states to separately collect textile waste by January 2025, and promotes EPR schemes as an economic tool.	×	✓	✓	Legal Framework	2023	Moderate	(Lüttin, 2024b)
Unfair Commercial Practices Directive	The EU	Empowering consumers by tackling unfair practices and ensuring product transparency in durability, reparability, and recyclability.	✓	✓	✓	Legal Framework	2024	High	(Lüttin, 2024b)
Regulation on the registration, evaluation, authorization, and restriction of chemicals	The EU	Regulating chemical production and disposal protects human health and the environment. Firms producing or importing over 1 tonne of chemicals annually must register with the European Chemicals Agency to ensure safe management.	✓	×	✓	Legal Framework	2021	High	(European Commission, 2021)

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Getting rid of electrical and electronic equipment. Disposal decision and service life in the light of institutional economics

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Keywords: Consumer behavior; Disposal; Service life; Electrical and electronic equipment (EEE); Institutional economics.

Abstract: Within the product life cycle, the user's decision regarding disposal (i.e. getting rid of the product) at the end of the utilization phase plays an important role in terms of the service life of a device of electrical and electronic equipment (EEE). This article first examines from an economic perspective whether and how consumers dispose of EEE. The costs of ownership, the utility of ownership, and disposal costs are identified as the key determinants for this decision. It is the costs of ownership that is the actual cause of the will to dispose, and it is the latter two determinants that prevent the user from disposing of them. While the size of the utility of ownership is already frequently analyzed in the discourse on repair, the perspective of disposal costs seems to receive little attention. Therefore, the article continues to investigate the extent to which the determinant of disposal costs can be put to use for regulation towards a circular economy. To this end, three disposal paths (circular, official-final, illegal), the regulatory objectives associated with them (prevention, safe disposal) and the types of hurdles associated with the respective disposal path (pecuniary, transaction costs, spatial, sanctional) are considered. The result is a complex situation for regulation, not least because of a path of illegal disposal that is not easy to control, which makes it difficult to simply apply economic pricing instruments. Instead, the concept of 'hurdle management' is introduced, which offers a perspective for future regulatory efforts with regard to disposal costs.

Introduction

The sector of electrical and electronic equipment (EEE) faces major circular economy challenges. One key measure is to extend the service life of EEE so that fewer new equipment needs to be produced. Therefore, within the product life cycle, the user's decision regarding disposal (i.e. getting rid of the product) at the end of the utilization phase plays an important role. One reason for this is that this decision directly determines the circularity of the device to a large extent. Another reason is that the conditions of this decision certainly have an influence on the user's earlier decisions in the usage phase. Effectively, the disposal decision has a lot to do with the duration of a product's service life.

This article first examines from an economic perspective whether and how consumers dispose of EEE. It also examines the extent to which the determinant of disposal costs can be put to use for regulation towards a circular economy.

An economic conceptualization of disposal

The starting point for an economic analysis of disposal is the realization that ownership is not free – even if we were given the product as a gift. There are costs of ownership (C_{own}), simply because a physical thing takes up space. There is also the potential cost of tidying up and cleaning around something, as well es costs of care and maintenance. The amount of cost depends very much on the specific device. But it is certain that for physical items these costs are always positive. And this is the ultimate reason for the desire to get rid of something (Lersner 1981, 2).

Applying a rational choice approach, an interest in owning products in the first place lies in the fact that the consumer considers the utility of ownership to be greater than the costs of ownership ($U_{own} > C_{own}$). After a while, the utility of ownership may decline due to various obsolescence reasons (Mellal 2020), so that

* This paper does not necessarily reflect the opinion or the policies of the German Federal Environment Agency.

the ratio reverses ($U_{own} < C_{own}$). There is, in other words, a negative net value for the owner (Birn 1992, 419; Shevchenko/Danko 2023, 234).
However, the decision on disposal depends on one more category: the disposal costs (C_{dis}). This is because at least you have to bring the now unwanted EEE somewhere, which takes some effort. So, not only the ownership but also the disposal is costly to the user.
Against this background, the consumer opts for the disposal if (see also Figure 1):

$$(U_{own} + C_{dis}) < C_{own}$$

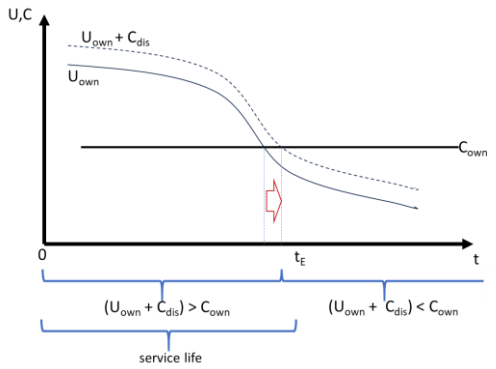


Figure 1. The user's disposal decision based on time dimension.

Consequently, while the cost of ownership (C_{own}) favors disposal, both the utility of ownership (U_{own}) and the disposal costs (C_{dis}) counteract disposal and extend the service life of the respective device. In this context, the discourse on repair and repairability addresses the strengthening of the utility of ownership (e.g. Reimann 2024). On the other hand, from an environmental economics perspective, increasing disposal costs (to the level of the social costs of disposal, see Pigou 1920) is also a useful regulatory starting point for extending service lives of EEE. Furthermore, the perspective is worthwhile insofar as demand on repair markets is weak. This goes as far as the increasingly relevant phenomenon of preferential obsolescence, where the devices still work, the user merely loses interest and consequently repair does not address the problem of a short service life at all (Packard 1960, 58; Kummer et al. 2022, 541). However, the idea of addressing the disposal costs is quite challenging due to the fact that there is more than just one disposal path.

Three competing disposal paths

To keep it simple, three disposal paths can be distinguished, that are available to the user.

1) The *circular* disposal path: The owner might sell the device or just give it away on second-hand markets for another person to use (Frahm et al. 2025). As a result, the service life of the device is extended. Apart from the continued use of the device, this appears the most 'sustainable' option.
2) The *official-final* disposal path: The owner wishes to dispose of the appliance without another use being anticipated and she uses the official channels provided for this purpose. The conditions for this path are laid down in particular in the European WEEE Framework Directive (Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment) and the corresponding national implementing legislation. A key requirement is that EEE should be disposed of separately from normal household waste (recital 14 and article 5 WEEE). This means that old devices can be treated properly during the after-use phase (Nuss et al. 2016, 38; Elmer et al. 2005, 2).
3) The *illegal* disposal path: To be more precise, it is a socially (including environmentally) harmful disposal that is reasonably made illegal by regulation. There are several forms of this category, namely the disposal by landfill, the unseparated disposal in the household waste, and the sale of appliances for dismantling with unfavorable environmental consequences. Which form of waste disposal is suitable depends, among other things, on the size of the device. Small devices fit into a household waste garbage can while large devices do not. In any case, an "improper disposal" (Kummer 2022, 542) on this disposal path is associated with ecological risks, especially in the case of electrical appliances.
From the user's point of view, these three disposal paths are each associated with different disposal costs. In the light of the rational choice assumption, the user will compare the costs C_{dis}^{circ}, C_{dis}^{off}, and, C_{dis}^{ill} and opt for the cheapest path (Bunde/Zimmermann 1988, 182; Birn 1992, 419). And based on the cheapest path the owner will not only decide *how* to dispose of it, but also *whether* to dispose of it. For in the light of the three disposal paths, the more precise version of the aforementioned condition about the 'whether' of disposal is:

$$(U_{own} + Min[C_{dis}^{circ}, C_{dis}^{off}, C_{dis}^{ill}]) < C_{own}\ .$$

To make it clear: The user's decision as to whether or not to dispose of the item is based solely on the disposal path with the lowest

disposal costs. This poses quite the challenge for regulation.

The institutional challenge of three competing disposal paths

The existence of three disposal paths poses a particular challenge for the institutional framework for EEE. Especially without the third, i.e. illegal disposal path, the problem of short useful lives could be solved relatively easily. One could apply the findings of neoclassical environmental economics and demand (higher) disposal fees from the user when handing over the waste on the official-final path (Pigou 1920). In this way, the environmental policy goal of prevention (recital 3 WEEE Directive) could be well addressed. The objective of prevention simply aims at reducing the amount of e-waste (Kloepfer 2001, 42; Lersner 2005, 11), it leads to longer service lives of products, it strengthens the circular strategies of slowing und closing (Shevchenko/Danko 2023, 225), and therefore plays a crucial role for the circular economy (of EEE). With this focus, the disposal costs of official-final disposal could simply be set high enough so that, if disposal takes place at all, the circular disposal path is increasingly chosen. In the area of waste policy and especially in connection with EEE, however, it is not possible to put a stop to the illegal disposal path without further ado. Therefore, regulation in connection with EEE waste is therefore rightly determined by a second objective in addition to prevention: the safe disposal of waste (recital 3 WEEE Directive). With regard to the three disposal paths, the objective of prevention attempts to strengthen non-disposal (further use) and circular disposal over official-final disposal. And the objective of safe disposal in turn attempts to strengthen official-final disposal over illegal disposal.

From an environmental perspective, the official-final disposal path appears ambivalent. While the circular disposal path (or continued use) clearly points in the direction of sustainability and the illegal disposal path is clearly harmful to the environment, this is not so easily possible to judge for official-final disposal. This is because this disposal path is relatively sustainable compared to the illegal one and relatively unsustainable compared to circular disposal or non-disposal. This means that the relationship between the two objectives prevention and safe disposal is also fraught with tension, as measures for controlling the incentives with regard to the official-final disposal path may be contradictory. In particular, while a disposal fee on the official-final disposal path should result in more prevention it can however lead to more illegal disposal and thus have a counterproductive effect with regard to the goal of safe disposal (Bunde/Zimmermann 1988, 182). Figure 2 illustrates this connection between the disposal paths, circular economy objectives and the sustainability perspective.

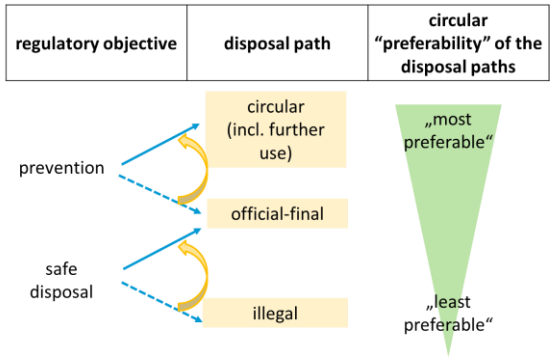


Figure 2. Two objectives and three disposal paths.

What is now advisable from a regulatory perspective in view of this rather complex situation? Regulatory intervention via disposal costs requires what one might call a differentiated 'hurdle management'. In order to approach this, a closer analysis of the disposal costs must be undertaken.

Disposal costs as the sum of various hurdles

An analysis of the disposal costs can be made by understanding them as a sum of various hurdles. The concept of hurdles is helpful, among other things, because it makes it clear that costs that have nothing to do with pecuniary costs play also quite an important a role (Gawel/Bretschneider 2017). With regard to disposal paths, the following types of hurdles may be relevant:

a) Pecuniary hurdle: Is there a pecuniary price (actual money) to pay for getting rid of the device? (Zimmermann et al. 2024, 11) Of all the hurdles considered, this is the only one that can also be negative, namely if you can make a profit from the device in the course of disposing. And that is the reason why: The device to be disposed of can be an economic good from the point of view of the market 'examining' this question, but it can also be waste. To a certain

extent, it oscillates between these two variants, so that waste, especially in the case of EEE, has a 'good-like character' (Bunde/Zimmermann 1988, 177). So, if it really is a good, then the owner can act as a supplier on the market and has the opportunity to generate revenue for it. And the pecuniary hurdle, i.e. the pecuniary costs of disposal, is negative. If, on the other hand, the market does not recognize any value in the appliance, then the owner willing to dispose of it is a demander. He demands the scarce goods of space and assimilation capacities for the appliance. In an ideal neoclassical world, he would then pay a fee for good reasons (ibid., 176). The pecuniary hurdle would then be positive.

b) Hurdle of process and transaction: This refers to the transaction costs, starting with gathering relevant information up to the entire settlement with the counterparty of the transaction.

c) Spatial hurdle: The appliance will have to be spatially moved in the course of disposal. This raises the question of the extent to which the disposer is burdened with the transportation (Best/Kneip 2011).

These hurdles b and c do refer to the dimension of convenience (Dixit/Vaish 2015; Wagner 2013; Yale/Venkatesh 1986) as well as to the dimension of time (Becker 1965).

d) Hurdles of expected sanction in case of illegality: In the case of illegal disposal (only), the expected value of the sanction level and the probability of detection plays a role as a hurdle (Becker 1968). As already indicated, the difficulty here lies in the fact that it is often challenging to control such socially harmful forms of disposal (Kloepfer 2001, 90).

Applying a rational choice perspective, the user will 'calculate' the sum of each disposal path and compare the 'relative prices', with the implications of the 'whether' and the 'how' of disposal mentioned above. Of course, this will vary a lot depending on the specific case. However, the general idea can be illustrated like in Table 1.

Table 1 illustrates once again how challenging a regulatory intervention in favor of useful lives with the help of disposal costs is. Let us assume that a user is considering getting rid of a small electrical appliance. What are the various hurdles on the different disposal paths?

		disposal path		
kind of hurdle		1) circular	2) official-final	3) illegal
a)	pecuniary	a1	a2	a3
b)	process and transaction	b1	b2	b3
c)	spatial	c1	c2	c3
d)	expected sanction	a priori "zero"	a priori "zero"	d3
Sum (overall C_{dis})		C_{dis}^{circ}	C_{dis}^{off}	C_{dis}^{ill}

Table 1. Disposal paths and their respective costs as a sum of respective hurdles.

Starting with the circular disposal path, the pecuniary hurdle may be 'zero' or 'less than zero'. Of course, this depends on the value or resale value of the appliance. What is certain, however, is that the hurdle of process and transaction is significantly positive. This is because it definitely takes time to find a buyer. The internet has greatly reduced the hurdle here, but the hurdle remains positive. In addition, there are the potential challenges of information asymmetry, such as the functional characteristics of the device (Frahm et al. 2025; Zimmermann et al. 2024, 8; Boyer et al. 2021). The spatial hurdle may vary and could also be a matter of negotiation between supply and demand. Overall, there are only no positive disposal costs for this path if revenues overcompensate the transaction costs. In all other cases, the user has positive disposal costs.

Next, we will look at the illegal disposal path, which quickly reveals the dilemma of regulatory control. From the user's perspective, the garbage can for household waste quickly comes into view for small devices. The pecuniary hurdle for such disposal is 'zero', as a regular fee for household waste is incurred anyway. Furthermore, the hurdle of process and transaction is zero, as I don't need a counterpart. In addition, the spatial hurdle is 'virtually zero', as at least you don't have to leave your own property. And finally, the hurdle of a possible sanction in the sense of an expected value is low, insofar as the probability of detection is low. All in all, the disposal costs

for this path are practically zero. This means that this disposal path dominates the circular disposal path in all cases in which the latter does not offer possible proceeds that more than compensate for the transaction costs. And the overall hurdle of 'zero' for the illegal disposal path puts the official-final disposal path under considerable pressure in light of the objective of safe disposal (Elmer et al. 2005, 2).

It is now easy to see that the waste regulation on EEE, in particular through the WEEE Directive, responds to this challenge for the official-final disposal path. For the pecuniary hurdle, the WEEE Directive stipulates that users can hand in their devices "at least free of charge" (recital 14 and article 5 paragraph 2a WEEE Directive; see also Elmer 2005, 1; Florian 2009, 42). This hurdle is therefore 'set to zero' in regulatory terms, whereby the national legislators are also given the option of setting a 'negative hurdle' here. With regard to the process and transaction hurdle, article 14 of the WEEE Directive, for example, stipulates that users must be "given the necessary information about: […] the return and collection systems available to them […]." And in practice, users do indeed feel "well informed" (Kummer 2022, 540f.). Finally, with regard to the spatial hurdle, the WEEE Directive stipulates that "[M]ember States shall ensure the availability and accessibility of the necessary collection facilities, taking into account, in particular, the population density […]" (article 5 paragraph 2a WEEE Directory, see also recital 14) The spatial hurdle is addressed in a plausible way. However, unlike the previous hurdles, the spatial hurdle cannot simply be set to 'zero' in regulatory terms. This is therefore the hurdle that is most likely to lead to positive disposal costs on the official-final disposal path.

This sketchy analysis makes it clear that the illegal disposal path is a challenge, even if regulation is already addressing it. And this is also the challenge for addressing the service lives via the disposal costs. And yet a more detailed analysis of the individual hurdles remains worthwhile in terms of the circular economy.

Conclusions for a circular economy regulation

The situation with the three disposal paths and the respective hurdles is challenging. How can we look at this in terms of the circular economy? First of all, it is helpful to keep a kind of 'ideal solution' in mind. And this 'ideal solution' is that, on the one hand, disposal fees address the avoidance goal and that, on the other hand, increased controls and sanctions make the socially harmful disposal path less attractive (Gawel 1995, 112).

However, the more practice-oriented work tends to consist of the hurdle management mentioned above, see also again Table 1. In conclusion, only a rough orientation with the help of four categories of hurdles is offered here.

- There are hurdles that simply *cannot be subject to regulation* (e.g. in many cases c3). There is simply no sensible regulatory option, let's say, to station the household waste garbage can further away from the house, just to increase the spatial hurdle here.
- There are hurdles that can be (and that are) *determined directly* from a regulatory perspective (a2, b2, c2, so the 'line' of official-final disposal). In this context, reward systems are occasionally discussed with a view to the official-final disposal route (Shevchenko et al. 2019).

In conclusion, however, the two remaining categories of hurdles should be emphasized here in particular, as they are not sufficiently recognized as such in the discourse:

- There are hurdles that depend on the *enforceability of sanctions* against illegal disposal (d3). It is worth finding out in which areas control options could be improved.

Finally, there are hurdles that can – at best, but still – be *influenced indirectly* by taking a closer look at the relevant markets (a1, b1, a3, b3), i.e. the circular second-hand market as well as the illegal market of socially harmful disposal

References

Becker, G. S. (1965). A theory of the allocation of time. *Economic Journal*, *75*(299), 493–517. https://doi.org/10.2307/2228949

Becker, G. S. (1968). Crime and punishment. An economic approach. *Journal of Political Economy*, *76*(2), 169–217.

Best, H., & Kneip, T. (2011). The impact of attitudes and behavioral costs on environmental behavior. A natural experiment on household waste recycling. *Social Science Research*, *40*(3), 917–930. https://doi.org/10.1016/j.ssresearch.2010.12.001

Birn, H. (1992). Rechtliche Instrumente zur Steuerung der Abfall- und Reststoffströme. *Neue Zeitschrift für Verwaltungsrecht*, *1992*(5), 419–425.

Boyer, R. H. W., Hunka, A. D., & Whalen; K. A. (2021). Consumer demand for circular products. Identifying custoimer segments in the circular economy. *Sustainabiliy*, *13*(22), 12348. https://doi. org/10. 3390/su132212348.

Bunde, J., & Zimmermann, H. (1988). Abfall aus ökonomischer Sicht. *Zeitschrift für angewandte Umweltforschung*, *1*, 175–182.

Dixit, S., & Vaish, A. (2015). Perceived barriers, collection models, incentives and consumer pref-erences. An exploratory study for effective implementation of reverse logistics. *International Journal of Logistics Systems and Management*, *21*(3), 304–318. https://doi.org/10.1504/IJLSM.2015.069729

Elmer, C.-F., Schatz, M., & Hirschhausen, Chr. von (2005). Effizienzanalyse der europäischen Elekt-roaltgeräte-Richtlinie (WEEE) sowie ihrer nationalen Umsetzungsmöglichkeiten, *Public Sector Management and Regulation Working Papers*, *WP-PSM-07*.

Florian, V.-V. (2009). *Herstellerverantwortung für Elektro-Schrott. Rechtsprobleme der Herstellerver-antwortung unter besonderer Berücksichtigung des Elektro- und Elektronikgerätegesetzes sowie der Richtlinie 2002/96/EG über Elektro- und Elektronikaltgeräte*, Verlag Dr. Kovač.

Frahm, L. B., Boks, C. & Laursen, L. N. (2025). It's Intertwined! Barriers and Motivations for Second-hand Product Consumption. *Circular Economy and Sustainability*, *5*, 653–674. https://doi.org/10.1007/s43615-024-00441-y

Gawel, E. (1995). *Ökologisch orientierte Entsorgungsgebühren. Ökonomische Analyse von Abfall- und Abwassergebühren als Mittel kommunaler Umweltpolitik*, Erich Schmidt Verlag.

Gawel, E., & Bretschneider, W. (2017). Specification of a human right to water. A sustainability assessment of access hurdles. *Water International*, *42*(5), 505–526.

Kloepfer, M. (2001). *Produktverantwortung für Elektroaltgeräte. Rechtsprobleme der Entsorgung von Altprodukten unter besonderer Berücksichtigung des Entwurfs einer Elektroaltgeräte-Verordnung*, Duncker und Humblodt.

Kummer, S., Löhle, St., & Schmiedel, U. (2022). Consumer survey on the final consumer behavior concerning the disposal of WEEE in Germany. *Waste Management & Research* , *40*(5), 538–544. DOI: 10.1177/0734242X211025198

Lersner, H. von (1981). Abfall als Wirtschaftsgut. *Natur und Recht*, *3*, 1–5.

Lersner, H. von (2005). § 24 Rücknahme- und Rückgabepflichten. In: Idem, Wendenburg, H., & Versteyl, L.-A. (eds.). *Recht der Abfallbeseitigung des Bundes, der Länder und der Europäischen Union. Kommentierungen der Abfallrahmen-richtlinie, des KrWG und weiterer abfallrechtlicher Gesetze und Verordnungen*. Vol. 6, Erich Schmidt Verlag, Kz. 0124.

Mellal, M. A. (2020). Obsolescence – a review of the literature. *Technology in Society*, *63*, 101347, https://doi.org/10.1016/j.techsoc.2020.101347

Nuss, Chr., Stindt, D., Sahamie, R., & Tuma, A. (2016). Eine quantitative Analyse europäischer Richtlinien und Verordnungen zur Abfall- und Kreislaufwirtschaft am Beispiel der Elektro- und Elektronikindustrie. Implikationen und Empfehlungen für eine transnationale Umweltpolitik. *Zeitschrift für Umweltpolitik & Umweltrecht*, *1/2016*, 37–69.

Packard, V. (1960). *The Waste Makers* (4. pr.). McKay Comp.

Pigou, A. C. (1920). *The Economics of Welfare*. Macmillan.

Reimann, M. (2024). The impact of a repair subsidy on repair prices, demand and repair company profitability. *Journal of Cleaner Production*, *469*, https://doi.org/10.1016/j.jclepro.2024.143102

Shevchenko, T., & Danko, Y. (2023). Consumer behaviors in the circular economy with special fo-cus on e-products. Chapter 12. In: B. Debnath, Das, A., Chowdary, P.A., & Bhattacharyya, S. (eds.). *Development in E-waste Management*, Taylor & Francis, 223–242. https://doi.org/10.1201/9781003301899

Shevchenko, T., Laitala, K., & Danko, Y. (2019). Understanding consumer e-waste recycling beha-vior. Introducing a new economic incentive to increase collection rates, *Sustainability*, *11*(9), 2656; https://doi.org/10.3390/su11092656

Wagner, T. P. (2013). Examining the concept of convenient collection: An application to extended producer responsibility and product stewardship frameworks, *Waste Management*, *33*(3), 499–507. https://doi.org/10.1016/j.wasman.2012.06.015

Yale, L., & Venkatesh, A. (1986). Toward the construct of convenience in consumer research. *Advances in Consumer Research*, *13*, 403–408.

Zimmermann, R., Inês, A., Dalmarco, D., & Moreira, A. C. (2024). The role of consumers in the adop-tion of R-strategies: A review and research agenda, *Cleaner and Responsible Consumption*, *13*, 100193, ttps://doi.org/10.1016/j.clrc.2024.100193

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National leadership for legislating longer product lifetimes: French policies and their interaction with European Union policies

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Abstract: Currently, the European Union (EU) is the "green leader", globally, in adopting policies to support longer product lifetimes. One reason for this state of affairs is that EU Member States are adopting progressive policies, which put pressure on the EU to set EU-wide laws to replace national ones. The main reason for this situation is that national rules may lead to distortions in trade in the EU Single Market, as corporations will find it difficult to be able to comply with different national rules and would prefer EU-wide standards. Currently, France is the undisputed leader in adopting policies for longer lifetimes, through policies including criminalization of planned obsolescence, modulated fees, repair policies, banning destruction of unsold products, and national indexes for repairability and durability of products. When the EU adopts similar policies, this can have several positive implications, but there can also be negative effects, for instance that the EU rules are less progressive than the national ones. The aim of this paper is to discuss the key benefits and drawbacks with EU harmonization of national rules, using France as an example. This paper maps the key French policies supporting longer product lifetimes and the upcoming EU rules aiming for EU-wide harmonization. Finally, we describe one policy where EU rules are likely to be less progressive than the French ones, mandatory repair information to consumers, to exemplify key trade-offs with harmonization.

Introduction

The European Union (EU) is currently the green leader globally (Bradford, 2020). This applies also to circular economy (CE) policies (Bocken et al., 2025), and product rules that support CE objectives (Dalhammar and Maitre-Ekern, 2024). The EU has adopted laws that aim to support longer product lifetimes *directly* through product design requirements for many product groups, as well as *indirectly*, by supporting product repairs through mandating provision of spare parts, manuals, and software updates in ecodesign requirements and a directive that strengthens consumers' right-to-repair.

There are two key reasons why the EU has adopted the most progressive policies: 1) the EU's own ambitious sustainability objectives, where longer product lifetimes are a way to support circular economy; 2) EU Member States have adopted several progressive policies related to products, which provide incentives for the EU to adopt similar ones. When national policies are adopted, this can cause fragmentation on the EU Single Market, as corporations may need to adjust products, and their packaging and labelling, depending on which country products are sold in, which is costly. This contrasts with the idea of a Single Market, where goods can trade freely, and corporations therefore argue that product related rules should be set at the EU level (Dalhammar, 2023). Thus, EU-wide standards replacing national standards reduce the costs of doing business. This also means that progressive EU Member States act as "green policy innovators", and national policies have often been very important "triggers" for EU rules in the past (Onida, 2005; Dalhammar, 2023).

In the context of product lifetimes, several EU Member States have adopted policies that – in various ways – support produce longevity, cf. Table 1. Currently, France is the clear "front-runner", in terms of adopting new, progressive policies related to issues like product lifetimes and repairability, and packaging, as have been noticed both by researchers (Dalhammar and Maitre-Ekern 2024) and mainstream media (Gros, 2024; Monbiot, 2023).

Policy	Where Implemented
Consumer information for repairability	France has a mandatory repair index for several product groups. Belgium voted for one last year. Several other EU countries preparing similar indexes..
Consumer info for durability	French repair index becomes durability index (2025).
Criminalization of planned obsolescence	France has criminalized planned obsolescence and also legally defined it.
Repair fund	France has introduced a repair fund, where producers will have to pay some of the costs for repairing broken products not covered by the legal guarantee.
Product labelling and information	France mandates producers of various product groups – e.g. electrical and electronic products, packaging, and textiles – label their products for several criteria, e.g. repairability, sustainability, recycled materials, micro plastics etc.
Eco-modulation	France has differentiated fees in EPR systems depending on properties that increase lifetime, repairability and recyclability.
Longer mandatory consumer guarantees	Several European countries have changed legal consumer guarantee periods ; e.g., Sweden introduced a 3 year guarantee period for most goods.
Lower taxes for repairers	Some countries have provided tax relief or lowered value added tax (VAT) for repairs / repair services
Measures addressing destruction of unsold/returned goods	Measures include a partial ban on some product destruction (France), reporting obligations (Germany), and reduced VAT on donated goods (Belgium).
Repair vouchers	Some Austrian cities issue repair vouchers subsidizing consumer repairs at local repairers. Austria now has a national voucher scheme for electronic devices.
Supporting infrastructure for re-use	Many cities in Europe are promoting re-use, e.g. by providing infrastructure at recycling stations to divert products from recycling.

Table 1. EU Member States policies to support longer lifetimes and repairs.

It should be noted that there are additional national policies to those mentioned in the table. For instance, Belgium has introduced a repair index that will enter into force in 2026 (Heens et al., 2024). For a review of different national and regional economic support schemes for repairs see Etzinger and Reimann (2023).

Several national policies, and especially the French mandatory Repair Index, have raised concerns among European industries (Dalhammar, 2023), but also among French industries, about the need to comply with both EU rules and national rules (Gros, 2024). EU-wide rules would thus support the functioning of the Single Market. Further, companies outside the EU often comply with EU laws to be able to export their products to the EU, and policymakers outside the EU often adopt policies like the EU ones (Bradford, 2020). Thus, there are several benefits associated with EU harmonization of national policies. But harmonization can also have downsides. EU product rules pre-empt national ones, and thus the existence of EU rules may stop progressive national policies. Furthermore, when EU rules are adopted, they may be less ambitious than national rules and thus constitute a partial "deregulation". Currently, there are concerns among actors in France that this will be the case when EU laws replace national rules.

Objective and outline

The aim of this research was to outline national policies that are often at the forefront of policy developments related to longer product lifetimes, analyse how EU have started to harmonize national practices, and explore how EU legal harmonization may lead to less ambitious policies.. In this paper, we show the results and discuss the key benefits and drawbacks with EU harmonization of national rules, using France as an example.

The next section accounts for the key French rules related to product lifetimes and repairability. We then look at the EU upcoming rules for smartphones and compare them with criteria applied in the French Repair Index, to show that setting EU-wide rules may lead to deregulation in some cases. We then shortly discuss expected future developments related to harmonization in the EU. We end the paper with conclusions and recommendations.

French policies for longer lifetimes

In recent years, France has been a front-runner in adopting policies for longer lifetimes. This has been the result of mobilisation of committed stakeholders (e.g. HOP - Halte à l'obsolescence programmée) that have made ambitious policies more politically feasible.

Ban of planned obsolescence

France is the first country in the world to make planned obsolescence an illegal offence. The first law targeting planned obsolescence was enacted in 2015 with the Energy Transition Act , making it punishable under the French Consumer Code. Planned obsolescence is legally defined by the law as "a set of techniques, including software, used by a product manufacturer to deliberately reduce the product's lifespan". Despite the recognition of this offence, no one has yet to be convicted.

The AGEC Act

The AGEC Act, known in French as "antigaspillage pour une économie circulaire", (Anti-Waste Law for a Circular Economy) is the most significant and innovative legislation on product sustainability. Introduced in 2020, the AGEC Act consists of 130 articles designed to accelerate the transition to a circular economy. It focusses on five key areas: eliminating disposable plastics; improving consumer information about environmental impact of products, reducing waste while promoting solidarity-based (as opposed to market-based) reuse, addressing planned obsolescence, and encouraging more sustainable production (see French Republic, 2020).

The reparability / durability index

The law has introduced a repairability index (see French Republic, 2020, Art. 16) for nine categories of products: washing machines (both front and top-loading), smartphones, laptops, televisions, electric lawnmowers, dishwashers, vacuum cleaners, and high-pressure cleaners.

The index evaluates the repairability of a product, scoring it out of 10. Its dual purpose is to restore the balance of information between consumers and manufacturers by offering greater transparency on product design and repairability, and to incentivize manufacturers to improve their scores, aiming to outperform competitors and use it as a selling argument. As such, the index does not replace eco-design regulations but encourages better practices through provision of information to consumers that in turn gives producers incentives to improve the repairability of products.

The repairability index for each product model is calculated based on criteria: documentation, ease of disassembly, availability of spare parts, and the price of spare parts. Manufacturers are responsible for calculating the index and must communicate it to retailers. It is mandatory for retailers, including online sellers, to display the index. The public authorities, the DGCCRF (Department of Competition, Consumer Affairs and Fraud Control), are tasked with ensuring that the index is displayed correctly and that the scores are accurate. The DGCCRF's 2024 activity report shows that more than 50% of the establishments inspected failed to meet their obligations in terms of displaying the repairability index: failure to display it, lack of precision in its calculation, etc. Inspections should therefore be more frequent to ensure compliance with the law (DGCCRF. 2024).

Recently durability indexes have appeared for televisions (since January 2025) and washing machines (since April 2025), replacing the repairability index (French Republic, 2020, Art. 16, II). The durability index for each product model is calculated based on two categories of criteria. In addition to assessing a product's repairability, this index also includes factors related to its reliability, such as resistance to falls and wear, ease of care and maintenance and the existence of a commercial warranty. A positive aspect of the durability index is the requirement for manufacturers to make their calculation grids for repairability indices publicly available. This transparency enhances the ability to verify the accuracy of the ratings, allowing not only authorities but also consumer associations and other stakeholders to hold manufacturers accountable.

Repair bonus

Part of the contributions collected by producer responsibility schemes ('eco-organizations') finances a repair fund, which reimburses part of the cost of repairing a good by a labelled repairer. The fund covers five categories of products: electronics and electrical appliances (Ministry of Ecological Transition, 2021a), clothing (Ministry of Ecological Transition, 2022a), DIY and gardening (Ministry of

Ecological Transition, 2021b), sports and leisure (Ministry of Ecological Transition, 2021c), and furnishings (Ministry of Ecological Transition, 2022b). The repair bonus assistance can vary from a few euros to 60 euros, and including all the sectors and their budgets up to 2028, the total amount is around 800,000, 000 euros.

Consumers do not need to complete any formalities; they simply visit a certified repairer, and the bonus is directly deducted from their bill. This is a key incentive for repair, especially given that 68% of French people do not repair their products due to cost concerns (Harris Interactive, 2020). For consumers to be motivated to repair a product instead of purchasing a new one, the cost of repair must not exceed 33% of the price of a new product (ADEME, 2021).

However, the impact on both consumers and repairers remains limited. There is a significant need for nationwide communication and a greater incentive scheme to get repairers on board, as well as harmonization in the communication and management of the fund to ensure that the bonus is a real incentive. For the moment, only 30% of the total bonus envelope has been used up, and according to a HOP study in January 2024, only 78% of surveyed repairers without the label wanted to join the scheme (Micheaux et al., 2024, p.6).

We can expect the bonus to be implemented in countries other than France, since the EU's Right to Repair Directive encourages member states to introduce various incentives, such as a repair bonus or circular VAT. As shown in table 1, some EU Member States have adopted other schemes to support repairs economically (see also Etzinger and Reimann, 2023).

Eco-modulation

A bonus system has been established for manufactured products based on the "polluter pays" principle to improve ecodesign of products. It came into force in France for electrical and electronic devices from 1st January 2025 (Ecosystem, 2024). This eco-modulation system consists of reducing the eco-contributions paid by manufacturers (which are often passed on in the final price) to reward products with the best repairability indexes within their categories. These eco-modulations are a natural extension of the repair index initiative, aiming to encourage manufacturers to prioritize product design and improve eco-design practices. In theory, it makes it possible to identify a product's repairability and durability through price. Yet, only the bonus system has been adopted so far and no penalties are in place (i.e. malus), limiting its impact.

Structural Changes Needed

Several structural adjustments also need to be made if the AGEC Act is to be properly implemented and achieve its ambitious objectives. Certain laws are not respected, and the penalties that go with breaking these laws are not applied. Numerous practices of planned obsolescence and obstacles to repair, such as serialization or software obsolescence, can be observed, even though these practices are illegal under the AGEC law. In the report from the Information Mission on the AGEC Law, serialization and irreparability practices in the EEE and automotive sectors are highlighted; however, no recommendations are made in this respect (Information Mission, 2024, p. 59)

Furthermore, the governance of EPR schemes remains unsatisfactory, since manufacturers are both "judges" and parties through the producer eco-organizations. The governance of eco-organisations is in fact the responsibility of manufacturers. We therefore recommend that the public authorities be put back at the heart of decision-making, to steer the schemes towards objectives of general interest, rather than the economic objectives of those who place products on the market. For example, according to report published by several French inspection authorities (Inspection générale des finances et al., 2024) it would be preferable to entrust ADEME (French Environment and Energy Management Agency) with the implementation of reuse and repair funds instead of the eco-organizations, as their governance conflicts with these missions. This is an observation also shared by the rapporteurs of the report evaluating the AGEC Act (Information Mission, 2024).

Will EU policies be less ambitious? The example of the Repair Index

The introduction of a Europe-wide repairability index is a very positive step to inform over 450 million people in the 27 EU member states about product durability. However, the devil is in the details: the provisions proposed at the European level risk undermining the progress

made in France, as the measures are significantly less ambitious.

In October 2023, the European Commission issued an unfavourable opinion on France's planned durability index for smartphones, considering it contrary to EU law (Breton, 2023). The Commission argued that a European repairability index would soon be incorporated into the energy label for smartphones (albeit with different criteria).

Certain important criteria not included in French index, are considered in the European index; e.g., if parts are serialized and an additional five steps in the disassembly score. It also accounts for the duration of software maintenance after a product's launch, with an eco-design regulation stipulating a minimum of five years of software support from the date of market release. However, overall and for most criteria, the European index is considerably less ambitious than the French one. The French durability index includes twenty-two durability criteria, whereas the European index only includes five. An example of the currently proposed EU label and the French label can be seen in Figures 1 and 2.

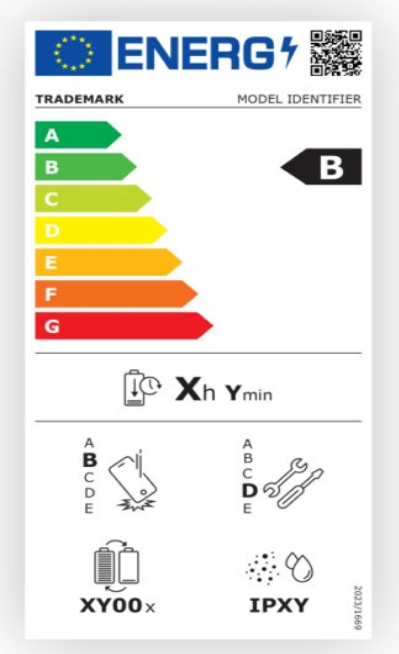


Figure 1 The proposed EU label
Source: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12798-Energy-labelling-of-mobile-phones-and-tablets-informing-consumers-about-environmental-impact_en

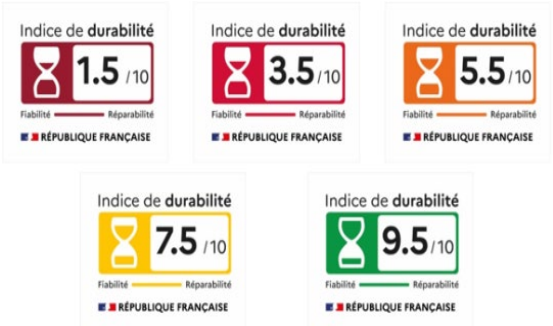


Figure 2. French Repairability Index
Source: https://www.ecologie.gouv.fr/politiques-publiques/indice-durabilite

Three main issues limit the effectiveness of the European label criteria. First, there is no pricing criterion, even though the law requires spare parts to be available at a reasonable price, without defining what constitutes "reasonable." Secondly, while an index is intended to highlight those products and producers who do better than minimum ecodesign standards, the European index still gives points and rewards manufacturers who merely comply with minimum ecodesign requirements. Finally, the label's readability is a significant issue. The index will be displayed alongside other information without an overall score, making it hard for consumers to quickly compare products. This dispersal of information could prevent consumers from easily identifying which products are genuinely more durable and repairable.

There are additional, albeit secondary, issues where the European labelling is less effective than the French index. For instance, it highlights energy consumption - a criterion that is of negligible importance for smartphones. Furthermore, the transparency of score details is limited, with insufficient granularity in the transmitted scores.

EU harmonization: current and (expected) future developments

The EU's ecodesign regulation for smartphones and tablets which comes into force in June 2025 (see Table 2) includes innovative minimum requirements, e.g. the requirement for parts and software to be available for several years, a minimum delivery time for parts, as well as obligations to be able to dismantle certain parts easily, or to use reusable fasteners. Some similar requirements have also been introduced for other product groups, including white goods.

Examples of mandatory Ecodesign provisions	Examples of mandatory labelling provisions
●Specified spare parts available 7 years after product placed on market ●Spare parts available for professional repairers ●Ease-of-disassembly obligations ●Operation system upgrades available for at least 5 years after last placement on market ●Repair and maintenance information available to professional repairers. ●Maximum delivery times for spare parts. ●Information obligations for price of spare parts. ●Provisions on 'resistance to drops', 'scratch resistance', 'protection from dust and water', 'battery endurance' ●Rules on software that enables reuse / repairs, / combats 'serialization'	●Rating of 'free fall reliability' ("drop test") ●Rating in repairability classes (aggregate scoring based on 'disassembly depth', 'fastener type', 'tools', 'spare parts', 'software updates', and 'repair information') ●Rating of battery endurance per cycle ●Ingress protection rating

Table 2. EU Ecodesign and labelling requirements for mobile phones and tablets.

The mandatory labelling requirements (see table 2) is the first example of EU labelling that harmonizes labelling practices (the EU Energy Labelling Regulation is the basis). It provides a 'blueprint' for expected similar EU labelling requirements for additional product groups, which may include a wide range including white goods, electronics, and furniture. As these EU rules are adopted, the legal scope for national measures will decrease.

Conclusions

The benefit of EU rules is that they apply in all EU member states, and in that way, the French rules may be seen as a success as they paved the way for EU-wide rules. However, if the EU rules that replace national rules do not reflect the ambition and scope of national rules, EU member states have to accept that some rules are "watered down". The alternative is to keep pushing for more stringent rules, both domestically and at the EU level.

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References

ADEME. (2021). *Fonds réparation de la filière équipements électriques et électroniques : Étude préalable*. https://librairie.ademe.fr/dechets-economie-circulaire/4744-fonds-reparation-de-la-filiere-equipements-electriques-et-electroniques.html

Assemblée Nationale. (2024, May 29). *Information report on the evaluation of the impact of Law No. 2020-105 of February 10, 2020, relating to the fight against waste and the circular economy (No. 2696).* Retrieved from https://www.assemblee-nationale.fr/dyn/16/rapports/cion-dvp/l16b2696_rapport-information.pdf

Bocken, N., Coffay, M., & Dalhammar, C. (2025). The Brussels and California Effects? Circular Economy Policy Influence Across Borders. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-025-00516-4

Bradford, A., & Bradford, A. (2020). *The Brussels Effect: How the European Union Rules the World.* Oxford University Press. https://doi.org/10.1093/oso/9780190088583.001.0001

Breton, T. (2023, October 27). *Detailed opinion on France's draft decree establishing a durability index for smartphones. European Commission.* Retrieved from https://www.documentcloud.org/documents/24164232-avis-circonstancie-thierry-breton-france

Dalhammar, C. (2023). Making sustainable products the norm on the Internal Market: an assessment of the proposal for a new Ecodesign Regulation. *Europarättslig Tidskrift Vol 1,* 2023.

Dalhammar, C. & Maitre-Ekern, E. (2024). How Can We Persuade Consumers to Purchase More Sustainable Products? A Review of European Legal Developments. In Santos Silva, A. et al. (eds.). *Routledge Handbook of Private Law and Sustainability*. Routledge. https://doi.org/10.4324/9781032662046-29

DGCCRF. (2024). *Bilan d'activité 2024 de la DGCCRF* [Report]. Ministère de l'Économie, des Finances et de la Souveraineté industrielle et numérique. https://www.economie.gouv.fr/files/files/directions_services/dgccrf/media-

document/Bilan-activite-2024-DGCCRF.pdf?v=1741945768

Ecosystem. (2024). *Modulation de l'éco-participation : primes et pénalités pour encourager l'éco-conception.* Retrieved from https://pro.ecosystem.eco/service/eco-conception/eco-modulation

Etzinger, I., & Reimann, M. (2023). Analyzing different design possibilities for a repair funding program: A conceptual framework. *30th EurOMA Conference*, Leuven, Belgium.

Information Mission (2024). *Rapport d'information sur l'évaluation de l'impact de la loi n° 2020-105 du 10 février 2020 relative à la lutte contre le gaspillage et à l'économie circulaire* (No. 2696). Retrieved from https://www.assemblee-nationale.fr/dyn/16/rapports/cion-dvp/l16b2696_rapport-information

Inspection générale des finances, Inspection générale de l'environnement et du développement durable, & Conseil général de l'économie. (2024). *Performances et gouvernance des filières à responsabilité élargie du producteur*. Retrieved from https://www.igedd.developpement-durable.gouv.fr/performances-et-gouvernance-des-filieres-a-a4040.html?

French Republic. (2020, February 10). *Law No. 2020-105 of February 10, 2020, on combating waste and promoting the circular economy.* Official Journal of the French Republic. Retrieved from https://www.legifrance.gouv.fr/jorf/article_jo/JORFARTI000041553781

French Republic. (2021, November 17). *Article L441-2 of the Consumer Code.* Official Journal of the French Republic. Retrieved from https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000044330817

Gros, M. (2024). France and the EU both want green economies — but are clashing over how. *Politico* Online: https://www.politico.eu/article/france-ambition-threat-eu-green-circular-economy-plan/

Harris Interactive. (2020). Les Français et la réparation : Perceptions et pratiques – Édition 2019. Retrieved from https://harris-interactive.fr/wp-content/uploads/sites/6/2020/06/synthese-francais-reparation-perception-pratique-2020.pdf

Heens, R., Opsomer, T. and Vonderscher, F. (2024). The Belgian repairability index includes the price of spare parts: will the EU level up with this ambition? https://repair.eu/news/the-belgian-repairability-index-includes-the-price-of-spare-parts-will-the-eu-level-up-with-this-ambition/

Micheaux, H., Beulque, R., Vonderscher, F., & Vasseur, L. (2024). *Repair bonus: Feedback from consumers and repairers on the repair fund for electrical and electronic equipment (EEE)*. Halte à l'Obsolescence Programmée. Retrieved from https://www.halteobsolescence.org/publication/repair-bonus-report/

Ministry of Ecological Transition. (2021a, October 27). Order establishing the specifications for eco-organizations, individual systems, and coordinating bodies in the extended producer responsibility sector for electrical and electronic equipment. Official Journal of the French Republic. Retrieved from https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000044273082

Ministry of Ecological Transition. (2021b, October 27). Order establishing the specifications for eco-organizations and individual systems in the extended producer responsibility sector for DIY and gardening products. Official Journal of the French Republic. Retrieved from https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000044273022

Ministry of Ecological Transition. (2021c, October 27). Order establishing the specifications for eco-organizations and individual systems in the extended producer responsibility sector for sports and leisure goods. Official Journal of the French Republic. Retrieved from https://www.legifrance.gouv.fr/loda/id/JORFTEXT000044273042

Ministry of Ecological Transition. (2022a, November 23). Order establishing the specifications for eco-organizations and individual systems in the extended producer responsibility sector for textiles, footwear, and household linen. Official Journal of the French Republic. Retrieved from https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000046600083

Ministry of Ecological Transition. (2022b, October 14). Order amending the specifications for eco-organizations in the extended producer responsibility sector for furniture elements. *Official Journal of the French Republic*. Retrieved from https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000046488845

Monbiot, G. (2023). When it comes to rich countries taking the environment seriously, I say: vive la France. *The Guardian* Online: https://www.theguardian.com/commentisfree/2023/jun/24/environment-france-emmanuel-macron-crisis-uk

Onida, M. (2004). Environmental protection by product policy: Focus on dangerous substances. *ELNI Review No 2/2004*

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Gendered threads: Policy barriers to sustainable textile lifecycles

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Keywords: Fashion; Textiles; Australia and Queensland; Gender; Policy.

Abstract: This research into global and Australian policy in textile circularity focusses on Queensland as a case study. Queensland is still lacking a comprehensive roadmap to textile circularity and does not have a strategy for used clothing collection. These activities are left to charities, which benefit from tax breaks, and industry, which is heavily subsidized with public money, ignoring the reality of an industry that is made of micro and small businesses and is predominantly female. Policies that are not scrutinized through a gender lens could continue to create gender disparities, inequalities and systemic barriers, leaving behind women who want to enter the formal repair economy.

Introduction

The textile sector is vital to any economy, creating jobs, driving prosperity, and influencing cultural values (Textile Exchange, 2023). However, each phase of the textile value chain faces significant environmental challenges, highlighting the need for more sustainable practices in the fashion industry. Over 100 billion garments are produced each year, with 92 million tonnes ending up in landfill (Earth.Org, 2023). Polyester remains the most produced fibre globally, accounting for 57% of total fibre production, with 500,000 tonnes of plastic microfibres annually contaminating oceans and threatening the food chain (Ellen MacArthur Foundation, 2017). Statistics indicate that the global textile market is expected to reach nearly $3 trillion by 2030, growing at an annual rate of 5.8% (Leal Filho et al., 2024).

To address these issues, systemic approaches to circularity, including sustainable design, extended use, repair and textile recycling offer solutions to the environmental and social challenges of the fashion industry. Governments and organizations like the European Union and the United Nations have introduced various policies and frameworks at global and national level (European Commission, 2022). The focus of those policies is on resource management through closing resource loops at scale. New industrial and chemical plants that sort, disassemble, shred or chemically transform old textile making it into new textile or feedstock for other uses and products have been established. These activities are often supported by significant investment, which have led to the establishment of a new “waste management paradigm” (Hannon and Zaman, 2018).

Despite all policies that have been surveyed in this study, including making textiles more durable, repairable and recyclable, or applying eco-design and extended producer responsibility (EPRS) for all fashion brands, they still neglect the potential of slowing the material and energy loop. This involves minimizing the flow of material into the amount of material entering the economy by focusing on practices such as refuse, reuse, repair and remake to ensure that materials retain their value for as long as possible (Bocken et al., 2022).

This paper takes the case of Queensland, Australia, to address gaps and barriers in current policy initiatives that privilege textile recycling under the broad strategy of resource management. The aim of this study is to gain insights into policies that promote the extension of textile life (ETL) through repair and upcycling in selected regions and countries that explicitly support a circular textile sector through the promotion of higher-order R strategies. The absence of gender perspectives on the CE of fashion and textiles has been acknowledged (Palm et al 2024), making a study on policies that promote gender equality an even more crucial area for future research.

Queensland does not have a road map to support the fashion and textile sector. Within the Queensland Resource Recovery Industry Development Program (RRIDP), innovative projects that include textile recycling are funded, however, small businesses must compete against large industrial entities. National initiatives like Seamless (Australian Fashion Council, 2023) claim to support ETL and reuse strategies, but most funding focuses on lower-order practices like recycling. Queensland's policies and other state strategies still lack system-wide approaches to prolong textile life.

This analysis leads us to the heart of the argument: is policymaking gendered? A focus on recycling over ETL favours a singular narrative and voice, which remains confined to processed materials that are destroyed to yield lower value. The process of circularity is, in fact, creative rather than destructive. The recycling process, its industrial scale and attendant policies, while part of the mix in dealing with waste, flows in one direction. That system focusses on engineering, chemistry, materials and environmental science treating clothing as waste transforming it into a new resource. In this sense, the recycling system maintains the current flow of resources in a single direction and makes no change to the current system. On the other hand, the generally small-scale approach to taking fashion production and extending the life of the current product into new product via creativity is an important strategy that creates new engagement with how we wear and use clothes. This reset of the engagement with clothes critically alters the fashion system, while the recycling process relies on passive consumption and the maintenance of the waste flow-through process. Policy and funding must reflect the important contribution of ETL.

Method

An exploratory, qualitative comparative policy analysis was conducted on international and Australian policies, with a focus on Queensland. The analysis involved desktop research to identify relevant policies published by the government and reputed organisational websites in the English language. Using key phrases and synonyms such as "Policy on Textile Sector in [region/country/state]" or "[Country/State] policy/strategies/actions for Textile Waste", only officially released proposals by government agencies or respected bodies that are pertinent to the subject were included. Twenty-seven documents were found that capture the most advanced policies in extending the life of textile products. This sample provides a benchmark for the pressing need to advance policies in Australia.

Findings were cross-referenced with official reputable publications and reports to ensure accuracy and reduce bias. An Excel database was created to extensively map and record key information such as the policy name, state/country/region, publication date, objectives and sources. Given the emphasis of the study on ETL, the analysis categorised policies by region detailing their aims, promotion of textile lifespan extension, and recommendations for a circular textile sector. A summary was created for a fast visualisation of the state of play (See Table 1 in the appendix).

Extending the Life of Products

The circular economy (CE) offers a sustainable solution to the environmental and social challenges of the textile industry by transforming linear processes into closed-loop systems, where fibres, materials, and products retain their value throughout their lifecycle and avoid landfills (Ellen MacArthur Foundation, n.d.-a). Circular textile business models emphasize longevity and durability by extending garment lifetimes through repairable designs, customized production, and repair/maintenance services. However, despite the identification of these areas as fundamental to closing the loop, policies have predominantly targeted the outer loop (recycling) than the inner loop (repair, upcycle, reuse) (Puglia et al. 2024). Policies in the outer loop are more mature, and thus attract more attention (Puglia et al., 2024).

In the CE, resource management strategies, also known as R ladder (Bassens et al., 2020, p.9), prioritizes "refuse, rethink, and reduce", followed by practices such as "reuse, repair, refurbishment, remanufacturing, and repurposing" to extend product lifespan, with recycling and recovery applied as last-resort measures for non-reusable materials. Research on the R ladder emphasises

extending product life (Potting et al 2017), instead of focussing solely on recycling, which with the zero-waste myth has attracted criticism (Hannon and Zaman, 2018). Global waste statistics suggest that despite four decades of substantial investment in the well-established "waste hierarchy principles, there are still major obstacles to achieving the foremost goals of reduce, reuse, repair and remanufacture" (Hannon and Zaman, 2018; Valenzuela & Böhm, 2017). Globally, only 8% of clothes are reused, and 10% are recycled, highlighting the need for improved textile management (Business Waste, n.d.). A Life Cycle Analysis (LCA) by Trzepacz et al. (2023) reveals that reuse generally outperforms recycling in reducing environmental impacts, particularly when it offsets CO_2 emissions and the need for new garment production.

Exploring Global Initiatives and Approaches towards a Circular Textile Sector

The global adoption of CE principles in the textile sector highlights various approaches to sustainability and waste reduction. These initiatives reflect a global commitment to circular textile practices, emphasising collaboration, innovation, and policy alignment to achieve sustainability and reduce environmental impact.

The 'EU Strategy for Sustainable and Circular Textiles' aims for durable, recyclable and eco-friendly textile products by 2030, incorporating eco-design, extended producer responsibility (EPR) and support for and ETL (European Union, 2022). France pioneered EPR for textiles in 2007 and enhanced regulations in 2022 to mandate recycled materials and incentivise repairs through the Fashion Repair Program (SGS, 2023; Republic Française, 2023). The Netherlands implemented EPR, targeting 50% textile reuse or recycling by 2025, and 75% by 2030, supported by innovations from the Dutch Circular Textile Valley (DCTV) (Ministry of Infrastructure and Water Management, 2023). The Nordic Region is focussing on separate textile waste collection by 2025, promoting repair and innovative recycling through initiatives like the Nordic Textile Collaboration (Munkholm et al., 2023). California is the first US state to adopt an EPR strategy for the recovery of textile waste through the recent bill Responsible Textile Recovery Act, which emphasises garment lifecycle management to enhance recovery, repair, and recycling (Senate District 29, 2024).

This brief survey of global policies is not intended to provide a detailed analysis of the funding initiatives that resulted from these policies. A comprehensive analysis would yield valuable insights into the allocation of funding related to these policies. However, it provides a benchmark for the analysis of policies and funding allocation in Australia and Queensland.

The Australian fashion industry and the Queensland case

Australians are avid consumers of fast fashion and cheap imports, resulting in high volumes of waste. Current domestic clothing production stands at approximately 3% of total new clothes sold (Allan and Allan, 2022), highlighting the country's heavy reliance on imports to meet consumer demand. On average, Australians buy 56 new apparel items a year (more than the US, the UK and China), equal to 14.8 kilograms per person (Allan and Allan, 2022), and discard 23 kilograms to landfill each year (Australian Fashion Council, 2023). The Australian fashion and textile industry faces several challenges to circularity. Due to manufacturing delocalisation in the 1980s, Australia is a prime producer of high-quality raw fibre (cotton and wool), but has little manufacturing infrastructures (Payne and Ferrero-Regis, 2019). Other challenges point to high levels of part time and casual workers, and shortage of skilled workers. Yet, with an industrial concentration in New South Wales and Victoria, the Australian fashion industry is made of 88% small business (Piller Westover, 2023), employs more workers than in the mining sector, contributing 1.5% to the national GDP.

The Seamless National Clothing Product Stewardship Scheme (Australian Fashion Council, 2023) promotes circularity through eco-modulated levies and investments in collection and recycling infrastructure, aiming to divert 60% of textile waste from landfills by 2027. The Scheme is voluntary with a vision that acknowledges four areas of intervention: circular design, circular business models, closing the loop and citizen behaviour change, while including "Support for the growth of the repair industry and a resurgence in repair skills as a critical component of keeping clothing in use for longer" (Australian Fashion Council, 2023). However, the Scheme funding is directed at clothing collection, reuse and

recycling through charities and industrial transformation. Without clear provision of funding, the repair strategy is left to consumers' behaviour through national campaigns directed at consumers to take care of clothing during use (Seamless 2023, p. 18).

In Queensland, the textile sector is Australia's third-largest regional hub for textile, clothing, and footwear (TCF) manufacturing in terms of economic output and workforce (Australian Fashion Council, 2021). However, the state suffers from the same structural issues of the industry at large. Queensland has strong cotton production, but its Textile Clothing and Footwear (TCF) manufacturing sector has experienced significant decline since the introduction of free trade agreements and delocalisation in the 1980s. Like the Australian fashion industry, Queensland TCF industry is composed of micro and small businesses, with 87% relying on between 1 and 19 employees, and the remaining 13% employing from 20 people up (Ferrero-Regis et al, 2024). In an industry that is dominated by small businesses, adopting circular practices like repair and reuse aligns with social benefits and growth goals. These businesses tend to be more flexible and adaptable (Piller-Westover 2023), and can innovate faster, but they operate on tight budgets.

Within the Queensland Resource Recovery Industry Development Program (RRIDP), innovative projects that include textile recycling are funded, however, the small businesses must compete against large industrial entities, such as Blocktexx, a textile recycling plant that uses chemical separation technology to process cotton and polyester into PET pellets and cellulose powder (State Development, Manufacturing, Infrastructure and Planning, 2024). Project Boomerang is a textile sorting facility being implemented, with the capacity to sort by material type and remove buttons and zippers, allowing for further recycling and reuse (Queensland Government, 2024). In August 2024, the Boomerang Project received AUD 4.97 million, and Blocktexx has received funding from the Queensland government, the Logan City Council and the Federal Government, totaling AUD 1,746,617 (Queensland Government 2023).

Conversely, during interviews with designers for the project *Mapping fashion networks and pre-consumer textile flows for circular communities* (Ferrero-Regis et al., 2024), it emerged that repair, alterations, upcycling and handmade businesses depend on micro-grants ranging from AUD 5,000 to 10,000, often used to help cover rent costs. These funds require navigating complex paperwork. Additionally, these grants are not specifically aimed at the fashion and textile industry; instead, they are typically directed towards broader initiatives.

At the time of writing, while states like NSW and Victoria introduce targeted actions supporting CE goals, such as Sydney's Textile Action Plan, the New South Wales Environmental Protection Agency (which mentions EPR in textiles), and Victoria's TCF Manufacturing report, the Queensland Government has not yet released a roadmap to textile circularity that could support the growth of the TCF sector within the state. Likewise, the Brisbane City Council lacks data on domestic clothing waste and does not have a strategy for used clothing collection and sorting. Queensland, like Australia, exports surplus clothing to other countries. At Australia level, an estimated 14% of donated clothes takes this route (Australian Fashion Council, 2022). Queensland is facing the same challenges related to textile waste as Australia (State Development Infrastructure and Planning, 2023), but a local system-wide textile life extension remains underdeveloped. Despite this, thriving small and micro businesses that have developed circular textile practices within their communities and neighbourhoods have been slowly transitioning to circularity for over than a decade (Ferrero-Regis et al., 2024).

Is textile policy gendered?

This analysis of Australian and states' textile policies emphasizes institutional limitations in textile policy-making that address handmade and ETL practices that slow down consumption, the use of virgin resources and the use of energy. These are practices typically associated with women's labour due to historical and cultural factors. Mending, for example, insinuates non-professional skill-intensive work, handmade and done by females (Middleton, 2014). Mending, repair and upcycle are practices rarely seen as marketable skills, which are instead associated with maintenance and care, typically self-repair (McQueen et al, 2022) and thus connected with consumers. As Middleton (2014) argues, consumers are tasked with garment care through sustaining and prolonging the life of clothing (Middleton 2014) and unpaid labour. In policymaking,

these practices fall into the category of "consumer education" or "behaviour and fail to recognize the complexities of consumption (Wang 2016). Instead, McRobbie et al (2019) argue that a case should be made for feminist fashion policy that puts female employment in fashion at the heart of public policy. Palm et al. (2024) emphasize the importance of a deep examination of gender impact in CE to promote inclusivity. Addressing local priorities may lead to the development of local legislation that can be more effectively monitored and enforced. The formalization of women's work in the textile industry is essential, especially for countries such as India (Kanupriya 2024). Additionally, active women participation of women in policymaking (Wang 2016) can facilitate inclusive and democratic processes.

McPhail (2003) exemplifies that in social work, most policies are seen as gender neutral. Likewise, it can be said that textile policies appear unbiased while attending to the urgent problem of waste. The analysis of Australian and Queensland funding schemes reveals that policy and funding schemes support large-scale innovations, like recycling technologies, over localized repair practices. The techno-deterministic approach in textile waste reduction prioritizes waste management and privileges male-dominated industries. In addition, formal or informal repair economies, irrespective of the sector, are undervalued and face various barriers, including lack of workforce with the appropriate skillset (Australian Government Productivity Commission, 2021). In the clothing and textile sector, repair practices are still seen as an extension of women's responsibilities for family care and resource management. In an industry largely dominated by women in low paid jobs – 77% of the workforce, and mostly made up of migrant women (Australian Fashion Council, 2021) – a gendered policy analysis would enable the recognition and formalization of ETL as a skill-based profession, offer financial incentives and support programmes that target specifically women-led enterprises. Support for ETL practices would also shift the narrative around repair from a traditionally feminine practice to a visible and formal economy that is central to sustainable living.

Conclusions

In Australia, an integrated policy at national, state and city level is essential to extend textile lifespans and reduce reliance on recycling and waste exports (Gbor & Chollet, 2024), with a comprehensive focus on higher-order R practices such as repair, reuse, and upcycling. Ideally, implementing integrated circular principles will foster a holistic transformation of the industry. At the micro level, consumers and enterprises adopt sustainable practices like repair and reuse; at the meso level, industries collaborate through eco-industrial parks; and at the macro level, governments implement policies such as the EU Strategy for Sustainable and Circular Textiles (Warwas et al., 2021). This strategy recognizes the complexities of the system, fosters interactions between the actors and especially leverages the flexibility and adaptive agility of micro and small businesses. A system of Policy Scorecard for gender mainstreaming should be devised to achieve gender equity, as suggested by Keleher (2013) in health policy. The focus on reuse and repair along with the strategy of extending the lifespan of clothing items should be included in the funding system to genuinely address the problem of clothing waste and create true circularity. The heavy emphasis on large scale recycling processes does not provide a viable pathway to circularity in and of itself.

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References

Allan, P. and & Allan, J. (2022). National Clothing Product Stewardship Scheme: Clothing data report. Australian Fashion Council. https://ausfashioncouncil.com/wp-content/uploads/2023/05/AFC-NCPSS-Data-Report.pdf

Australian Fashion Council (2021). From high fashion to high vis. https://ausfashioncouncil.com/wp-content/uploads/2021/05/From-high-fashion-to-high-vis-EY-final-report-31-May-2021.pdf

Australian Fashion Council. (2023). Roadmap to clothing circularity. Retrieved October 18, 2024, from https://ausfashioncouncil.com/wp-content/uploads/2023/06/Roadmap-to-Clothing-Circularity.pdf

Australian Fashion Council (2023). Scheme design report. Transforming how clothing is made, used, reused, and recycled in Australia to create circularity by 2030. https://ausfashioncouncil.com/wp-

content/uploads/2023/09/Seamless-Scheme-Design-Report.pdf

Australian Government Productivity Commission. (2021). Right to repair. Inquiry report. 97, 29 October. https://www.pc.gov.au/inquiries/completed/repair/report/repair.pdf

Bassens, D., De Boeck, S., Kębłowski, W., Lambert, D., & Reinhardt, H. (2020). Toward a circular economy scan: Measuring circular practices among retailers in the Brussels-Capital Region. ResearchGate. https://www.researchgate.net/publication/348415963_Toward_a_Circular_Economy_Scan_Measuring_Circular_Practices_among_Retailers_in_the_Brussels_Capital_Region

Bocken, N. M. P., Niessen, L., & Short, S. W. (2022*).* The Sufficiency-Based Circular Economy—An Analysis of 150 Companies *[Original Research. Frontiers in Sustainability*, 3. doi: 10.3389/frsus.2022.899289

Business Waste. (n.d.). Fashion waste facts and statistics. Retrieved December 5, 2024, from https://www.businesswaste.co.uk/your-waste/textile-recycling/fashion-waste-facts-and-statistics/

Ferrero-Regis, T. Lindquist, M., Van Lunn, C., Hopper, C. (2024). Mapping fashion networks and pre-consumer textile flows for circular communities, *International,Journal of Sustainable Fashion and Textiles*, 3:3, pp. 155-178. https://doi.org/10.1386/sft_00045_1

Gbor, N. and & Chollet, O. (2024). Textile waste in Australia. Reducing consumption and investing in circularity. May. https://connectqutedumy.sharepoint.com/personal/narayan6_qut_edu_au6DH9MOWYKKKU1VXAQLD2FQ/Documents/QUT_RC/Reports/The-Australia-Institute-Textiles-Waste-In-Australia-Web.pdf

Earth.Org. (2023). *Statistics about fast fashion waste*. Retrieved December 5, 2024, from https://earth.org/statistics-about-fast-fashion-waste/#:~:text=92%20million%20tonnes%20of%20textiles,on%20landfill%20sites%20every%20second

Edge Environment. (2023). The state of fashion: Textile circularity in Western Australia. Edge Environment. https://s37430.pcdn.co/wp-content/uploads/sites/2/2023/08/The_State_of_Fashion_Textile_Circularity_in_WA.pdf

Ellen MacArthur Foundation. (2017). A new textiles economy: Redesigning fashion's future. https://emf.thirdlight.com/file/24/uiwtaHvud8YIG_uiSTauTlJH74/A%20New%20Textiles%20Economy%3A%20Redesigning%20fashion%E2%80%99s%20future.pdf

Ellen MacArthur Foundation. (n.d.-a). Fashion and the circular economy - deep dive. https://www.ellenmacarthurfoundation.org/fashion-and-the-circular-economy-deep-diveRetrieved October 17, 2024, from

European Parliament. (2020). The impact of textile production and waste on the environment (infographics). https://www.europarl.europa.eu/topics/en/article/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics

European Union. (2022). EU Strategy for Sustainable and Circular Textiles. Retrieved from https://ec.europa.eu/environment/publications/eu-strategy-sustainable-and-circular-textiles_en

Guzzo, D., Pigosso, D. C. A., Videira, N., & Mascarenhas, J. (2022). A system dynamics-based framework for examining Circular Economy transitions. Journal of cleaner production, 333, 129933.

Hannon, J. and & Zaman, Atiq U. (2018). *Exploring the phenomenon of Zero Waste and future cities.* Urban Science, 2, 90; doi:10.3390/urbansci2030090, pp. 1-26.

Kanupriya. (2024). Linkages among trade, gender and environment: A review in the context of India's textile sector. *Decision* (September 2024) 51(3):397–409. https://doi.org/10.1007/s40622-024-00397-w

Keheler, H. (2013). Policy scorecard for gender mainstreaming: gender equality in health policy. *Autralian and New Zealand Journal of public health*, (37), 2, pp. 113-117. doi: 10.1111/1753-6405.12027

Leal Filho, W., Dinis, M. A. P., Liakh, O., Paço, A., Dennis, K., Shollo, F., & Sidsaph, H. (2024). *Reducing the carbon footprint of the textile sector: an overview of impacts and solutions*. Textile Research Journal, 00405175241236971.

Lewe, E. (2023). *Extended producer responsibility in the textiles industry*. FINIX Project. Retrieved October 17, 2024, from https://finix.aalto.fi/extended-producer-responsibility-in-the-textiles-industry/

McQueen, R. H., McNeill, L. S., Huang, Q., & Potdar, B. (2022). Unpicking the Gender Gap: Examining Socio-Demographic Factors and Repair Resources in Clothing Repair Practice. *Recycling*, *7*(4), 53. https://doi.org/10.3390/recycling7040053.

McPhail, B. A. (2003). A feminist policy analysis Framework. *The social policy journal*, 2-3, p. 38-61. DOI:10.1300/J185v02n02_04

McRobbie, A., Strutt, D., & Bandinelli, C. (2018). Feminism and the politics of creative labour enterprise in London, Berlin and Milan.

Australian Feminist Studies, *(34)* 100, p. 131-148.

Middleton, J. (2014). Mending, In Fletcher, K. Tham and Tham. M (eds), *Routldege Handbook of Sustainability and Fashion*, Routledge: London.

Ministry of Infrastructure and Water Management. (2023, April 14). *Decree rules extended producer responsibility for textile products*. Government of the Netherlands.

Mullen, M. (2023). Sweden's circular fashion industry. Circular Innovation Lab. https://www.government.nl/topics/circular-economy/documents/decrees/2023/04/14/decree-rules-extended-producer-responsibility-for-textile-products

Munkholm, L., Lindberg Laursen, B., Christensen, A. C., Trab Munk Christensen, A., Slater Christensen, B., Dam Larsen, J., & Tønder, R. A. (Miljøstyrelsen) (2023). Mapping Sustainable Textile Initiatives in the Nordic Countries. Nordic Council of Ministers. https://pub.norden.org/temanord2023-502/temanord2023-502.pdf

Palm, J., Lazorosxka, D., Valencia, M., Bocken, Södergren N. (2024). A gender perspective on the circular economy. A literature review and research agenda. *Journal of Industrial Ecology*, (28), pp. 1670-1683. DOI: 10.1111/jiec.13554

Payne, A. & Ferrero-Regis, T. (2019). Sustainable fashion in Australia: Raw fiber, fast fashion, and new localism. In Gwilt, A, Payne, A, & Ruthschilling, E A (Eds.) *Global perspectives on sustainable fashion.* Bloomsbury Visual Arts, United Kingdom, pp. 180-190. DOI: 10.5040/9781350058170.ch-005.1

Piller Westover, Lisa. (2023). Designing for circularity: sustainable pathways for Australian fashion small to medium enterprises. Journal of Fashion Marketing and Management 27(2), pp. 287-310. DOI:10.1108/JFMM-09-2021-0220

Potting, J., et al., (2017). Circular Economy: Measuring Innovation in the Product Chain. https://www.researchgate.net/publication/319314335_Circular_Economy_Measuring_innovation_in_the_product_chain

Puglia, M., Parker, L., Clube, R. M. K., Demirel, P., Aurisicchio, M. (2024). *The circular policy canvas: Mapping the European Union's policies for a sustainable fashion textile industry.* Resources, Conservation & Recycling, May. https://doi.org/10.1016/j.resconrec.2024.107459

Queensland Government (2024) Textile recycling business to divert 50,000 tonnes of landfill waste and create 140 jobs over four years. State Development, Infrastructure and Planning. https://www.statedevelopment.qld.gov.au/news-and-events/textile-recycling-business-to-divert-50,000-tonnes-of-landfill-waste-and-create-140-jobs-over-four-years

Queensland Government (2024). Project Boomerang – Salvos Stores textile recycling hub. https://www.qld.gov.au/environment/circular-economy-waste-reduction/funding-grants/salvos-textile-recycling

Republic Française (2023). Repair bonus: Financial assistance to patch your clothes and shoes. https://www.service-public.fr/particuliers/actualites/A16951?lang=en

Senate District 29. (2024). Responsible Textile Recovery Act of 2024 signed by governor. https://sd29.senate.ca.gov/news/press-release/responsible-textile-recovery-act-2024-signed-governor?utm_source=substack&utm_medium=email

SGS. (2023). France updates requirements for the textile fashion industry. https://www.sgs.com/en/news/2023/01/safeguards-1023-france-updates-requirements-for-the-textile-fashion-industry

State Development, Manufacturing, Infrastructure and Planning 2024. https://www.statedevelopment.qld.gov.au/industry/critical-industry-support/resource-recovery/industry-development-program

Textile Exchange (2023). Materials Market report. https://textileexchange.org/app/uploads/2023/11/Materials-Market-Report-2023.pdf

Trzepacz, N., Bekkevold Lingås, D., Asscherickx, L., Peeters, K., van Duijn, H., Akerboom, M. (2023). LCA-based assessment of the management of European used textiles, Norion. January. https://euric.org/images/Position-papers/lca-based-assessment-of-the-management-of-european-used-textiles_corrected.pdf

United Nations Environment Programme. (n.d.). Circular economy presentation. World Trade Organization. https://www.wto.org/english/tratop_e/tessd_e/07_circ_economy_1_presentation_by_unep.pdf

Valenzuela, F., Böhm, S. (2017), Against wasted politics: A critique of the circular economy. *Ephemera: Theory and politics in organization,* (17) 1, 23-60. https://ephemerajournal.org/contribution/against-wasted-politics-critique-circular-economy

Wang, S. (2016). *Green practices are gendered: Exploring gender inequalities caused by sustainable consumption policies in Taiwan*. Energy Research and Social Science. (18). 88-95.

http://dx.doi.org/10.1016/j.erss.2016.03.005

Warwas, I., Podgórniak-Krzykacz, A., Przywojska, J., & Kozar, Ł. (2021). Going green and socially responsible–textile industry in transition to sustainability and a circular economy. *Fibres & Textiles in Eastern Europe*, (3) 147, 8-18.

Zero Waste Europe. (2022). Factsheet: Finland textiles.https://zerowasteeurope.eu/wp-content/uploads/2022/11/ZWE-EWWR2022-factsheet_Finland-textiles.pdf

Appendix

Region/ Country	Strategy/ Plan/Action/Policy	Does it explicitly support/ discuss ETL?
European Union	EU Strategy for Sustainable and Circular Textiles- 2022	
	Transition Pathway for the Textiles Ecosystem- 2023	
	Extended Producer Responsibility (EPR) for Textiles	
France	EPR	
	France's Fashion Repair Program	
The Netherlands	EPR for Textiles	
	The Dutch Circular Textile Valley	
Sweden	EPR & Business Models	
Denmark	Sectoral agreement for a more circular industry	
	EPR	
	Separate textile collection	
Finland	Separate textile collection	
California	The Responsible Textile Recovery Act, or SB 707	
Australia	National Clothing Product Stewardship Scheme-SEAMLESS	
	National Waste Policy 2018	
QLD	Waste Management and Resource Recovery Strategy	
	Queensland Resource Recovery Industries- 10-Year Roadmap and Action Plan	
	Resource Recovery Industry Development Program (RRIDP)	
	Recycling Enterprise Precincts A "How To" Guideline	
	Queensland procurement strategy- 2023	
	Queensland Government Procurement Statement 2024/ Buy Qld	
	Final Review Report Waste Management and Resource Recovery Strategy- July 2024	
	Queensland's waste disposal levy	
	Project Boomerang - Salvos Stores textile recycling hub	
SA	South Australia's Waste Strategy 2020-2025	
NSW	NSW Waste and Sustainable Materials Strategy (2041). (Stage 1: 2021–2027)	
	NSW Environmental Protection Authority (2024)	
	Textile Action Plan for Sydney Councils 2021	
Tasmania	Tasmanian Waste and Resource Recovery Strategy 2023-2026	
WA	Waste Avoidance and Resource Recovery Strategy 2030	
	The State of Fashion & Textile Circularity in WA	
ACT	ACT Waste Management Strategy 2011-2025	
	ACT Circular Economy Strategy and Action Plan 2023-2030	
Northern Territory	Northern Territory Circular Economy Strategy 2022 - 2027	
Victoria	Recycling Victoria: A New Economy (2020)	
	Insider Tips on Running a Textile Waste Program	
	Victorian Textile, Clothing and Footwear (TCF) Manufacturing: Future Jobs, Technology, and Economic Growth	

Legend

Does it explicity support/ discuss ETL?

- Yes, it does support & discuss ETL
- Yes, it does support ETL
- It does support & discuss ETL to some extent
- No, it doesn't support or discuss ETL

Table 1: Summary Table of ELT Strategies/Plans/Actions/Policies

Research paper
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Does the EU *Eco-design for Sustainable Product Regulation* Address Premature Obsolescence? A Systemic Perspective on Barriers to Longer Product Lifetime

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Keywords: Premature obsolescence; Long product lifetime; Eco-design for Sustainable Product Regulation (ESPR).

Abstract: Premature obsolescence has significant environmental and socioeconomic impacts. Extending the lifetime of products is a key aim of the Eco-design for Sustainable Product Regulation (ESPR), recently introduced by the European Commission. Several barriers to achieving longer product lifetime have been identified in the literature. By examining the systemic interplay among these barriers and forms of premature obsolescence, we develop a framework to analyse the potential effectiveness of ESPR. Our findings reveal that these barriers are interconnected and mutually reinforcing, confirming the need for public policies that address these interactions and reduce premature obsolescence. Moreover, while the ESPR successfully addresses technical and economic challenges related to product lifetime extension, it remains limited in tackling symbolic obsolescence and ingrained societal consumption patterns.

Introduction

On 18th July 2024, the European Commission adopted the new Eco-design for Sustainable Product Regulation (ESPR henceforth) (European Commission, 2024). Its aim is to promote the sustainability of products in the European market by increasing their circularity and their environmental performance. To achieve this, the ESPR further enhances the focus on strategies for prolonging product lifetime, via increasing product durability, reliability, repairability, upgradability and reusability. Product lifetime refers to the period from when a product is purchased until it is no longer used (Jensen, 2021). A key factor influencing product lifetime is obsolescence, which refers to the state of a product being outdated or no longer in use (Butt et al., 2015; Mellal, 2020). Often, “natural” obsolescence is “planned”, that is deliberately accelerated by supply-side strategies driven by the competitive process. As it is not easy to disentangle to what extent this is due to explicit business strategies (Dalhammar et al., 2023), the term “premature” obsolescence is often preferred, and is also used in ESPR.

Public policies for addressing premature obsolescence and extending product lifetime are justified by both socio-economic and environmental motives. Premature obsolescence generates useless resource depletion and waste (Maycroft, 2009; Friedel, 2013; Guiltinan, 2009; Bisschop et al., 2022; Rivera & Lallmahomed, 2016). The firms’ risk of passively suffering obsolescence is often seen as a driver of firms’ innovation, but this can cause adverse effects such as fostering incremental upgrades on existing technologies rather than ground-breaking innovations (Guiltinan, 2009; Bisschop et al., 2022), complicating investment decisions given the uncertain life of fixed assets (Moonitz, 1943), undermining economic performance, efficiency, organizational effectiveness and safety of firms whose capital goods and technologies are becoming obsolete (Sørensen and Stuart, 2000; Ma, 2021; Mellal, 2020). Additionally, accelerated obsolescence can exacerbate income and wealth inequality (Monserand, 2022), engender consumers’ dissatisfaction and harm wellbeing (Becher & Sibony, 2021). Consequently, extending product lifetime can potentially reap both environmental and socioeconomic benefits (Kagawa et al., 2006).
To the best of our knowledge, the literature appears to lack a systemic view of the interplay between various barriers to long-lasting products. To contribute to filling this gap,

building on Jensen (2021), we propose here a systemic perspective linking barriers to longer product lifetime (hereafter referred to as LPL) and forms of obsolescence. This theoretical framework enables us to explore ESPR's potential in reducing barriers to LPL and its role in mitigating premature obsolescence. Some studies on the ESPR have already been published, although they were conducted before the final legislative text was released[1].

A Systemic Perspective on Barriers to LPL and Premature Obsolescence

This section offers a systemic perspective on barriers to LPL and premature obsolescence. First, after revisiting the literature, we propose an improved classification for premature obsolescence. Second, we recall the many barriers to LPL. Third, we outline the interactions between these barriers and their link with premature obsolescence.

Within the literature on obsolescence, many classifications have been proposed, some of which overlap, while others refer to the same concept under different names or can be subsumed into more general categories (Dallhamar, 2023; Becher & Sibony, 2021; Mellal, 2020; Cooper, 2004; Keeble, 2013). To address these issues, we propose here four macro-categories to classify premature obsolescence.

- *Forced functional obsolescence*[2] occurs when a product can no longer perform its intended function due to decisions made by manufacturers, either by producing short-lived products or by 'killing' products. Firms can decide to use low-quality materials or components that wear out quickly (i.e., material obsolescence), to poorly design products resulting in deterioration after a short time (i.e., in-built obsolescence), to stop the production of spare parts (i.e., logistical obsolescence) or to force software updates that are not compatible with the product.
- *Technical (or technological) obsolescence* occurs when a product becomes undesirable due to advancements in technology. It happens when a newer product devaluates an existing one, making the older version outdated despite being functional.
- *Economic obsolescence* (also known as financial obsolescence) occurs because of economic factors. On the consumer side, a functional product may be replaced if newer models involve lower operational costs. Consumers may also decide not to repair a faulty product if the repair costs, including spare parts, are too expensive as compared to buying a new replacement model (i.e., limited-repair obsolescence). On the producer side, economic obsolescence can occur if supporting an existing product becomes financially unviable.
- *Symbolic obsolescence* occurs when consumers view a product as no longer desirable due to a desire for novelty or perceive it as outdated because of social factors such as peer expectations or changing fashion trends, often triggered by marketing campaigns. Perceived obsolescence shortens the consumer replacement cycle.

When addressing the barriers to LPL, a broadly accepted classification was provided by Jensen et al. (2021). We expanded it by adding two additional barriers, that is, product repairability (Van den Berge et al., 2023; Magnier & Mugge, 2022) and consumer purchasing power (Cooper, 2010). Table 1 summarises the barriers, categorised by those encountered by businesses, product developers, and consumers.

[1] Previous studies have dealt with ESPR by examining its contribution to circular economy (Galatola, 2024; Park, 202 and climate goals (Fabšíková, 2024), by suggesting methods to set eco-design standards (Schuberth et al., 2024; Yang & Vezzoli, 2024; Bundgaard et al., 2024), or by focusing only on one measure such as the Digital Product Passport (Götz et al., 2022; Lövdahl et al., 2023)

[2] Keeble (2013) makes a distinction between "forced" and "natural" obsolescence. "Natural" obsolescence refers to the inevitable aging or deterioration of products over time, occurring without human intervention or deliberate manipulation. As our focus is on premature obsolescence, we specifically address forced functional obsolescence.

Business	Product Developer	Consumer
B1. High cost of changing the business model	B6. Inability to follow fast-moving trends and fashions	B10. Short lifecycles promoted by retailers affects user behaviour
B2. Customer rejection of the business model change	B7. Technological innovation makes long-lasting products obsolete	B11. Lack of attachment to the products
B3. High price points of long-lasting products	B8. Change in societal behaviour makes long-lasting products obsolete	B12. Barriers to repair products
B4. Vulnerability regarding short, fixed leasing periods	B9. Lack of focus on longevity in innovation	B13. Customers are partly unaware of material quality/ Lack of product information
B5. Time-consuming changes in customer perceptions of products and brands		B14. Evaluating longevity in a purchase situation
		B15. Misperception of modularity in advanced products
		B16. Consumer purchasing power

Table 1. Barriers to long-lasting products, Adapted from Jensen (2021)

We can now outline the most relevant interactions between barriers and premature obsolescence. As a general point, it is worth noting that all these barriers are shaped by the societal and psychological conditions characteristic of capitalism, which include a desire for novelty, materialistic values, and compensation for declining social capital through consumption. More importantly, the interplay of barriers faced by businesses, developers, and consumers exacerbates premature obsolescence.

Let us begin from the economic challenges businesses face when increasing product lifetime. Firstly, such a shift requires initial investments (B1)[3]. Additionally, long-lasting products often have higher production costs, creating a competitive disadvantage for firms in price-sensitive markets, where cheaper, less durable alternatives dominate (B3)[4]. The higher cost of more durable goods often acts as a direct barrier for low- and middle-income consumers (B16). Moreover, if a brand is perceived as offering short-lived products, changing this perception can take time, thereby jeopardizing the firm's short-term profitability (B5).

The risk of economic obsolescence for the company is further increased by customers' resistance to this business model shift (B2). This resistance arises from several demand-side barriers. First, it is often difficult to evaluate longevity (B14) due to lack of information or awareness on product quality (B13) leading consumers to choose cheaper, less durable options. Second, when manufacturers opt to produce modular products to extend product lifetime, customers may perceive these products as less advanced compared to the integrated ones (B15).

Moreover, retailers also play an important role. Their business models influence consumer behaviour and manufacturers' priorities regarding product longevity. Short leasing or rental periods, as well as subscription models, incentivise frequent product turnover over durability (B4) and reduce consumer's attachment to the product (B10), discouraging the production of long-lasting goods.

When looking at consumers, psychological and sociological factors cannot be overlooked. The taste for novelty leads consumers to replace functional items with aesthetically appealing new variants, a behaviour exploited by firms. Materialism drives status-seeking through consumption, social conformity (Keeble, 2013), and supports mass production systems (Matutinović, 2007). Consumption activates the brain's pleasure circuits, fostering a sense of gratification (Sterling, 2016). Declining social

[3] According to Jensen et al. (2021), small and medium-sized enterprises are particularly hesitant or unable to make such investments without a guaranteed return, as they are more vulnerable and often operate in markets characterized by rapid technological advancements.

[4] This effect can be mitigated in the case of luxury goods targeting affluent consumers, as a price premium may not necessarily pose an obstacle for this consumer segment.

capital encourages consumerism as a coping mechanism for emotional distress, thereby fuelling economic growth (Bartolini & Sarracino, 2021). Together, these factors trigger frequent consumption and reinforce symbolic obsolescence.

The dynamics described above highlight how the interplay between demand and supply-side barriers to LPL encourage firms to adopt practices that intentionally shorten product lifetime by using low-quality materials, designing products with inherent flaws, discontinuing essential spare parts, and implementing software updates that reduce functionality—actions that drive forced functional obsolescence and boost repeated purchases. Moreover, to sustain demand growth, designers create products with incremental changes and manufacturers reserve advanced features for premium models. These strategies push consumers to replace functional goods in pursuit of exclusive features, reinforcing technological obsolescence.

Consequently, product developers face challenges in designing long-lasting products. For instance, the emphasis on new product development reduces the focus on product longevity (B9). Moreover, long lasting products are likely to go out of fashion and lose value for customers due to fast moving trends (i.e. symbolic obsolescence) (Lilley et al., 2016) (B6). Additionally, companies producing durable technological goods face challenges in committing to specific technologies (B7), such as a loudspeaker manufacturer relying on Bluetooth, which risks obsolescence as consumers adopt Wi-Fi streaming or other alternatives (Jensen, 2021). Finally, changes in social practices or laws can make long-lasting products obsolete (B8). All these factors make development of long-lasting products risky.

Additionally, these fast-moving trends and poor product design reduce consumers' emotional attachment to their products (B11). This leads to less care, poor maintenance, and premature disposal of products. Due to a lack of attachment, dissatisfaction with appearance, or preference for updated models lead to symbolic obsolescence, where consumers may opt to dispose rather than repair (Magnier & Mugge, 2022). Repairs are further complicated by limitations in time, knowledge, and skills (McLaren et al., 2015), along with poor design and the lack of spare parts (logistical obsolescence). Additionally, consumers can see replacement as faster and more convenient than repair services which entail high labour costs (Van den Berge et al., 2023; Dalhammar et al. 2023). These various challenges prevent consumers from repairing durable goods (B12).

In summary, as these barriers are interconnected and mutually reinforcing, public policies must consider these interactions to effectively contrast premature obsolescence.

ESPR: Addressing barriers to LPL and Premature Obsolescence

This section analyses how the ESPR addresses barriers to LPL and different forms of premature obsolescence.

The ESPR bridges the European Green Deal, the Circular Economy Action Plan and the Eco-design Directive 2009/125/EC, introducing critical design requirements for a broader range of products[5] than in previous policies and on issues that have been often under-emphasized. Its goal is to enhance product sustainability by prioritizing durability, reliability, repairability, upgradability, reusability (i.e., LPL attributes), energy efficiency, recyclability, and waste reduction, while ensuring functionality, safety, affordability, and fair impact on small businesses (European Commission, 2024).

The ESPR encompasses many policy instruments, however for the purposes of this paper, it suffices to note that it introduces eco-design requirements both on performance and information. The performance requirements are introduced to eliminate the worst performers and promote the best ones through requirements on specific product parameters. The information requirements mandate the provision of clear and accessible information about environmental sustainability and technical issues (such as installation, use, maintenance, and end-of-life handling). To

[5] While the previous Directives were aimed at energy-using and energy-related products, the new ESPR extends to products such as iron and steel, aluminium, textiles (garments and footwear), furniture, tires, detergents, paints, lubricants, chemicals, information and communication technology (ICT) products and other electronics, and energy-related products, whereas medical and veterinary products, food, living plants and micro-organisms are kept out of the scope.

facilitate this, the ESPR introduces the digital product passport (DPP) in addition to the traditional tools (labels or user manuals). These requirements are supported by financial incentives for SMEs, micro-businesses, and consumers (European Commission, 2024, p. 13-14,20).

Barriers / ESPR Regulations	Support to business	Support to customers	Information requirements	Performance requirements
1. High cost of changing the business model	Direct			
2. Customer rejection of the business model change		Indirect		
3. High price points of long-lasting products	Indirect	Direct		Direct
4. Vulnerability regarding short, fixed leasing periods				Indirect
5. Customer perceptions of products and brands	Indirect	Indirect	Direct	
6. Inability to follow fast-moving trends and fashion	Direct	Indirect		Direct
7. Technological innovation makes long-lasting products obsolete				Direct
8. Change in societal behaviour makes long-lasting products obsolete				
9. Lack of focus on longevity in innovation	Direct	Indirect	Indirect	Direct
10. Short lifecycles promoted by retailers affects user behaviour			Indirect	
11. Lack of attachment to the products			Indirect	Indirect
12. Barriers to repair products		Indirect	Direct	Direct
13. Customers are partly unaware of material quality / Lack of product information			Direct	
14. Evaluating longevity in a purchase situation			Direct	
15. Misperception of modularity in advanced products			Direct	
16. Consumer purchasing power for durable products	Indirect	Direct		

Table 2. Analysis of ESPR tackling barriers to LPL

For each of the barriers identified in Table 1, we examined whether ESPR addresses them, either directly or indirectly. We considered whether each measure in the regulation directly targets the barriers or whether it is able to indirectly address them only through a mediating mechanism or only when certain conditions are met, also depending on how it will be implemented. Table 2 summarises our findings.

The ESPR offers financial assistance to businesses to help overcome economic barriers in transitioning to long-lasting products. This support encompasses fiscal incentives, investments in physical and digital infrastructure, access to financing, employee training, and both organizational and technical assistance. They are likely to reduce the initial cost of the transition (B1) and, by lowering costs, mitigate the price increase (B3), while also potentially financing marketing campaigns to influence customers' brand perception (B5). Financial incentives for consumers (such as eco-vouchers and green taxation) also support

demand for these businesses, making long-lasting products more accessible (B16). Meanwhile, the combination of financial incentives and performance requirements encourages the developers to focus on product longevity rather than solely attempting to follow fast-moving trends (B9). This approach also helps create a level playing field for long-lasting products, reducing the likelihood of firms facing unfair competition from cheap, low-quality products (B3, B6). Moreover, performance requirements encourage product modularity and upgradability which tackles the risk of technological lock-in for long-lasting products (B7). Finally, information requirements enable conscious consumer purchases, drawing attention to LPL attributes (B12, B13, B14, B15).

While ESPR succeeds in addressing various barriers to LPL, we observe that some barriers are not, or only indirectly, addressed. This includes barriers related to retailers' business models. Producers' vulnerability to short, fixed leasing periods could be mitigated by performance requirements fostering LPL, which could eventually extend leasing periods (B4). Besides, information requirements could partially counteract the effect of short lifecycles promoted by retailers on consumers' perception of product lifetime (B10). Another barrier that is only indirectly addressed is consumer resistance to shifts in business model (B2). This barrier can be mitigated through consumers' financial incentives, but only if they are tied to renting or leasing options. Additionally, lack of attachment to products (B11) is also only indirectly treated through the combination of higher average product longevity and accessible information, which are likely to influence customer expectation on product longevity. Finally, ESPR does not address changes in societal behaviour that can make long-lasting products obsolete. Tackling this issue is challenging, as such changes are often unpredictable, difficult to control, or influenced by external laws.

A key aspect of our research was to examine how ESPR deals with premature obsolescence. The eco-design requirements, supported by financial incentives for both consumers and producers, partially address the interplay between barriers on the demand- and supply-side. They mainly help combat *functional obsolescence* caused by low-quality materials, poor design, lack of spare parts, or software incompatibilities following operating system updates, especially by relieving barriers on product development. The ESPR also addresses *technological obsolescence* to a certain extent, by promoting product modularity and upgradability without affecting the original function of the product. Additionally, it partly tackles *economic obsolescence* by financially supporting producers in adopting sustainable business models and by reducing repair costs for consumers through affordable and accessible spare parts. However, nothing is proposed to reduce labour costs of repair services or to provide financial support for consumer repairs. Hence, this policy makes the shift to long-lasting products more economically viable, thus enabling businesses to avoid choices that trigger *functional obsolescence*.

Finally, the ESPR has limitations in addressing *symbolic obsolescence*. It indirectly tackles this issue by removing the worst-performing products from the market, thereby increasing product longevity, and possibly making long-lasting products more socially desirable as they gradually become the norm. However, it does not include measures on advertisements or marketing campaigns that contribute to symbolic obsolescence, by triggering curiosity for novelty, the pursuit of social status through purchases, or consumption associated with stimulating the brain's pleasure circuits, nor it includes initiatives, such as educational activities, to address these underlying mechanisms.

Conclusions

This article proposes a systemic perspective linking barriers to LPL with forms of premature obsolescence. After highlighting the interactions between business, product development and consumer barriers, we find that the ESPR addresses most of the technical and economic barriers associated with the transition to long-lasting products. However, it overlooks the psychological and sociological factors underlying the current consumerist paradigm that drives symbolic obsolescence. It should be recognised that transitioning business models and product development processes toward the production of longer-lasting goods is not solely a technical and economic challenge; it also requires paradigm shift. The dominant social paradigm equates success with material wealth, driving excessive

consumerism and encouraging the production of short-lived goods (Richins & Dawson, 1992).

Further research is needed to analyse the synergies and trade-offs between the ESPR and other EU policies addressing barriers to LPL and premature obsolescence (e.g., Right to Repair, consumer protection law), as these policies can either reinforce or undermine the effectiveness of ESPR, strengthening barriers to product lifetime extension.

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References

Bartolini, S. and Sarracino, F., (2021). Happier and Sustainable. Possibilities for a post-growth society. MPRA Paper No. 108309. https://mpra.ub.uni-muenchen.de/108309/

Becher, S. I., & Sibony, A. L. (2021). Confronting product obsolescence. Colum. J. Eur. L., 27, 97.

Bernays, E. (1928). Propaganda. Brooklyn: Ig Publishing, (2005), 37.

Bisschop, L., Hendlin, Y., & Jaspers, J. (2022). Designed to break: planned obsolescence as corporate environmental crime. Crime, Law and Social Change, 78(3), 271–293. https://doi.org/10.1007/s10611-022-10023-4

Burns, B., (2010). Re-evaluating obsolescence and planning for it. In: Cooper, T. (Ed.), Longer Lasting Products - Alternatives to the Throwaway Society. Gower Publishing Limited, Farnham, England, pp. 39–60.

Bundgaard, A. M., Huulgaard, R. D., & Remmen, A. (2024). Getting the Priorities Right in Material Efficiency: From the Ecodesign Directive to the Ecodesign for Sustainable Products Regulation. International Conference Electronics Goes Green 2024+: From Silicon to Sustainability, EGG 2024 - Proceedings, Berlin. DOI: 10.23919/EGG62010.2024.10631182

Butt, T. E., Camilleri, M., Paul, P., & Jones, K. G. (2015). Obsolescence types and the built environment - Definitions and implications. International Journal of Environment and Sustainable Development, 14(1), 20–39. https://doi.org/10.1504/IJESD.2015.066896

Cooper, T. (2004). Inadequate life? Evidence of consumer attitudes to product obsolescence. Journal of Consumer Policy, 27(4), 421-449. DOI: 10.1007/s10603-004-2284-6

Cooper, T. (2010). Longer lasting products. Alternatives to the Throwaway Society. Farnham/Surrey: Gower. https://doi.org/10.4324/9781315592930

Dalhammar, C., Maitre-Ekern, E., Richter, J. L., Svensson-Hoglund, S., & Milios, L. (2023). 7. Regulation with a lasting impact? Policies for product durability. Labor and Organization Volume 10, 159. DOI: 10.1515/9783839463963-008

European Commission. (2024). Regulation - EU - 2024/1781 - EN - EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1781&qid=1719580391746

Fabšíková, T. (2024). Legal Regulation Related to Products in the Context of the European Union's Climate Objectives[PRÁVNÍ REGULACE SOUVISEJÍCÍ S VÝROBKY V KONTEXTU CÍLŮ EVROPSKÉ UNIE V OBLASTI OCHRANY KLIMATU]. Acta Universitatis Carolinae Iuridica, 70(1), 63–75.https://doi.org/10.14712/23366478.2024.5

Friedel, R. (2013). Obsolescence: Origins and Outrages. Technology and Culture, 54(1), 167–169. https://doi.org/10.1353/TECH.2013.0014

Galatola, M. (2024). Circular economy and product sustainability in Europe. In Cyclic Economy: Policies in Major Countries and the EU (pp. 21–35). De Gruyter.https://doi.org/10.1515/9783110767179-002

Götz, T., Berg, H., Jansen, M., Adisorn, T., Cembrero, D., Markkanen, S., & Chowdhury, T. (2022). Digital product passport : the ticket to achieving a climate neutral and circular European economy? https://epub.wupperinst.org/frontdoor/index/index/docId/8049

Guillard, V., Le Nagard, E., & de Campos Ribeiro, G. (2023). A typology of consumers regarding perceived obsolescence: The paradox of eco-conscious consumers. Journal of Cleaner Production, 412, 137202. DOI: 10.1016/j.jclepro.2023.137202

Guiltinan, J. (2009). Creative destruction and destructive creations: Environmental ethics and planned obsolescence. Journal of Business Ethics, 89(SUPPL. 1), 19–28. https://doi.org/10.1007/s10551-008-9907-9

Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021). Barriers to product longevity: A review of business, product development and user perspectives. Journal of Cleaner Production, 313, 127951. https://doi.org/10.1016/j.jclepro.2021.127951

Kagawa, S., Tasaki, T., & Moriguchi, Y. (2006). The environmental and economic consequences of product lifetime extension: Empirical analysis for automobile use. Ecological Economics, 58(1), 108–118. https://doi.org/10.1016/j.ecolecon.2005.06.003

Keeble, D. (2013). The culture of planned obsolescence in technology companies.

Lilley, D., Smalley, G., Bridgens, B., Wilson, G. T., & Balasundaram, K. (2016). Cosmetic obsolescence? User perceptions of new and artificially aged materials. Materials & Design, 101, 355-365. https://doi.org/10.1016/j.matdes.2016.04.012

Lövdahl, J., Hallstedt, S. I., & Schulte, J. (2023). IMPLICATIONS OF EU INSTRUMENTS ON COMPANY CAPABILITIES TO DESIGN MORE SUSTAINABLE SOLUTIONS–PRODUCT ENVIRONMENTAL FOOTPRINT AND DIGITAL PRODUCT PASSPORT. Proceedings of the Design Society, 3, 2245–2254. https://doi.org/10.1017/PDS.2023.225

Ma, S. (2021). Technological Obsolescence. http://dx.doi.org/10.2139/ssrn.3964128

Magnier, L., and Mugge, R. (2022) Are short product lifetimes ineluctable? An exploration of consumers' perceptions of lifetime extension strategies, in Lockton, D., Lenzi, S., Hekkert, P., Oak, A., Sádaba, J., Lloyd, P. (eds.), DRS2022: Bilbao, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.507

Matutinović, I. (2007). An Institutional Approach to Sustainability: a Historical Interplay of Worldviews, Institutions and Technology. Journal of Economic Issues, Vol XLI, No.4, 1109-1137. DOI: 10.1080/00213624.2007.11507089

Maycroft, N. (2009). Consumption, planned obsolescence and waste.

McLaren, A., & McLauchlan, S. (2015). Crafting sustainable repairs: practice-based approaches to extending the life of clothes.

Mellal, M. A. (2020). Obsolescence–A review of the literature. Technology in Society, 63, 101347. https://doi.org/10.1016/j.techsoc.2020.101347

Monserand, A. (2022). Buying into inequality: a macroeconomic analysis linking accelerated obsolescence, interpersonal inequality, and potential for degrowth. European Journal of Economics and Economic Policies: Intervention, Vol. 19 No. 1, 119–137 DOI: 10.4337/ejeep.2022.01.09

Moonitz, M. (1943). The Risk of Obsolescence and the Importance of the Rate of Interest on JSTOR. https://www.jstor.org/stable/1826804?seq=2

Pandelaere, M., (2016). Materialism and well-being: the role of consumption. Curr. Opin. Psychol. 10, 33–38. https://doi.org/10.1016/j.copsyc.2015.10.027

Richins, M.L., Dawson, S., (1992). A consumer values orientation for materialism and its measurement: scale development and validation. J. Consum. Res. 19 (3), 303–316. https://doi.org/10.1086/209304

Rivera, J. L., & Lallmahomed, A. (2016). Environmental implications of planned obsolescence and product lifetime: a literature review. In International Journal of Sustainable Engineering (Vol. 9, Issue 2, pp. 119–129). Taylor and Francis Ltd. https://doi.org/10.1080/19397038.2015.1099757

Schuberth, J., Ebert, T., Schlegel, M. C., Rödig, L., Jepsen, D., Memelink, R., & Hauschke, F. (2024). The Front-Runner Approach—Facilitating Progressive Product Policy by Using Information from EU Product Databases. Energies, 17(2), 504. https://doi.org/10.3390/en17020504

Shi, T., Huang, R., & Sarigöllü, E. (2022). Consumer product use behavior throughout the product lifespan: A literature review and research agenda. Journal of environmental management, 302, 114114. https://doi.org/10.1016/j.jenvman.2021.114114

Sørensen, J. B., & Stuart, T. E. (2000). Aging, Obsolescence, and Organizational Innovation. Administrative Science

Quarterly, 45(1), 81-112. https://doi.org/10.2307/2666980

Sterling, P. (2016). Why We Consume: Neural Design and Sustainability. Great Transition Initiative (February).http://www.greattransition.org/publication/why-we-consume

Van den Berge, R., Magnier, L., & Mugge, R. (2023). Until death do us part? In-depth insights into Dutch consumers' considerations about product lifetimes and lifetime extension. Journal of Industrial Ecology, 27(3), 908-922. https://doi.org/10.1111/jiec.13372

Yang, D., & Vezzoli, C. (2024). Designing Environmentally Sustainable Furniture Products: Furniture-Specific Life Cycle Design Guidelines and a Toolkit to Promote Environmental Performance. Sustainability (Switzerland) , 16(7), 2628. https://doi.org/10.3390/su16072628

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Sufficiency in European Product Policies: Status Quo and Future Potentials

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Keywords: sufficiency; policy; electronics; production; consumption

Abstract: Technological innovations and efficiency measures have been the primary focus of many policies aimed at meeting global sustainability and resource security goals. However, it has been established in literature that these measures alone are unlikely to drive long-term sustainability or reduce absolute resource demands. Sufficiency-oriented approaches, which focus on slowing down and minimising resource use, are often overlooked in current policy frameworks and business strategies, especially in resource-intensive sectors like the electronics industry. Given the pressing need to address resource overconsumption and its environmental impacts, it is essential to explore how sufficiency can be incorporated into product policies. This paper analyses the current state of sufficiency-oriented measures in European product policies, taking consumer electronics and electrical devices as a case study, and proposes supplementary instruments that can advance sustainability targets. We also develop a categorization framework for sufficiency policies to lay the groundwork for future empirical research, which can help guide policy developments and encourage broader adoption of sufficiency strategies.

Introduction

While the transition to a circular economy (CE) is often seen as a key part of the solution to sustainability challenges and support our efforts to stay within planetary boundaries (Desing et al. 2020; McDonough and Braungart, 2002), most CE business and governmental strategies currently focus on efficiency (doing more with fewer resources) and consistency (developing technologies with minimal environmental impact). This approach emphasises decoupling environmental impacts from economic growth through resource efficiency measures, recycling targets and technological innovations, without addressing an overall reduction in material use (Bocken et al., 2022; Figge et al., 2014; Morseletto, 2020; York et al., 2022). Sufficiency, by contrast, calls for systemic change and absolute reduction of resource needs, by avoiding waste, extending product lifespans, and shifting social practices (Maitre-Ekern and Dalhammar, 2019). While there is an overlap between these three sustainability strategies (Rudolf and Schmidt, 2025), as shown in Figure 1, sufficiency-oriented measures, are also needed to realise global sustainability goals and resource security targets (Cordroch et al. 2022; IPCC, 2022; Sachs, 2015).

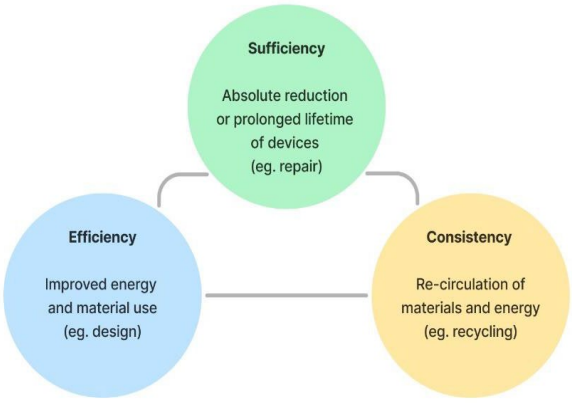


Figure 1: Interconnected sustainability strategies in EU product policies (own visual)

Despite growing recognition of its importance, sufficiency remains underrepresented in policy efforts (Zell-Ziegler et al., 2021; Calisto Friant et al., 2020), while mainstream eco-efficiency approaches have largely failed to achieve sustainable consumption patterns (Spangenberg and Lorek, 2019). Sufficiency approaches face resistance from various stakeholders (Gumbert et al. 2022; Suski et al. 2023). Businesses view sufficiency as a threat to their operations based on profit maximisation

(Bocken and Short 2016), and thus, most sufficiency-oriented business initiatives remain a niche (Niessen and Bocken, 2021). Policymakers also fear losing public support due to negative perceptions of sufficiency, such as its association with deprivation (Mont and Lehner, 2023). However, public legitimacy for sufficiency policies is growing gradually in the Global North (O'Dell et al., 2024; Jenny et al, 2024; Lage et al. 2023).

While most scholars agree that sufficiency is unavoidable, there has been an intensive debate about what sufficiency entails and how it should be defined (Jungell-Michelsson and Heikkurinen, 2022). Sufficiency has transitioned among scholars from being viewed as a moral responsibility of individuals, to the basis for unavoidable policy interventions (Lage et al., 2024, Santarius, et al., 2022; Spangenberg and Lorek, 2019). Literature highlights that relying on individual or organisational sufficiency leads to a slow and marginal progress that lacks widespread adoption, as mainstream social, economic, and policy frameworks deeply influence the possibilities to act (Greene et al., 2024).

Consequently, systemic approaches through policy interventions are necessary to enable sufficiency on a larger scale (Mont et al., 2022). Scholars have thus emphasized the need for further research on advancing sufficiency strategies in policies and identifying the factors that hinder their implementation. (e.g. Iten et al., 2024). In this conference paper, we aim to contribute to the literature by analysing the current state of European product policy efforts to advance sufficiency strategies, including the promotion of lower and slower consumption practices, while also exploring potential future policy approaches.

Defining sufficiency in policymaking

Most sufficiency literature examines what is required to achieve dual ecological and social goals - staying within planetary boundaries while ensuring social equity. Another key stream focuses on "action-oriented" approaches to achieving these objectives (Iten et al., 2024). Scholars debate whether the focus of sufficiency is solely on reducing consumption and/or production (e.g. Figge et al., 2014), whether it is a state to achieve or if it also involves a transformative process involving shifting to slower consumption practices (Speck, 2016) and slower production or service practices (Zechiel, 2024; Niessen and Bocken, 2021). Additionally, scholars explore the concept of "enoughness," including both its upper and lower limits and what those entail (Spengler 2016; Tröger and Reese 2021).

Instead of applying the definition of sufficiency as non-consumption (e.g. Stengel, 2011), we decided to adopt a broader yet pragmatic definition. Drawing on Lange et al. (2023) and Speck (2016), we define sufficiency in product policies as a strategy to reduce the overall resource demands of end-use products by transforming social practices and integrating accessible, low-impact options — such as lessen and slow down — into consumption and production patterns. "Lessen" aims to reduce absolute quantities of products by avoiding overconsumption or limiting sales. "Slow down" focuses on decelerating consumption and production by qualitative product changes and supporting extended lifetime practices. Guided by Zechiel (2024), our focus centres on reducing overconsumption among high-consuming classes and addressing overproduction, rather than questioning basic human needs. Through our analysis, we aim to contribute to research that seeks to develop a set of measures to guide policymakers toward more sufficiency-oriented strategies (e.g. Best et al., 2022).

We have decided to focus specifically on electronic and electrical devices in this work as a case study, as the electronics industry is among the top eight sectors contributing to over 50% of global carbon emissions (Singh and Ogunseitan, 2022), and discarded electronics are among the most problematic and fastest increasing waste streams (Baldé et al, 2024). While the absolute reduction of material consumption has clear environmental benefits, promoting product longevity through durability and repairability also reduces the environmental impact associated with resource extraction, manufacturing, and disposal (Cordella et al., 2021). Moreover, encouraging durability and repairability can reshape the relationship between manufacturers and consumers, requiring greater responsibility for product care from both sides (Beyeler & Jaeger-Erben, 2022), that may challenge the underlying linear material culture of novelty-seeking fuelling early product replacements (Jaeger-Erben et al., 2021a). Our guiding research questions are as follows:

1. What is the status quo of sufficiency strategies in current European product policies?
2. What policy instruments can foster sufficiency-oriented lifestyles and business practices in the consumer electronics sector?

Methods

Since scholars agree that few sufficiency-oriented policies have been implemented (e.g., Zell-Ziegler et al., 2021; Mont et al., 2022), we take a pragmatic approach to analysing the current state of sufficiency in European product policy, and like other scholars (e.g. Iten et al., 2024; Lage et al, 2024), we examine policies that may achieve sufficiency outcomes, even if they are not explicitly labelled as such.

We apply the parameters outlined below to enable us to identify and categorise sufficiency in current product policies:

1. Product stage: Upstream supply chain / Design and Production / Retail and Purchase/ Use-Phase / End-of-Life
2. Levels of sufficiency – Determining which sustainability strategy a specific measure belongs to is not always straightforward, as some measures may produce overlapping outcomes with efficiency or consistency. This led Fischer et al. (2013) to create a scale to measure the level of sufficiency-orientation: none to slight (e.g. use of smaller appliance) / medium (e.g. less convenient appliance) / strong (e.g. a time-intensive behavioural change, such as refraining from using a device for a period of time) / very strong (e.g. doing without appliance, complete change of practice)
3. Policy instrument type: regulation, information-based, planning and infrastructure provision, economic measure (Heyen et al. 2013)
4. Push (eliminating counterproductive practice) or pull measure (supporting stakeholders to take up more sustainable practices, such as producing or consuming more sustainable products and services) (Gröne, 2016; Lage et al., 2024)

Status quo of sufficiency in European product policies

While the second European Circular Economy Action Plan (COM 2020/98) has oriented product policies to encompass more the entire product lifecycle, most circularity strategies still focus on downstream approaches and end-of-life processes such as recovery and recycling (Baldassarre and Saveyn, 2023; Calisto-Friant et al. 2024). However, the Ecodesign for Sustainable Products Regulation (ESPR) (EU 2024/1781), the Directive on the Repair of Goods (EU 2024/1799) and the updated Battery Regulation (EU 2023/1542) represent a recent policy shift toward extending product lifetimes. They establish minimum design requirements for selected products entering the European market, extending beyond energy efficiency standards to include criteria for durability and repairability, such as easier removability of portable batteries.

They also mandate that producers provide spare parts and repair services within a reasonable time and at a reasonable price and strengthen consumer repair rights such as extended consumer warranties after repairs. Upcoming repairability labels aim primarily to encourage sustainable product choices among consumers, while also potentially prompting manufacturers to change their product designs. All these policy developments may lead to slower consumption that can be identified as a sufficiency strategy.

Nevertheless, current European measures primarily focus on improving product quality, without adequately addressing the unsustainable levels of resource consumption and the underlying linear structures driving them. While ecodesign standards promote the design of more durable and repairable products, repair and reuse remain economically less viable options for consumers. For instance, it remains unclear what constitutes 'reasonable' pricing for spare parts and repairs. Additionally, fast product turnover driven by linear business strategies is barely addressed. The only exception is that the ESPR also includes an upcoming ban on returned and unsold goods, which could encourage producers and retailers to reconsider overproduction and wasteful practices. However, this ban will initially apply only to textiles and footwear, with only mandatory reporting required for other product categories. See Table 1 below for an overview.

European Union:	Product stage	Sufficiency level	Instrument type	Push or pull measure
Extended Ecodesign Regulation: minimum requirements on durability, lifetime, repairability of products, limiting anti-repair practices; mandatory availability of certain spare parts	Design, Production and Use-phase	Strong	Regulation	Push for producers, Pull for consumers and repairers
Right to repair: extended warranty, online repair platform, service price form, manufacturers have to repair products within a reasonable time and for a reasonable price	Design, Production and Use-phase	Medium	Regulation and Information	Push for producers, Pull for consumers and repairers
Updated Battery Regulation: more removable and replaceable portable batteries, performance and durability standards	Design, Production and Use-phase	Medium	Regulation	Push for producers, Pull for consumers and repairers
Repairability labelling: based on repair index	Design, Retail and Purchase	Medium	Information	Pull for both producers and consumers
Digital product passport: information on product's origin, materials, environmental impact, disposal and possibility for repair data	All stages	Medium	Information	Pull for all stakeholders
Member states:	**Product stage**	**Sufficiency level**	**Instrument type**	**Push or pull measure**
Criminalisation of planned obsolescence (France and Italy)	Design and Production	Strong	Regulation	Push for producers
Banning the destruction of unsold goods (France, and coming up on EU level)	Retail, Purchase and End-of-Life	Very strong	Regulation	Push for producers, retailers and consumers
Repairability and durability scores (France)	Retail and Purchase	Medium	Information	Pull for both producers and consumers
Extended Producer Responsibility with eco-modulation for repairability and durability, and with a repair fund for post-warranty repairs (France)	Design, Production and Use-Phase	Medium	Economic	Push for producers, Pull for consumers
Tax incentives for repairs (e.g., in Sweden)	Use-Phase	Medium	Economic	Pull for consumers and repairers
Repair vouchers (Austria and Germany)	Use-Phase	Medium	Economic	Pull for consumers
Supporting the cooperation between stakeholders in recycling centres and those involved in reuse and repair (many municipalities, eg., Brussels)	End-of-Life and Use-Phase	Strong to Very strong	Planning and infrastructure provision	Pull for stakeholders involved in repair and reuse
Supporting community repair facilities, such as repair cafés (e.g., public funding in Germany)	Use-Phase	Strong to Very strong	Planning and infrastructure provision	Pull for stakeholders involved in repair and reuse

Table 1: Policy interventions to advance sufficiency in products' lifecycle (own table)

Some member states have also implemented product policies to advance sustainable consumption. For instance, France and Italy have introduced legislative measures to combat planned obsolescence, aiming to reduce the number of products entering the market with intentionally poor design (Dalhammar et al., 2022). Unlike the upcoming European ban on the destruction of goods, France's ban also includes electronics, and Germany has already implemented a reporting mechanism (Roberts et al., 2023). Furthermore, many municipal governments support reuse and repair for local stakeholders by allowing diverting items and spare parts from recycling centres (Dalhammar et al., 2021; Zucaro et al., 2022), with the updated EU Waste Framework (EU 2018/851) supporting these efforts by calling for treating end-of-life objects as resources rather than waste and emphasising the priority to reduce waste. Additionally, community repair initiatives, such as those in Germany, are state funded by up to 3000 Euro, enabling the adoption of a stronger repair culture (BMUV, 2024).

Economic measures have been also adopted by national and local municipalities to enable consumer repairs (Meyer and Molnár, 2024). In France, a repair fund was established to offer discounts on repairs, financed through eco-modulation fees paid by manufacturers. However, this measure was found to have limited effects on product design and consumer practices due to minimal incentives (Right to Repair Europe, 2024; Micheaux and Aggeri, 2021). Moreover, while the European VAT revision (EU 2022/542) extended tax reductions possibilities to household appliance repairs, no member state has implemented this yet, only to other products such as shoes and bicycles (Dalhammar et al., 2022). In Sweden, labour costs are partially deductible from taxes when repairs take place in homes. As a different approach, Austria and Germany have introduced repair vouchers to subsidise consumer repairs, but these are planned as temporary measures and do not challenge the mainstream linear market (Molnár and Jaeger-Erben, 2025). As voucher schemes are financed from public funding, they also do not have any direct financial effect on producers.

Possible Future Directions for Circular Product Measures for Sufficiency

Many stakeholders recognize the need for a radical transformation in our production and consumption systems to enable sustainable development (e.g., COM 2020/98; Kreinin et al., 2024). However, comprehensive sufficiency strategies are largely absent from policy implementation at both the European and national levels. Some scholars argue that true sufficiency policy requires a transformative shift in the entire sociopolitical and economic systems and not just adapting existing measures (Callmer and Bradley, 2021), a so-called “deep” transformation instead of a “superficial” one (Newell et al., 2021). This section offers suggestions to strengthen sufficiency in product policies. As visualised below in Figure 2, most current policy measures target only the design and use-phase of electronics. Our policy recommendations that are not yet implemented are marked in red.

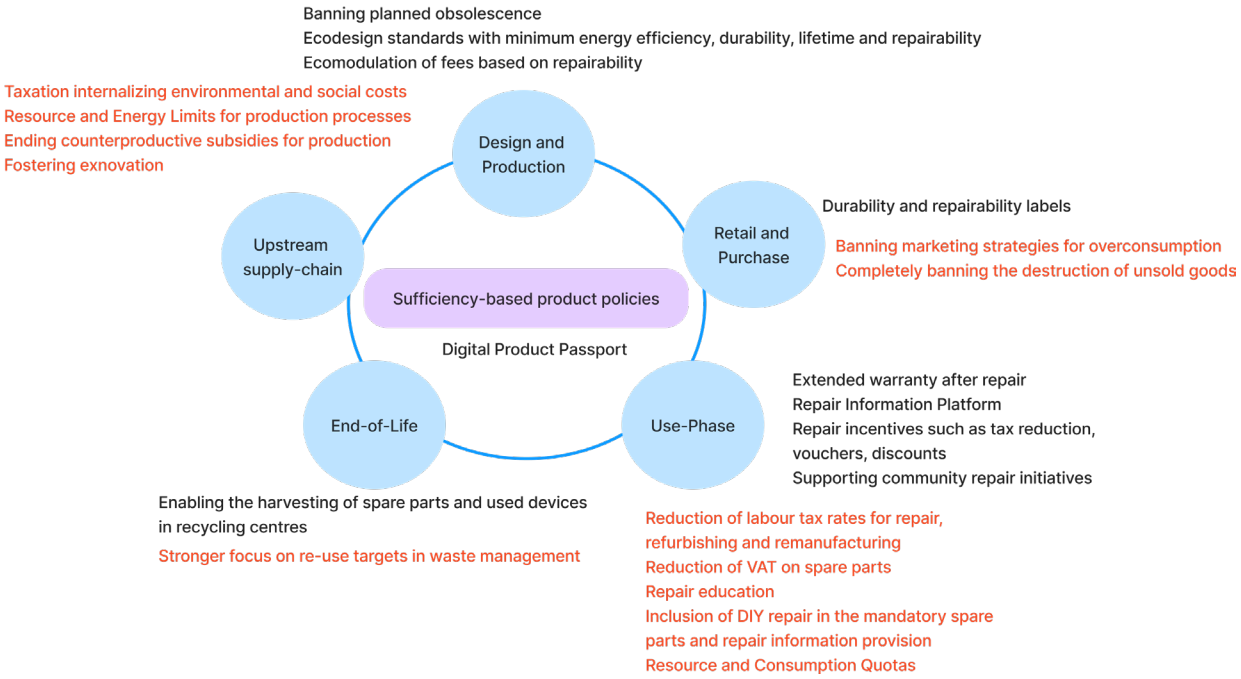


Figure 2: Status quo and future possibilities for a sufficiency-oriented product policy framework (own visual)

Supporting a transformation within production systems

For a truly sustainable circular economy, policies must encourage a shift towards "making do with less" and encouraging moving beyond profit growth as primary objectives of businesses and GDP growth for states (Bocken et al., 2022). Possible policy interventions could include:

1. Limiting the Externalization of Costs: The low costs of new products must be addressed to slow down product replacements. While the market price of a product currently excludes negative social and environmental externalities, the mandatory "true price" would account for these, incorporating both social issues (e.g., forced or child labour, health risks, inadequate wages) and environmental issues (e.g., air pollution, fossil fuel consumption, and land use changes) (Malinauskaite and Jouhara, 2024). Additionally, counterproductive state subsidies, such as those for fossil fuels, should be eliminated.

2. Tax incentives: Labour taxes on repair services should be reduced in Europe, while taxes on production processes should be increased. Raising corporate tax rates based on resource use would encourage more sustainable production practices. For example, higher taxes could be imposed on non-durable or non-repairable items.

3. Differentiated Producer Responsibility Fees: Manufacturers of short-lived products should pay higher fees into extended producer responsibility schemes than those producing durable goods. This would discourage planned obsolescence and incentivize product longevity.

4. Slower innovation cycles and incentivized exnovation: While technological innovation is essential for sustainability, it often falls short in displacing deeply rooted unsustainable structures. For example, more resource- and energy-efficient products do not necessarily lead to an overall decrease in resource use, due to factors like rebound effects and increased consumption (Laurenti et al. 2015). Exnovation is the deliberate phase-out of unsustainable technologies, infrastructure, and practices to achieve socio-ecological sustainability. This process can be facilitated through "exnovation governance," which involves policies and strategies designed to support and manage this transition (Heyen et al., 2017). Through setting standards, for instance, policymakers can encourage longer product lifespans and reduce constant product upgrades, fostering a more sustainable innovation approach.

5. Product standards: Policymakers could set absolute limits on energy and resource consumption standards for products, regardless of size or type (Calwell, 2010). Additionally, life cycle cost assessments used as the basis for setting legal standards under the Ecodesign Directive could incorporate social costs of carbon (Sonnenschein et al., 2019).

6. Sufficiency Investment Funds: Governments could establish funds specifically for sufficiency initiatives and for businesses with sufficiency aims. Institutional investors, such as pension funds, should be also encouraged to prioritize investments for sufficiency initiatives (Bocken and Short, 2021).

Supporting consumer behaviour change for more sufficiency

While transforming production and business practices is crucial, promoting changes in consumer behaviour towards more sufficiency is equally important. Scholars suggests that information-based approaches such as product labels alone are insufficient to support a change in consumption practices (Sahakian and Dobigny, 2019), and to create lasting impacts, stronger instruments such as regulations and economic incentives are needed (Spangenberg and Lorek, 2019). Potential policies include:

1. Promote a Circular Society Mindset: Policy makers should encourage a shift in consumer roles from passive users to active caretakers and value-creators of products. In a “circular society” (Jaeger-Erben et al., 2021b), consumers should have the right to own, repair, and modify their electronics, with equal access to information and spare parts. Education for repair skills should be promoted in schools and vocational training programmes, as being able to repair devices would encourage a more sustainable human-device relationship (Van der Velden, 2021) and a material culture against novelty-seeking (Jaeger-Erben et al., 2021a). Another approach could be to regulate advertising strategies that promote over-consumption, such as through bulk purchase discounts (Bocken and Short, 2021).

2. Economic Incentives for Sustainable Consumer Practices: Longer product use, device care, and the reuse of products can be incentivized through vouchers and similar measures that reward consumers for their actions.

3. Product regulation strategies that increase costs could promote sufficiency by encouraging the consumption of fewer and higher-quality goods. Previous studies highlighted that product price and quality are key factors influencing consumer willingness to repair products (Mrad et al., 2025; Fachbach et al., 2021). Higher product prices could also reduce potential rebound effects that might occur when lower prices of other products or services result from improvements in efficiency or labour cost reductions—an issue commonly associated with efficiency measures (Pufé, 2017).

4. Resource and Consumption Quotas: As a more radical measure, quotas on high-impact resource activities could be imposed to directly limit excessive use. However, this approach may raise challenges related to democratic planning beyond growth (Durand et al., 2023).

5. For a long-lasting change in consumption practices, alternative, more sustainable consumption activities must be better linked to practices that are part of people’s routines (Spurling et al. 2013). For instance, more repair facilities could be placed in popular places, such as in shopping malls.

Conclusion

Given the need for sufficiency strategies to reduce societal resource demands, this work analysed the current state of European product policies and proposed supplementary instruments to enhance their effectiveness. Our analysis reveals that more radical measures are necessary to support sustainable production and consumption practices. Upcoming policy frameworks, such as the Circular Economy Act must focus on strategies beyond efficiency measures to reduce resource needs; however, it currently falls short in this regard (Euractiv, 2025). While this study presents the results of a literature and policy review, future research could gather empirical data from relevant stakeholders to refine our conceptual framework and better understand how the proposed sufficiency-oriented measures could function in practice.

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References

Baldassarre, B. and Saveyn, H.G.M. (2023) A systematic analysis of EU publications on the Circular Economy. Sevilla, Spanie: European Commission, Joint research Centre, doi:10.2760/36203

Baldé, C.P, Kuehr, R., Yamamoto, T., et al. (2024). Global E-waste Monitor 2024, https://ewastemonitor.info/the-global-e-waste-monitor-2024/

Bengtsson M, Alfredsson E, Cohen M, et al. (2018) Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. Sustainability Science 13(6): 1533–1547. https://doi.org/10.1007/s11625-018-0582-1

Best B, Thema J, Zell-Ziegler C et al. Building a database for energy sufficiency policies [version 1; peer review: 2 approved]. F1000Research 2022, 11:229 https://doi.org/10.12688/f1000research.108822.1.

Beyeler, L., Jaeger-Erben, M. (2022) How to make more of less: Characteristics of sufficiency in business practices. Front. Sustain. 3:949710. doi: 10.3389/frsus.2022.949710

BMUV (2024). Bundesumweltministerium fördert erstmals Repair-Cafés und Selbsthilfewerkstätten, 21.10.2024. https://www.bmuv.de/pressemitteilung/bundesumweltministerium-foerdert-erstmals-repair-cafes-und-selbsthilfewerkstaetten (last accessed: 09.11.2024)

Bocken, N. M. P., Niessen, L., and Short, S. W. (2022). The sufficiency-based circular economy—an analysis of 150 companies. Front. Sustain. 3, 899289. doi: 10.3389/frsus.2022.899289

Bocken, N. M., and Short, S. W. (2021). Unsustainable business models–Recognising and resolving institutionalised social and environmental harm. J. Clean. Product. 12, 7828. doi: 10.1016/j.jclepro.2021.127828

Bocken, N., and Short, S. W. (2016). Towards a sufficiency-driven business model: experiences and opportunities. Environ. Innov. Soc. Trans. 18, 41–61. doi: 10.1016/j.eist.2015.07.010

Calisto Friant, M., Vermeulen, W.J.V., Salomone, R. (2024) Transition to a Sustainable Circular Society: More than Just Resource Efficiency. Circ.Econ.Sust. 4, 23–42. https://doi.org/10.1007/s43615-023-00272-3

Calisto Friant, M., Vermeulen, W.J.V. & Salomone, R. (2020) A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm, Resources, Conservation and Recycling, 161, https://doi.org/10.1016/j.resconrec.2020.104917

Callmer, Å., Bradley, K. (2021) In search of sufficiency politics: the case of Sweden. Sustain Sci Pract Policy 17:196–209. https://doi.org/10.1080/15487733.2021.1926684

Calwell, C. (2010). Is Efficient Sufficient: The Case for Shifting Our Emphasis in Energy Specifications to Progressive Efficiency and Sufficiency." Stockholm, Sweden: European Council for an Energy Efficient Economy.

Cordella, M., Alfieri, F., Sanfelix, J. (2021). "Reducing the carbon footprint of ICT products through material efficiency strategies: A life cycle analysis of smartphones," Journal of Industrial Ecology, Yale University, vol. 25(2), pages 448-464. doi: 10.1111/jiec.13119

Cordroch, L., Hilpert, S., Wiese, F. (2022). Why renewables and energy efficiency are not enough - the relevance of sufficiency in the heating sector for limiting global warming to 1.5 °C., Technological Forecasting and Social Change, 175, https://doi.org/10.1016/j.techfore.2021.121313

Dalhammar, C., Hartman, C., Larsson, J., Jarelin, J., Milios, L., Mont, O. (2022). Moving away from the throwaway society. Five policy instruments for extending the life of consumer durables. Mistra, Sustainable

Consumption, Report 1:12E. Gothenburg: Chalmers University of Technology. https://research.chalmers.se/publication/528688/file/528688_Fulltext.pdf

Dalhammar, C., Wihlborg, E., Milios, L. et al. (2021) Enabling Reuse in Extended Producer Responsibility Schemes for White Goods: Legal and Organisational Conditions for Connecting Resource Flows and Actors. Circ.Econ.Sust. 1, 671–695. https://doi.org/10.1007/s43615-021-00053-w

Desing, H., Brunner, D., Takacs, F., Nahrath, S., Frankenberger, K., Hischier, R. (2020). A circular economy within the planetary boundaries: Towards a resource-based, systemic approach, Resources, Conservation and Recycling, Volume 155, https://doi.org/10.1016/j.resconrec.2019.104673

Durand, C., Hofferberth, E., Schmelzer, M. (2023). Planning beyond growth: The case for economic democracy within ecological limits. Journal of Cleaner Production. 437. 10.1016/j.jclepro.2023.140351.

Euractive (2025) Commission still hesitating over new targets in Circular Economy Act, https://www.euractiv.com/section/eet/news/commission-still-hesitating-over-new-targets-in-circular-economy-act/ (last accessed: 25.03.2025)

European Commission (COM 2020/98). Communication from the Commission: A new Circular Economy Action Plan for a cleaner and more competitive Europe: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A98%3AFIN.

European Union (EU 2024/1781). Regulation establishing a framework for the setting of ecodesign requirements for sustainable products. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1781&qid=1719580391746

European Union (EU 2024/1799) Directive on common rules promoting the repair of goods, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024L1799

European Union (EU 2023/1542) Regulation concerning batteries and waste batteries, https://eur-lex.europa.eu/eli/reg/2023/1542/oj

European Union (EU 2022/542). Council Directive (EU) 2022/542 of 5 April 2022 on rates of value added tax. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022L0542

European Union (EU 2018/851). Directive on waste. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.150.01.0109.01.ENG

Fachbach, I., Lechner, G., Reimann, M. (2022), “Drivers of the consumers’ intention to use repair services, repair networks and to self-repair,” J. Clean. Prod., 346, 130969. https://doi.org/10.1016/j.jclepro.2022.133096

Figge, F., Young, W., & Barkemeyer, R. (2014). Sufficiency or efficiency to achieve lower resource consumption and emissions? The role of the rebound effect. Journal of Cleaner Production, 69. https://doi.org/10.1016/j.jclepro.2014.01.031

Fischer C., Griesshammer R., Barth, R., Brohmann, B., Brunn, C., Heyen, D.A., Keimeyer, F., Wolff, F. (2013). When less is more. Sufficiency: terminology, rationale and potentials. Oeko-Institut. https://www.oeko.de/oekodoc/1879/2013-007-en.pdf

Gorge, H., Herbert, M., Özçağlar-Toulouse, N., & Robert, I. (2015). What Do We Really Need? Questioning Consumption Through Sufficiency. Journal of Macromarketing, 35(1), 11-22. https://doi.org/10.1177/0276146714553935.

Greene, M., Hobson, K., Jaeger-Erben, M. (2024). Bringing the circular economy home – Insights from socio-technical perspectives on everyday consumption, Cleaner and Responsible Consumption, Volume 12, 100157, https://doi.org/10.1016/j.clrc.2023.100157.

Gröne, M.C. (2016). Energiesuffizienz als Strategie zur Förderung nachhaltiger Stadtentwicklung (sustainable urban energy transition): Akteure und Maßnahmen auf kommunaler Ebene

am Beispiel der Stadt Wuppertal. Wuppertal Papers. https://www.econstor.eu/bitstream/10419/144814/1/864827423.pdf

Gumbert, T., Mamut, P., Fuchs, D., Welck, T. (2022). Sustainable consumption and the power of economic growth: exploring alternatives to the growth-dependency narrative. Consumption and Society. 1. 1-21. doi: 10.1332/JPPD7512.

Heyen, D.A., Hermwille, L., Wehner, T. (2017). Out of the Comfort Zone! Governing the Exnovation of Unsustainable Technologies and Practices, GAIA 26/4: 326–331, https://d-nb.info/1150292326/34

Heyen DA, Fischer C, Barth R, Brunn, C., Grießhammer, R., Keimeyer, F., Wolff, F. (2013). When less is more. Sufficiency—need and options for policy action. https://www.oeko.de/oekodoc/1880/2013-008-en.pdf

IPCC (2022). Mitigation of Climate Change. Summary for Policymakers. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York. https://doi.org/10.1017/9781009157926.001

Iten, T., Seidl, I. & Pütz, M. Sufficiency policy: a definition, conceptual framework, and application to municipalities. Sustain Sci 19, 1709–1734 (2024). https://doi.org/10.1007/s11625-024-01534-1

Jaeger-Erben, M., Frick, V., Hipp, T. (2021a) Why do users (not) repair their devices? A study of the predictors of repair practices. Journal of Cleaner Production, Vol. 286, https://doi.org/10.1016/j.jclepro.2020.125382

Jaeger-Erben, M., Jensen, C., Hofmann, F., and Zwiers, J. (2021b). There is no sustainable circular economy without a circular society. Res. Conserv. Recycl. 168, 105476. doi: 10.1016/j.resconrec.2021.105476

Jenny, A., Müller, U., Skelton, R., & Mastai, N. (2024). Policies for sufficiency: factors influencing acceptance in the Swiss population. Sustainability: Science, Practice and Policy, 20(1). https://doi.org/10.1080/15487733.2024.2420415.

Jungell-Michelsson, J., Heikkurinen, P. (2022). Sufficiency: a systematic literature review. Ecol Econ 195:107380. https://doi.org/10.1016/j.ecolecon.2022.107380

Kreinin, H., Fuchs, D., Mamut, P., Hirth, S., Lange, S. (2024) Transforming provisioning systems to enable 1.5° lifestyles in Europe? Expert and stakeholder views on overcoming structural barriers, Sustainability: Science, Practice and Policy, 20:1, doi: 10.1080/15487733.2024.2372120

Lage, J., Best, B., Froese, T., Zell-Ziegler, C. (2024). Policy-Making as a Crucial Element for Sufficiency on the Business Level. Discussing the Role of Policies to Push Sufficiency beyond Pioneers. In: Maike Gossen/ Laura Niessen (Eds.), Sufficiency in Business, p.325-340. Bielefeld: transcript Verlag. https://doi.org/10.14361/9783839469101-020

Lage, J., Thema, J., Zell-Ziegler, C., Best, B., Cordroch, L., Wiese, F. (2023). Citizens call for sufficiency and regulation — A comparison of European citizen assemblies and National Energy and Climate Plans, Energy Research & Social Science, Vol.104,103254, https://doi.org/10.1016/j.erss.2023.103254

Laurenti, R., Sinha, R., Singh, J. & Frostell, B. 2015 Some pervasive challenges to sustainability by design of electronic products - A conceptual discussion. Journal of Cleaner Production 108, 281–288. doi: 10.1016/j.jclepro.2015.08.041

Maitre-Ekern, E., & Dalhammar, C. (2019). Towards a hierarchy of consumption behaviour in the circular economy. Maastricht Journal of European and Comparative Law, 26(3), 394-420. https://doi.org/10.1177/1023263X19840943

Malinauskaite, J. and Hussam, J. (2024). Circular economy: Policies to drive sustainability and the measures to improve energy efficiency. 10.1016/B978-0-443-18454-3.00002-3.

McDonough, W., and Braungart, M. (2002). Cradle to Cradle: Remaking the Way We Make Things, 1st Edn. New York, NY: North Point Press.

Meyer, K. and Molnár, M. (2024). A comprehensive overview of the current repair incentive systems: repair funds and vouchers, 12.2.2024. https://runder-tisch-reparatur.de/repair-funds-europe/ (last accessed: 09.11.2024)

Micheaux, H., Aggeri, F. (2021). Eco-modulation as a driver for eco-design: a dynamic view of the French collective EPR scheme, doi: 10.1016/j.jclepro.2020.125714

Molnár and Jaeger-Erben, 2025 (forthcoming) Supporting consumer engagement in electronics repair: effects of financial incentives and voucher schemes, Journal of Responsible Production and Consumption, doi: 10.1108/JRPC-09-2024-0049

Mont, O., and Lehner, M. (2023). From sufficiency to sustainable abundance: dispelling a myth. Paper presented at 5th SCORAI, 21st ERSCP, and Wageningen University Conference, Wageningen, Netherlands. https://osf.io/79asj

Mont, O., Lehner, M. and Dalhammar, C. (2022). Sustainable consumption through policy intervention—A review of research themes. Front. Sustain. 3:921477. doi: 10.3389/frsus.2022.921477.

Morseletto, P. (2020). Targets for a circular economy. Res. Conserv. Recycl. 153, 104553. doi: 10.1016/j.resconrec.2019.104553.

Mrad, M., Semaan, R.W., Christodoulides, G. Prandelli, E. (2025). Give me a second life! Extending the life-span of luxury products through repair, Journal of Retailing and Consumer Services, Vol.82,104055, https://doi.org/10.1016/j.jretconser.2024.104055.

Newell, P., Twena, M., and Daley, F. (2021). Scaling behaviour change for a 1.5-degree world: challenges and opportunities. Global Sustainabil. 4, 1–13. doi: 10.1017/sus.2021.23

Niessen, L., and Bocken, N. M. P. (2021). How can businesses drive sufficiency? The business for sufficiency framework. Sustain. Prod. Consump. 28, 1090–1103. doi: 10.1016/j.spc.2021.07.030

O'Dell, D., Contu, D. and Shreedhar, G. (2025) Public support for degrowth policies and sufficiency behaviours in the United States: a discrete choice experiment. Ecological Economics, 228. 10.1016/j.ecolecon.2024.108446.

Pufé, I. (2017). Nachhaltigkeit (3. ed.). utb. https://doi.org/10.36198/9783838587059

Right to Repair Europe (2024) Reforming Extended Producer Responsibility to Promote Repair, https://repair.eu/wp-content/uploads/2024/08/EPR-and-Repair-Funds-1.pdf

Roberts, H., Milios, L., Mont, O., Dalhammar, C. (2023) Product destruction: Exploring unsustainable production-consumption systems and appropriate policy responses, Sustainable Production and Consumption, Vol. 35, 300-312, https://doi.org/10.1016/j.spc.2022.11.009.

Rudolf, M., Schmidt, M. (2025). Efficiency, sufficiency and consistency in sustainable development: Reassessing strategies for reaching overarching goals, Ecological Economics, 227, https://doi.org/10.1016/j.ecolecon.2024.108426

Sachs, J. D. (2015). The age of sustainable development. Columbia University Press.

Sahakian, M., Dobigny, L. (2019). From governing behaviour to transformative change: A typology of household energy initiatives in Switzerland, Energy Policy, Volume 129, p.1261-1270, https://doi.org/10.1016/j.enpol.2019.03.027.

Sandberg, M. (2021). Sufficiency transitions: a review of consumption changes for environmental sustainability. J. Cleaner Prod. 293, 126097. doi: 10.1016/j.jclepro.2021.126097

Santarius T, Bieser JCT, Frick V et al (2022) Digital sufficiency: conceptual considerations for ICTs on a finite planet. Ann Telecommun. https://doi.org/10.1007/s12243-022-00914-x

Singh, N., Ogunseitan, O. A. (2022). Disentangling the worldwide web of e-waste and climate change co-benefits,

Circular Economy,100011, https://doi.org/10.1016/j.cec.2022.100011.

Spangenberg, J.H., Lorek, S., Jun. 2019. Sufficiency and consumer behaviour: from theory to policy theory to policy. Energy Pol. 129, 1070–1079. URL. https://linkinghub.elsevier.com/retrieve/pii/S0301421519301764. https://doi.org/10.1016/j.enpol.2019.03.013

Sonnenschein, J., Mundaca, L. (2019). Is one carbon price enough? Assessing the effects of payment vehicle choice on willingness to pay in Sweden, Energy Research & Social Science, 52, p.30-40, https://doi.org/10.1016/j.erss.2019.01.022.

Speck, M. (2016), Konsum und Suffizienz : eine empirische Untersuchung privater Haushalte in Deutschland, Springer Fachmedien Wiesbaden, doi: 10.1007/978-3-658-13488-4.

Spurling, N., McMeekin, A. (2015). Interventions in practices: sustainable mobility policies in England Y. Strengers, C. Maller (Eds.), Social Practices, Intervention and Sustainability: beyond Behaviour Change (first ed.), Routledge, London (2015), pp. 78-94, doi: 10.4324/9781315816494

Suski, P., Palzkill, A., Speck, M. (2023). Sufficiency in social practices: An underestimated potential for the transformation to a circular economy, Frontiers in Sustainability, doi: 10.3389/frsus.2022.1008165.

Tröger J, Reese G (2021) Talkin' bout a revolution: an expert interview study exploring barriers and keys to engender change towards societal sufficiency orientation. Sustain Sci 16:827–840, https://doi.org/10.1007/s11625-020-00871-1.

van der Velden M. (2021). Fixing the world one thing at a time: community repair and a sustainable circular economy. J Clean Prod 304:127151. https://doi.org/10.1016/j.jclepro.2021.127151.

York, R., Adua, L., Clark, B. (2022). The rebound effect and the challenge of moving beyond fossil fuels: a review of empirical and theoretical research Wiley Interdisciplinary Reviews: Clim. Change, 13 (4), doi: 10.1002/wcc.782.

Zechiel, F. (2024). Beyond Efficiency and Consistency – Achieving Sustainability through Service-enabled Sufficiency. In: Bruhn, M., Hadwich, K. (eds) Sustainable Service Management. Forum Dienstleistungsmanagement. Springer Gabler, Wiesbaden. https://doi.org/10.1007/978-3-658-45146-2_13

Zell-Ziegler, C., Thema, J., Best, B., Wiese, F., Lage, J., Schmidt, A., Toulouse, E., Stagl, S. (2021) Enough? The role of sufficiency in European energy and climate plans, Energy Policy, Volume 157, https://doi.org/10.1016/j.enpol.2021.112483

Zucaro A, Maselli G and Ulgiati S. (2022). Insights in Urban Resource Management: A Comprehensive Understanding of Unexplored Patterns. Front. Sustain.Cities, https://doi.org/10.3389/frsc.2021.807735.

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What's the Problem with Product Obsolescence? Critical Policy Perspectives from Australia's Right to Repair Inquiry

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Keywords: Circular Economy; policies for extended lifetimes; product obsolescence; mandatory design standards; right to repair.

Abstract:
Extending product lifetimes is a critical aspect of achieving Circular Economy outcomes, however current policy discussions in Australia do not adequately address product obsolescence (PO). Using a problematisation analysis method, this research aims to uncover how PO is framed within Australia's Right to Repair (R2R) Inquiry and how these problematisations impact the effective transition to a Circular Economy. The document analysis results indicate that Australian regulatory interventions shift responsibility for PO onto consumers, framing the issue as one of consumer choice driving rapid disposal. It was found that despite strong support for design stage interventions in submissions to the Inquiry, the report ultimately recommended against placing PO obligations on producers. Instead, the report suggested introducing labelling requirements, placing the burden of obsolescence on consumers. This framing reflects an ideology of economic rationalism, driven by governmental hesitancy to strongly regulate the private sector. In this representation, the environmental impacts of PO, and the importance of regulation in environmental conservation, are minimised. The Australian approach can be contrasted with the European Union approach which places responsibility on producers to design products in accordance with eco-design requirements and disseminate repairability information, emphasising the role of comprehensive policy mixes in driving positive environmental outcomes. The contrasts between these solutions reflect different understandings of not only what the problem with PO is, but also who is responsible for it. This research posits that without a reconceptualisation of the problem representation of PO in Australia, Circular Economy outcomes will not be achieved.

Introduction

Extending product lifetimes is a significant goal of a Circular Economy (CE) (Ellen Macarthur Foundation, n.d.). However, there is economic disincentive to design products to last or to design them in a way that allows parts or the whole to be repaired, reused, or recycled (Maitre-Ekern & Dalhammar, 2016; Waldman, 1993). As more products become obsolete after a relatively short period or after limited usage, more and more products are dumped earlier in their potential lifetimes, undermining the effective transition to a CE (Box, 1983; Pope, 2017). Whilst shortened product lifetimes have increasingly been brought to the government's attention (Productivity Commission, 2021b), current policy frameworks in Australia do not adequately regulate the issue of product obsolescence.

This paper aims to analyse policy documents targeting PO in Australia to uncover the problematisations inherent in the framing of waste generation within them, and how these problematisations advance or limit the transition to a CE (Bacchi, 2009). Firstly, this paper will provide the background of PO and its policy frameworks in Australia. Secondly, this paper will critically analyse the 'solutions' presented in the Right to Repair (R2R) Inquiry to uncover the problematisations of PO (Bacchi, 2009) and their impact on the systematic transition to CE in Australia (Geels, 2019; Gunningham & Sinclair, 2017). Finally, as part of the method, this paper will discuss the Australian response in context to the problematisations of PO in the European Union (EU).

Background

Product obsolescence (PO) was first proposed in 1932 as a remedy to the Great Depression which advocated for the deliberate manufacture of goods to fail after a short time, stimulating the economy through consumption (Becher & Sibony, 2021). Since then however, it has been

generally agreed that PO is a significant problem that leads to excessive consumption, waste generation, and poor competition practices (Becher & Sibony, 2021; Bisschop et al., 2022; Ellen Macarthur Foundation, 2021; Maitre-Ekern & Dalhammar, 2016; 2024/1781, 2024).

PO is a complex concept made up of several techniques, such as planned, functional, and psychological obsolescence, employed by firms to encourage consumers to buy more and own for shorter periods (Becher & Sibony, 2021). Planned obsolescence includes purposeful design of products to have uneconomically short lives to stimulate further purchases (Becher & Sibony, 2021). Functional obsolescence refers to manufacturers using subpar quality materials, making products irreparable, or forcing software updates that render the product dysfunctional (Becher & Sibony, 2021). Functional obsolescence impacts the recyclability of products at the end-of-life stage too (Productivity Commission, 2021b). Finally, psychological obsolescence refers to the marketing techniques firms employ to instil a desire for "something a little newer, a little better, a little sooner than necessary" (Adamson et al., 2003).

Despite the focus of this paper on PO, it is important to mention that concepts of repairability and durability are inextricable from a comprehensive understanding of PO, both being intrinsic to the advancement of longer product lifetimes (Maitre-Ekern & Dalhammar, 2016). Durability refers to a product's lifetime at design and its ability to withstand the demands of its function, whilst repairability aims to increase lifetimes past their durable expiration (Dalhammar et al., 2023).

Examples of product obsolescence are rife throughout both history and the globe, resulting in economic and environmental failures (Productivity Commission, 2021b). Notably, PO generates negative externalities, namely the creation of waste, which is rarely internalised by the waste creator (Rivera & Lallmahomed, 2016). Due to the complex and varied nature of PO and the arguments made by manufacturers that they do not deliberately induce obsolescence in their products, there appears a significant need for legislative intervention through the introduction of a multi-level multi-policy regulatory framework (Gunningham & Sinclair, 2017; Maitre-Ekern & Dalhammar, 2016; 2024/1781, 2024).

In Australia, there is currently no regulatory obligation on manufacturers to ensure their products do not become prematurely obsolete. Though the Australian Consumer Law (ACL) suggests that manufacturers should ensure their products are durable or repairable, there are no mandated guidelines over what that means in a material context (Competition and Consumer Act 2010 (Commonwealth), Sch 2). In recognition of this gap, the Productivity Commission (an advisory body to the Australian Government) developed a national report into the 'right to repair' in Australia, which aimed to address the "*expense of repair and product design [that] accelerates the transfer of consumer goods into waste*" (Productivity Commission, 2021b).

Submissions to the Inquiry emphasised that issues with durability and repairability begin at the design stage, stating: "*Ideally [products] should be designed to be able to be refurbished, repaired, reused, long before we're focusing on recycling*" (Productivity Commission, 2021a). More submissions further highlighted the unwillingness of manufacturers to engage in sustainable production without regulatory intervention, stating that "*most manufacturers can do whatever they want without seriously considering the waste or environmental impact…* (Productivity Commission, 2021a). Despite these submissions, the report asserted that there was little evidence to support the intentional practice of PO and affirmed the need to stimulate economies of growth (Productivity Commission, 2021b, pp. 22, 24).

Methodology and Scope

This paper will analyse the proposed solutions for PO in the R2R Inquiry through Bacchi's 'what is the problem represented to be' (WPR) approach (Bacchi, 2009). This approach to policy analysis proposes that rather than solving problems, policies produce them. (Bacchi, 2009). This discursive framing of an issue is an important consideration for multi-level perspectives when shaping socio-political interpretations of problems (Geels, 2019). The dissonance between the regulatory suggestions in the submissions and the findings of the Commission demonstrates a lack of understanding of how product design contributes to PO, and therefore CE outcomes. Problematisation analysis demonstrates that

the framing of PO in policy directly impacts the solutions put in place to address it and can act to undermine the development of effective legislative reform. Uncovering problem representations is a useful way to analyse regulatory reforms and provide understandings of the current regulatory barriers impacting the effective transition to a CE.

With mind to Bacchi's acknowledgment that the relevance of WPR questions vary depending on the aims of the study, this paper sets further boundaries by examining solutions with reference to five of six questions from the WPR method. The research identified questions 1, 3, 4, 5, and 6 as most relevant to this paper's aims (Table 1)

Table 1: WPR questions from (Bacchi, 2009)

1	What's the 'problem' represented to be in a specific policy or policy proposal?
3	How has this representation of the 'problem' come about?
4	What is left unproblematic in this problem representation? Where are the silences? Can the 'problem' be thought about differently?
5	What effects are produced by this representation of the 'problem'? Who is likely to benefit from this representation?
6	How has this representation of the problem been questioned, disrupted, and replaced?

The analysis began by focusing on question one through an exploration of the PO solutions proposed by submissions to the R2R Inquiry. The R2R's analysis of the solutions were then reversed to identify the implied problem the analysis disseminated (Bacchi, 2009, p. 48). Although the report ultimately denied that PO is a problem, Bacchi asserts this method can also be used to clarify implications in understandings of issues that are denied "problem" status (Bacchi, 2009). These problematisations were then placed into tables and the representations further interrogated to give rise to Questions 3-6.

For length, a complete list of representations identified within the R2R Inquiry have been amalgamated into Table 2. This approach was replicated for a brief analysis of the EU Eco-design Sustainable Product Regulation (ESPR) to effectively answer question 6 (Table 3).

Table 2: (Productivity Commission, 2021b)

Right to Repair Inquiry	
Proposed Solutions from Submissions/ R2R Inquiry Analysis	**Problem Representation**
Submissions suggested expanding consumer protection laws to explicitly address unfair conduct and consumer harm associated with planned obsolescence. Laws included outright bans on PO. R2R Inquiry argued that existing ACL provisions are adequate and that any bans would be a disproportionate response.	The analysis of this solution posited that government regulation is an overreach. The report silenced submissions that outlined they have trouble accessing ACCC resolutions and upheld a singular submission that ACL provisions will disadvantage consumers. Planned Obsolescence is represented to be a consumer driven but industry fixable issue.
Submissions suggested introducing mandatory design requirements for durability and/or repairability. This included banning or heavily restricting the sale of irreparable consumer electronics and developing minimum repairability standards. R2R Inquiry decided that this would result in costly products and less choice. Although they considered that increased lifetimes may offset increased price, they ultimately decided that consumers would continue to throw away products for a net loss to the consumer. The inquiry suggested that an extension of existing	The analysis of this solution represented that the consumer is at fault for premature obsolescence due to discarding items before their end-of-life silencing drivers of psychological obsolescence. This section discussed the importance of maintaining economic productivity and low prices even at the detriment of the environment. Planned Obsolescence is represented to be an issue of consumer choice, and industry self-regulation should be sufficient to target the issue.

environmental impact protection i.e. carbon price, would be more effective.	
Submissions suggested tax incentives or subsidies for repair. R2R Inquiry decided that the costs associated with funding the program would be too high and there would be limited benefits i.e. not likely to encourage repair practices. They also discussed that these subsidises would also be granted to consumers who are already repairing their products without incentive.	In their analysis of this solution, the report only considers the cost of running the program and suggests funding would be better used to pursue policies that address specific environmental impacts. However, this analysis neglects to address the significant impact waste generation has on environmental outcomes and how policy must be amended to target this issue. In its consideration of the cost/benefits of the program, the report ultimately decided that the economic costs outweigh the benefit of stimulating repairability through tax incentives. The problem representation within this solution is economic, ensuring that costs do not increase.
Submissions suggested improving information standards. R2R considered that manufacturers argue labelling already exists and new labels would impose costs on manufacturers and taxpayers for the delivery of the program. However, they ultimately discussed that there is significant evidence to suggest labelling would be beneficial as it gives consumers access to more information in their purchasing decisions. The R2R Inquiry proposed that a pilot scheme should be introduced.	The analysis of these solutions emphasises the consumer's responsibility to manage durability and repairability. The report does not consider the role of manufacturers in stimulating PO and may not appropriately address planned obsolescence. Using this method, although consumers will know that the product is expected to last 5 years, they may not know other products in the area should last 20 without spending time researching these labels and products in depth. Planned Obsolescence is represented to be an issue of consumer choice and places the onus on being aware of market trends and durability on consumers. This model does place the burden of the information on manufacturers but does not address product labelling from an environmental perspective i.e. increased plastic waste from stickers, booklets, signage etc.

Findings and Discussion

Question 1: What is the Problem Represented to be?

Despite the emphasis on design stage interventions in submissions to the Inquiry, the final report advanced the same narrative as its predecessors, focussing unilaterally on interventions at the consumption stage rather than addressing durability and repairability at design (Productivity Commission, 2021b). In their limited consideration of design stage interventions, the report discussed PO through a purely economic lens, failing to acknowledge environmental problematisations of the issue (Productivity Commission, 2021b).

The submissions to the report highlighted the potential for numerous solutions including mandatory design standards (MDS), tax incentives, specific ACL provisions, and improved access to information (Table 2). In its consideration of these solutions, the report posited that "*evidence on premature obsolescence is mixed*" and *"interventionist responses to premature obsolescence are not needed*" (Productivity Commission, 2021b, p. 36). The cost and benefit analysis of each solution reflected an economic agenda that emphasised the driving role of consumers in perpetuating the issue.

Through its analyses of the proposed solutions within submissions, the report ultimately suggested a pilot scheme for durability labelling standards to address the information gap, placing the onus on pursuing fair and equitable durability standards back onto the consumer. The framing of the issue is, therefore, one of consumer choice stimulating product obsolescence, rather than design limiting product lifetimes.

The solutions proposed in the R2R Inquiry represent rapidly diminishing product lifetimes as a purely economic issue. In doing so, the prevailing economic system is left unquestioned, and the root of the issue unaddressed.

Question 3: Waste as Economic Rationalism

The dominance of economic rhetoric within Australian environmental law has meant that waste regulation has exclusively considered economic harm and health outcomes in its provisions. (Rootes, 2009). China's ban on waste exports in 2018 signalled a paradigm shift in the way Australia thought about waste, forcing the country to trade an export-oriented waste model for one that prioritised resource recovery (Dorninger et al., 2021). Despite this shift and the various commitments made by the Australian Government to implement CE initiatives since 2018 (Department of Climate Change, Energy, the Environment and Water, 2018), the introduction of the Recycling and Waste Reduction Act in 2020 did not take bold action to embed CE outcomes in its policy mechanisms, focusing instead on voluntary industry self-regulation and bans on waste exports (Recycling and Waste Reduction Act 2020 (Commonwealth), 2020).

The prominence of this ever-accumulating waste trade and recovery system reflects an ideology of economic rationalism dichotomous to environmental conservation- a representation that is reflected by the framing of the problem within the R2R Inquiry (Silva et al., 2016). This emphasis on economic productivity in historical regulation has meant that policy that encourages sustainable design and production- concepts vital to addressing product lifetimes- is virtually non-existent in Australia (Gertsakis & Scallan, 2021; Keulemans, 2021).

Question 4: Uncovering the Silences

Despite the Commission acknowledging the need for government intervention to reduce the environmental impacts of PO, they maintained their position that the environmental detriment of continued production does not outweigh the economic detriment of reducing consumption through design interventions (Productivity Commission, 2021b). The report clearly shifted the onus for obsolescence onto the consumer, stating "*the lifespans of products…becoming shorter… is often driven by consumers choosing to replace their products with newer ones rather than products breaking.*" (Productivity Commission, 2021b, p. 226). In this way, the Commission neglected to consider the contributory role companies play in stimulating psychological obsolescence, reframing the problematisation as one of individual choice, instead of industry driving unsustainable economic demands in a finite world.

Furthermore, in their consideration of MDS, the report outlined that this would increase costs to the consumer which would not be offset by the longer lifetimes due to consumer behaviour. What the report did not consider is that increased product lifetimes and their associated costs would have the potential to address psychological obsolescence as consumers may be less likely to prematurely dispose of products due to the increased cost. What this silence reveals is the Commissions' prioritisation of the economic status quo, ensuring that products continue to be cheap so as not to reduce consumption.

It must be acknowledged that the Productivity Commission was not the best forum for discussions of environmental sustainability. Indeed, its advisory role is limited by the linear economic system it occupies and therefore its analysis was guided by the need to balance interests only within this economic system. As such, policy considerations focussed on maintaining economic productivity, whilst environmental issues were not adequately considered in the cost and benefit analysis. Nonetheless, a majority of submissions highlighted that PO is inextricably linked with negative environmental impacts (Productivity Commission, 2021a). Without stringent regulation at the design phase created with environmental considerations in mind, manufacturers will continue to encourage rapid consumption, and linear shortened lifetimes will endure.

Question 5: The Future of Obsolescence in Australia's "Circular Economy"

Extending product lifetimes and reducing waste through design for durability, reuse, and repair, is key to achieving a CE (Bakker et al., 2021). It has been estimated that extending the lifespans of e-products by only 10 per cent in Australia would reduce waste generation by 60,000 tonnes and emissions by 1.2 million tonnes by

2030 (Bontnick et al., 2021, p. 8). Despite the critical role design stage interventions play in supporting CE transitions, PO has not been clearly addressed in Australian waste legislation or policy. Indeed, the National Waste Report 2020 found that between 2018-2019, Australia generated 75.8 million tonnes of waste- an increase of 9% from the previous decade. This is expected to increase to 19% by 2030 (Blue Environment Consulting, 2020, p. x). While the report did not provide specific recommendations, it highlighted the need for more effective waste management solutions in Australia.

Although Australia appears to acknowledge the issue, current problematisations of PO represent a siloed approach to waste management, reflecting an institutional ideology that 'locks in' to uphold incumbent neo-liberal discourse (Walker, 2000). Despite evidence that single policy frameworks are not adequate to manage environmental externalities, the Productivity Commission appears more concerned with economic rhetoric than evidence-based frameworks through their proliferation of a standalone information strategy (Gunningham & Sinclair, 2017; Payne, Nay & Maguire, 2017). Effective management of PO requires a systematic multi-level transition towards CE principles, necessarily supported by ecological framings of the issue and complementary policy mixes (Geels, 2019; Gunningham & Sinclair, 2017). Until Australian regulation addressing shortened product lifetimes is introduced, the future of a CE in Australia will remain untenable.

Question 6: A New Durability Paradigm? Lessons from the European Union

Question Six of Bacchi's method is critical to an analysis of policy mechanisms that guide or disrupt CE, as an oft-quoted barrier to the transition to a CE in Australia is the lack of examples of successful circular initiatives (Feldman et al., 2024). Consequently, it

appears critical to consider Australian policy in context to other jurisdictions with stringent PO regulations, such as the European Union (EU).

In 2020, the EU introduced the New Consumer Agenda which emphasised the prioritisation of environmental objectives over economic interests, delineating itself from traditional conceptualisations of environmental regulation (European Commission, 2020). This environmental framing is clearly reflected in their regulatory mechanisms for PO- specifically in the Eco-design for Sustainable Products Regulation (ESPR) (2024/1781, 2024).

The ESPR directly regulates the manufacture of products to ensure they are not being designed with obsolescence in mind. Quite succinctly, Article 5.2 of the ESPR states: "*Ecodesign requirements shall… ensure… that products do not become prematurely obsolete, for reasons that include...[planned and functional obsolescence techniques]*" (2024/1781, 2024). In direct contrast to the R2R Inquiry in Australia, regulation in the EU not only admits but defines the existence of PO. The wording of the definition too places the onus of PO on the producers, framing the issue as one created at the design stage and driven by manufacturers.

Fundamentally, the ESPR recognises PO as a significant environmental issue resulting in significant environmental impacts (2024/1781, 2024, p. (7)). Unlike Australian policy decisions that continue to uphold economic problematisations and assign responsibility to consumers, the EU problematisation of PO frames the issue as one driven by design stage decisions, and as such requiring design stage interventions (Table 3).

Another key consideration in Australia's R2R Inquiry was the increased costs associated with better design. The Commission was concerned about the social utility of regulating durability into product design and ultimately decided the economic and social costs outweighed the environmental detriment. However, the ESPR addressed this consideration, simultaneously mandating eco-design requirements to reduce PO, and maintaining that products should, as much as reasonable, remain affordable (2024/1781, 2024, p. Article 5 (11) (c)). This problematisation does not diminish the individual responsibility or benefit of the consumer, but rather balances the interests of the environment and the consumer to promote conscientious and lasting product ownership through the durability focus within their frameworks.

In EU conceptualisations of the issue, it is evident that the economy of a product should reflect its true cost- to the manufacturer, the consumer, and the wider environment.

Table 3: Policy (2024/1781, 2024)

Eco-Design for Sustainable Product Regulation	
Solution	**Problem Representation**
Ecodesign requirements	Article 5 sets out that ecodesign requirements must be set out on a number of environmental objectives such as expected generation of waste, recycled content, material efficiency etc and specifically states that the requirements should ensure that products do not become prematurely obsolete. The representation of the problem of PO is one framed in environmental sustainability considerations. Article 5.9(a)(i) requires requirements to consider "Union priorities for the climate, the environment, energy efficiency, resource efficiency and security, including a non-toxic circular economy, and other related Union priorities and targets". It's important to note that although the regulation does require that the requirements do not significantly negatively impact affordability, it states that this should be calculated in relation to access to second-hand products, durability, and life cycle costs. This assessment does not consider whether consumers throw away products prematurely, therefore targeting psychological obsolescence. This solution problematises PO as an environmental public policy issue necessarily mitigated by appropriate mandatory government intervention
Information Requirements and Digital Product Passport/Labels	Article 7 sets out minimum information requirements in relation to its performance under Article 5 requirements. The information should include how to use, maintain, and repair the product to maximise durability and minimise its impact on the environment; collection options at end-of-life; substances of concern used in the product; and include a score for its durability, repairability etc. These information requirements must be disseminated via a Digital Passport, Label, online website, or in a user manual. Article 9 sets out the requirements for the creation of a Digital Product Passport to assist in better information requirement dissemination and better tracking of product lifecycles across the value chain. Article 16 sets out requirements for labels pursuant to Article 7. These information requirements demonstrate the understanding of consumers' role in mitigating waste without problematising the issue as economic or consumer driven. Through the burden of information being placed on the manufacturer/importer, the solution represents the problem as one driven by design stage decisions and further problematised by consumer misinformation. The focus on substances of concern within this article also represents an overarching emphasis on improving environmental outcomes in product development.
Transparency or Ban of Destruction of Unsold Consumer Goods	Articles 23 – 25 set out the requirements for reducing the destruction of unsold consumer goods including through provisions to take necessary measures to prevent the destruction, transparency, and information standards, as well as a total prohibition on certain products by 2026. The products on the prohibited list are decided in relation to their environmental impacts of destruction. This prohibition can be derogated for a number of reasons including unfitness for recycling or remanufacture; health and safety; non-acceptance of donations; and where destruction has the least negative environmental impacts. In this way, the problem with PO and waste generation lies with the purposeful over-manufacture of products and as such the responsibility for discarding the products ethically and sustainably is placed on the manufacturer/discarder. The specific emphasis on the environmental impacts of destruction reflects a problematisation centred on enduring positive environmental outcomes through policy frameworks. The problem is represented as an environmental conservation issue.

Conclusions

Product Obsolescence and rapid waste generation is a significant problem for the global community. However, the policy frameworks between regions differ greatly and represent vastly different understandings of what the problem is, and who is responsible for it. In Australia, PO has been recognised as an economic problem, driven by consumer choice, and as such the regulatory response has been to shift responsibility onto consumers through the introduction of a product labelling scheme. This creates no obligation for producers of goods and fails to internalise the negative externalities associated with waste. This standalone policy mechanism does not adequately address the root cause of PO and works to uphold the economic status quo to the detriment of CE outcomes.

This approach is in contrast with policy mechanisms in the EU, where the environmental problematisation of PO has resulted in a host of regulatory tools that address environmental concerns by placing responsibility onto the producers through eco-design and information standards. The comprehensive, multi-policy framework introduced in the ESPR reflects a deep understanding of the driving role regulation plays in a systemic transition to a CE.

To adequately address the issue of PO and effectively transition to a CE, Australian regulation must adopt the problematisations reflected in EU policy to create environmentally focussed multi-level and multi-policy regulatory frameworks that intervene in PO at the design stage of the product lifecycle. Without a reframing of the problematisations inherent in Australian understandings of PO, firms will continue to employ strategies that reduce product lifetimes to the detriment of the Circular Economy in Australia.

References

Adamson, G., Stevens, B., & Milwaukee Art Museum (Eds.). (2003). Industrial strength design: How Brooks Stevens shaped your world. The MIT Press.

Bacchi, C. L. (2009). Analysing policy: What's the problem represented to be? Pearson.

Bakker, C. A., Mugge, R., Boks, C., & Oguchi, M. (2021). Understanding and managing product lifetimes in support of a circular economy. Journal of Cleaner Production, 279, 123764. https://doi.org/10.1016/j.jclepro.2020.123764

Becher, S. I., & Sibony, A.-L. (2021). Confronting Product Obsolescence. Columbia Journal of European Law, 27(2), 97–151.

Bisschop, L., Hendlin, Y., & Jaspers, J. (2022). Designed to break: Planned obsolescence as corporate environmental crime. Crime, Law and Social Change, 78(3), 271–293. https://doi.org/10.1007/s10611-022-10023-4

Blue Environment Consulting. (2020). National Waste Report. Department of Agriculture, Water, and the Environment. https://www.dcceew.gov.au/sites/default/files/env/pages/5a160ae2-d3a9-480e-9344-4eac42ef9001/files/national-waste-report-2020.pdf

Bontnick, P.-A., Bricout, J., Grant, T., & Legoe, G. (2021). E-Product Stewardship in Australia (p. 8) [Executive Report]. https://www.dcceew.gov.au/sites/default/files/env/pages/d347d42b-d755-481b-bc38-71683b5d1958/files/e-stewardship-executive-summary-2021.pdf

Box, J. M. F. (1983). Extending Product Lifetime: Prospects and Opportunities. European Journal of Marketing, 17(4), 34–49. https://doi.org/10.1108/EUM0000000004830

Dalhammar, C., Maitre-Ekern, E., Luth Richter, J., Svensson-Hoglund, S., & Milios, L. (2023). 7. Regulation with a lasting impact? Policies for product durability. In M. Jaeger-Erben, H. Wieser, M. Marwede, & F. Hofmann (Eds.), Durable Economies (pp. 159–200). transcript Verlag. https://doi.org/10.1515/9783839463963-008

Dorninger, C., Hornborg, A., Abson, D. J., Von Wehrden, H., Schaffartzik, A., Giljum, S., Engler, J.-O., Feller, R. L., Hubacek, K., & Wieland, H. (2021). Global patterns of ecologically unequal exchange: Implications for sustainability in the 21st century. Ecological Economics, 179, 106824. https://doi.org/10.1016/j.ecolecon.2020.106824

Ellen Macarthur Foundation. (n.d.). The circular economy in detail. Ellen Macarthur Foundation. https://www.ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive

Ellen Macarthur Foundation. (2021). France's Antiwaste and Circular Economy Law: Eliminating waste and promoting social inclusion. Ellen Macarthur Foundation. https://emf.thirdlight.com/file/24/kLSzgopkL.2CJxQkLb3XkLQIS7_/Case%20Studies%20-

%20French%20Anti%20Waste%20Law.pdf

European Commission. (2020, November 13). Commission Communication on a New Consumer Agenda- Strengthening consumer resilience for sustainable recovery. European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0696

Feldman, J., Seligmann, H., King, S., Flynn, M., Shelley, T., Helwig, A., & Burey, P. (Polly). (2024). Circular economy barriers in Australia: How to translate theory into practice? Sustainable Production and Consumption, 45, 582–597. https://doi.org/10.1016/j.spc.2024.02.001

Geels, F. W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. Current Opinion in Environmental Sustainability, 39, 187–201. https://doi.org/10.1016/j.cosust.2019.06.009

Gertsakis, J., & Scallan, S. (2021). A submission to the Australian Government Productivity Commission on Right to Repair. Productivity Commission. https://www.pc.gov.au/__data/assets/pdf_file/0020/273008/sub125-repair.pdf

Gunningham, N., & Sinclair, D. (2017). Smart regulation. Regulatory Theory: Foundations and Applications, 133–148.

Keulemans, G. (2021, February). Right to Repair Productivity Commission Submission from Dr Guy Keulemans, UNSW Sydney. Productivity Commission. https://www.pc.gov.au/__data/assets/pdf_file/0003/275133/sub144-repair.pdf

Maitre-Ekern, E., & Dalhammar, C. (2016). Regulating Planned Obsolescence: A Review of Legal Approaches to Increase Product Durability and Reparability in Europe. Review of European, Comparative & International Environmental Law, 25(3), 378–394. https://doi.org/10.1111/reel.12182

Payne, A., Nay, Z., & Maguire, R. (2021). Regulating a circular economy for textiles in Australia (Version 1). University of Limerick. https://hdl.handle.net/10344/10245

Pope, K. (2017). Understanding planned obsolescence: Unsustainability through production, consumption and waste generation. Kogan Page.

Productivity Commission. (2021a). Public Hearings: Transcript of Proceedings—Right to Repair Inquiry (p. 381). https://www.pc.gov.au/inquiries/completed/rep air/public-hearings.

Rivera, J. L., & Lallmahomed, A. (2016). Environmental implications of planned obsolescence and product lifetime: A literature review. International Journal of Sustainable Engineering, 9(2), 119–129. https://doi.org/10.1080/19397038.2015.1099757

Rootes, C. (2009). Environmental movements, waste and waste infrastructure: An introduction. Environmental Politics, 18(6), 817–834. https://doi.org/10.1080/09644010903345587

Røpke, I. (2016). Complementary system perspectives in ecological macroeconomics—The example of transition investments during the crisis. Ecological Economics, 121, 237–245. https://doi.org/10.1016/j.ecolecon.2015.03.018

Silva, A., Stocker, L., Mercieca, P., & Rosano, M. (2016). The role of policy labels, keywords and framing in transitioning waste policy. Journal of Cleaner Production, 115, 224–237. https://doi.org/10.1016/j.jclepro.2015.12.069

Waldman, M. (1993). A New Perspective on Planned Obsolescence. The Quarterly Journal of Economics, 108(1), 273–283. https://doi.org/10.2307/2118504

Walker, W. (2000). Entrapment in large technology systems: Institutional commitment and power relations. Research Policy, 29(7–8), 833–846. https://doi.org/10.1016/S0048-7333(00)00108-6

Legislation/Policy

Competition and Consumer Act 2010 (Commonwealth) (2010).

Department of Climate Change, Energy, the Environment and Water. (2018). National Waste Policy. https://www.agriculture.gov.au/sites/default/files/documents/national-waste-policy-2018.pdf

Productivity Commission. (2021b). Right to Repair (Inquiry Report 97). Commonwealth of Australia.

Recycling and Waste Reduction Act 2020 (Commonwealth) (2020).

Regulation (EU) 2024/1781, Pub. L. No. 2024/1781 (2024). http://data.europa.eu/eli/reg/2024/1781/oj

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Availability of spare parts and product lifetime in Brazilian law

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Keywords: Circular economy; product lifetime; repair; spare parts; availability.

Abstract

Circular economy, hereinafter 'CE', is high on the political agenda across the globe despite the differences it may assume in the Global South compared with the Global North.
In the CE, repair is an important strategy to extend product lifetime. Factors enabling product repair are manifold, including repairability, affordability of repair services, and information to repairers, whether professional ones or consumers themselves.
This text discusses one of such enabling factors, namely the availability of spare parts, and how it is regulated by Brazilian law. It does so in comparison to the law of the European Union, hereinafter 'EU'.
Differently from some EU ecodesign regulations establishing a fixed minimum period for the availability of spare parts after the placing on the market of the last model of a given product, Brazilian statutory law sets forth that the minimum period should be reasonable and never inferior to product lifetime. Case law, in applying statutory law, determines product lifetime – for the purpose of making spare parts available – in a rather piecemeal fashion. Court decisions are unclear as to whether product lifetime should depend on product use by the consumer or not. Lack of uniformity exists also regarding the criteria or evidence needed to arbitrate product lifetime.
It is argued that Brazilian law does not promote product repair, thus running counter to the aim of its National Circular Economy Strategy of creating a regulatory environment favourable to the CE. Legislation should be improved to provide clear, i.e. fixed time frames for the different product categories.

Global South and circular economy

CE is high on the political agenda across the globe. Yet, the theory and practice of CE are still dominated by a worldview of the Global North, as opposed to the Global South (Muchangos, 2021).
The Global North/South divide is a construct introduced by development theorists to address the asymmetry of power among nations (Sud & Sánchez-Ancochea, 2022). As a conceptual abstraction, it is based on various – albeit not uncontroversial – criteria Sud & Sánchez-Ancochea (2022) to provide a taxonomy of the world.
For the purposes of this text, a simplified distinction between the Global North and the Global South is assumed, one drawn in terms of wealth and its distribution: the Global South comprises low(er)-income countries still marked by social inequality.
The North-South disparity is reflected in how the CE agenda is shaped. In the Global South, CE still generally concentrates on waste management (Muchangos, 2021; Ospina-Mateus & others, 2023) often in connection with the inclusion of informal waste collectors, which is consistent with a reality of social inequality. Challenges upstream the life cycle of resources such as chemicals and products receive scant attention in the Global South. Regarding product regulation, some authors note that the Global South still draws upon best practice from the Global North, particularly the EU (Haswell & others, 2024).

Circular economy in Brazil: an agenda under construction

In mapping the CE concept in the Global South, one author found that, 'except for […] China, data and analysis, surveys, discussions, and practical contributions of the CE in [the Global South] have been limited' (Muchangos, 2021). This calls for obtaining more information about CE from other Global South countries, including Brazil.

Brazil is the world's tenth largest economy and the largest economy in Latin America, a subregion of the Global South. As such, the country plays a central role also in shaping CE in both academic and practical terms. To be sure, two bibliometric reviews (Muchangos, 2021; Ospina-Mateus & others, 2023) show Brazil as leading the academic production on CE in Latin America. In practice, the 2025 edition of the World Circular Economy Forum, one of the world's leading events on CE, will be held in São Paulo, the biggest city in the American continent.

Despite the protagonism of Brazil, analyses of its CE policies are still scarce, especially from a legal perspective and to a foreign audience. This text seeks to take a modest step to bridge said gap while reducing the paucity of information about CE in a Latin American country of the Global South.

The first official document on CE in Brazil is the National Circular Economy Strategy, hereinafter 'Strategy', launched by the federal government in June 2024 via Decree No. 12,082.

The Strategy introduces neither rights nor obligations, let alone formulates a policy or an action plan, whether generic or sector specific, in stark contrast e.g. to the EU's action plans of 2015 and 2020, both of which address specific industries and propose concrete measures to advance the CE.

Instead, the Brazilian Strategy only provides a definition of CE and authorises the creation of the National Circular Economy Forum, a consultative body to assist the federal government in achieving several goals, including, but not limited to, the creation of a regulatory and institutional framework favourable to the CE.

Following the Strategy, the draft National Circular Economy Plan for the period 2025-2034, hereinafter 'draft Plan', was out for public consultation from mid-February to mid- March 2025. The draft Plan is a generic, i.e. not sector-specific, document full of commonplace objectives to achieve the goals established by the Strategy.

Based solely on the 2024 Strategy and the 2025 draft Plan, CE policy in Brazil remains wishful thinking, including in legal terms. However, this does not preclude one to analyse whether the existing legislation may be conducive to a CE or even improved to that end.

In this sense, this text revolves around whether and how the availability of repair parts is regulated in Brazil in comparison to EU law as a strategy to foster product repair and thus extend product lifetime in a CE.

Product lifetime and availability of spare parts in Brazil and the EU: a comparative perspective

There are several reasons for comparing Brazil with the EU. First, given the high mobility of products, their environmental impacts are ubiquitous in a globalised world. Second, as mentioned, product policy is still in its infancy in the Global South, which still draws upon from best practice from the Global North, notably the EU (Haswell & others, 2024). Third and most importantly from a legal perspective, in both the EU (an economic union) and Brazil (a republic federation), powers to legislate over environmental and consumer protection matters are shared between the Union and the (Member) States. The Union sets minimum standards, whereas the (Member) States may adopt more stringent measures. In continent-sized jurisdictions like the EU and Brazil, this system of shared powers serves as a mechanism to accommodate diversity with the necessity of harmonisation.

Availability of spare parts in the EU in a nutshell

Directive (EU) 2024/1799 on common rules promoting the repair of goods requires manufacturers of the products covered by the Union legal acts listed in Annex II to meet the repairability requirements laid down by said legal acts. These are product-specific implementing measures, in the form of regulations, adopted under the framework of Directive 2009/125/EC on ecodesign, replaced by Regulation (EU) 2024/1781, the so-called Ecodesign for Sustainable Products Regulation.

Most of the ecodesign regulations listed in Directive (EU) 2024/1799 impose repairability requirements that include the availability of spare parts for a *fixed* minimum period, which – depending on the spare part or product category – normally vary from seven to ten years after the placing of the last unit of the product model on the market.

Availability of spare parts in Brazilian statutory law

Unlike the EU, where availability of sparts parts is mandated by ecodesign regulations, in Brazil the matter is dealt with by consumer – not environmental – protection law, more specifically by Federal Law No. 8,078/1990, known as the 'consumer protection code', hereinafter CPC.

Article 32 of the CPC requires manufacturers and importers to make spare parts available so long as the manufacture and importation of the products that they place on the market have not ceased. After cessation, availability shall be maintained for a *reasonable period of time*.

Article 13 of Federal Decree No. 2,181/1997 elaborates on the availability-of-spare-parts rule of the CPC by adding that the reasonable period of time must never be less than the *lifetime of the product*.

Instead of fixing the minimum period for the availability of spare parts, as EU law does, the Brazilian CPC and its implementing decree leave the decision to be made on a case-by-case basis considering product lifetime. In a civil law country like Brazil, if the lawmaker does not stipulate the time frame, courts are to do so (Benjamin, 2022).

Brazilian case law on product lifetime

Given that statutory law defines neither reasonable period of time nor product lifetime, how is the minimum period for the availability of spare parts to be established in a courtroom?

At least two questions arise. Firstly, is product lifetime to be determined *abstractly* for a whole product category, as is the case of ecodesign regulations in the EU, or *concretely* for a specific product used by a specific consumer? In other words, should product lifetime depend on product use for the purposes of making spare parts available?

Secondly, is product lifetime to be arbitrated based on the evidence provided by the parties to the legal dispute? If so, are judges bound by the evidence produced? If not, or if there is no evidence, how are judges to decide?

A survey of case law in the past decade (2004-2014) has been conducted to understand how courts answer these questions. The database used was Jusbrasil, available at <https://jusbrasil.com.br>, and the keywords employed were 'spare parts', 'reasonable period of time', and 'product lifetime' ('peças de reposição', 'período razoável de tempo', and 'vida útil do produto' in Portuguese, respectively).

Results comprise a total of ten decisions of state courts, most of them from small claims courts. Under Brazilian procedural law, not only are consumer protection matters not dealt with by federal courts, but rulings from small claims courts cannot be challenged by *Superior Tribunal de Justiça*, hereinafter 'STJ', the highest court harmonising the application of federal law by courts. As for the products covered by the decisions, they all deal with the lifetime of consumer electronics.

Regarding the first question (abstract vs. concrete determination of product lifetime), only four of the ten decisions determine product lifetime abstractly for a whole product category. Interestingly, they resort to a piece of regulation from Brazil's Federal Tax Authority on income tax owed by legal persons, which contains a list of products and their respective lifetime for the purpose of calculating depreciation rates and thus deductible tax. By contrast, one court (out of the remaining six) firmly ruled that the lifetime of a product 'depends on the use and care by the consumer'.

Concerning the second question (determination of product lifetime based on the evidence produced or other criteria), one judgement adopted the product lifetime indicated by the original equipment manufacturer (100,000 hours = ca. 11 years). Differently, in two cases, the decisions were based on the degree of technological development instead of the evidence provided by the parties: for one court, cutting-edge devices should have longer lifetimes, whereas another court found that where technology advances rapidly, lifetimes are shorter. In both instances, product lifetime was arbitrated by the court based on a criterion of its choice.

Discussion

In contrast to EU law, where legislation sets a *fixed* minimum period for the availability of spare parts for an entire product category, thus harmonising the issue across Member States, Brazilian statutory law mandates that spare parts be available for a reasonable period, never inferior to product lifetime. This lack of definition by the Legislative transfers the decision to the Judiciary, which can only be reached case by case.

But case law on product lifetime for the purposes of availability of spare parts is not

coherent. Dealing exclusively with the lifetime of consumer electronics, judgements stem from state small claims courts and lack uniformity in terms of whether product lifetime should be determined abstractly by product category or concretely for an individual product. Besides, rulings do not follow any pattern as to the parameters or evidence necessary to arbitrate product lifetime.

The situation is explained in part by the fact that decisions from small claims courts cannot be challenged at STJ, the final appeal court harmonising the application of federal legislation by lower courts. The absence of consistent criteria to determine product lifetime is far from creating a favourable regulatory environment, as envisaged by the country's 2024 National Circular Economy Strategy. There is room for legislative improvement, which is particularly important in a civil law country like Brazil.

In practice, the lack of coherence in Brazilian statutory and case law creates legal uncertainty that affects consumers, repairers, and manufacturers. Repair may be denied to consumers that did not know that (and how) they should have been more careful. Repairers cannot adequately plan the supply of spare parts and ultimately offer their service. And manufacturers may be found liable for infringing the CDC without knowing that they should have made spare parts available for a longer period.

Conclusions

Availability of spare parts is a necessary, albeit insufficient, condition for product repair. Consumer protection law in Brazil prescribes that once the manufacture or importation of the product ceases, the minimum period for the availability of spare parts must never be less than product lifetime. Instead of determining the time frame, like EU law does, statutory law transfers the task to the Judiciary. But case law is erratic, thus not only running counter to the National Circular Economy Strategy's aim of creating a regulatory environment favourable to the CE but also failing to promote product repair. The CPC or its implementing decree should be modified to provide clearer (i.e., *fixed*) time frames, thereby providing legal certainty to manufacturers, repairers, and consumers.

References

Benjamin, A. H. V. (2022). Art. 32. In Grinover *et al.*, *Código brasileiro de defesa do consumidor* (13th ed., pp. 291). Forense.

Haswell, F *et al*. The geography of circularity missions: a cross-country comparison of circular economy policy approaches in the Global North and Global South. *Environmental Innovation and Societal Transitions* 52 (2024), 100883. https://doi.org/10.1016/j.eist.2024.100883

Muchangos, L. S. Mapping the circular economy concept and the Global South. *Circular Economy and Sustainability* 2 (2021), 71-90. https://doi.org/10.1007/s43615-021-00095-0

Ospina-Mateus, H. *et al*. Analysis in circular economy research in Latin America: a bibliometric review. *Heliyon* 9:9 (2023) e19999. https://doi.org/10.1016/j.heliyon.2023.e19999

Schröder, P. *et al.* (ed.). *The circular economy and the Global South: sustainable lifestyles and green industrial development*. Abingdon, Routledge, 2019.

Sud, N. and Sánchez-Ancochea, D. Southern discomfort: interrogating the category of the Global South. *Development and Change* 53:6 (2022), 1123-1150. https://doi.org/10.1111/dech.12742

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Towards Building Circularity in Queensland: Policy Gaps in the Built Environment

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Keywords: Australia, Circular Economy; Policy Analysis; Disassembly; Deconstruction; Adaptive Reuse.

Abstract
This study evaluates Queensland's policies supporting circular economy practices in the building and construction industry. Through systematic review, it reveals that while current initiatives have improved construction waste recovery rates, policies focus primarily on recycling rather than higher-order circular practices like deconstruction and material reuse. The research identifies opportunities for policy reform and incentives to advance Queensland's transition to a circular economy in the built environment.

Introduction
The building and construction industry is a major consumer of resources and contributor to waste creation and consequently a major market for reclaimed building components and recycled materials (Amarasinghe et al., 2024; Mollaei et al., 2023). The circular economy, unlike the linear "take, make, and dispose" approach, is a production, consumption and cycling model focused on extending material lifecycles, recovering and regenerating resources, and maintaining their highest value use for as long as possible (Queensland Government, 2024d). Queensland's building and construction industry is at a critical moment in its transition to a circular economy, with mounting environmental challenges, approaching Brisbane 2032 Games, Paris Agreement, and the housing crises, necessitating urgent action (Evans, June 16; Foth et al., 2022; Marsh & Stilwell, 2023). This study evaluates Queensland's existing policies, highlighting critical gaps and opportunities within the state's policy landscape.

Scope
This research critically examines Queensland's existing policies related to the circular economy in the built environment, with a specific focus on deconstruction, adaptive reuse, waste management, and circular business models. By identifying policy gaps and limitations, the study paves the way for insights to address Queensland's unique challenges. The aim is to enhance sustainable practices, promote resource recovery, and establish a resilient framework for transitioning the state's building and construction industry to a circular economy, especially considering the environmental and societal imperatives.

Methodology
The research uses a qualitative dual-track systematic review, combining academic sources from Scopus with grey literature like government documents and industry reports. This approach merged theory with practice for a robust foundation in the study analysis.

Key Legislative Frameworks Supporting Circularity in Queensland
The *Waste Reduction and Recycling Act 2011* serves as Queensland's primary legislation to support circularity. It promotes waste mitigation, recycling, and resource recovery, emphasizing shared responsibility among governments, businesses, and communities. The Act includes product stewardship for managing the lifecycle of priority products and provides guidelines for industries like construction and demolition to reduce reliance on landfills(Queensland Government, 2011).

The *Queensland Waste Management and Resource Recovery Strategy* outlines ambitious goals, including a 25% reduction in household

waste, 90% diversion from landfills, and a 75% recycling rate by 2050. Focused on economic opportunities and environmental benefits, the strategy leverages tools like the waste levy,

infrastructure development, and product stewardship, with attention to the construction sector for enhancing material reuse and recovery (Queensland Government, 2011).

The *Queensland Resource Recovery Industries 10-Year Roadmap and Action Plan* aims to accelerate the state's transition to a circular economy. Key initiatives include a $100 million Resource Recovery Industry Development Program, recycling enterprise precincts, and landfill bans. Special attention is given to the construction and demolition sector through projects that promote material reuse, recycling, and incorporation of recycled content in new developments (Queensland Government, 2019a).

The *Resource Recovery Industry Development Program (RRIDP)* supports resource recovery industries with infrastructure grants, project funding, and feasibility studies. Targeting 1.1 million tonnes of waste diversion annually, the program has facilitated over $200 million in capital investment and created hundreds of jobs. It includes investments in construction and demolition (C&D) waste facilities, such as advanced processing technologies, sorting systems, and recycling lines (Queensland Government, 2024b).

The *Queensland Waste Disposal Levy*, introduced in 2019, discourages landfill use by increasing disposal costs in designated levy zones. Funds from the levy support resource recovery projects and align with Queensland's waste management targets. It particularly benefits the construction sector by funding projects for C&D waste processing infrastructure and promoting recycling and sustainable alternatives to landfill disposal (Queensland Government, 2024c).

The *Queensland Waste Management and Resource Recovery Strategy Review Report (2019–2023)* highlights significant achievements, including an 81.2% recovery rate for C&D waste in 2022–23, exceeding the 2025 target. This progress underscores the success of implemented strategies in advancing resource recovery and circular economy goals (Queensland Government, 2024a).

The *ReMade in Queensland (ReMiQ)* initiative is a $10 million fund designed to support manufacturers and recyclers in incorporating recovered materials into products. Offering matched funding of $50,000 to $2.5 million, the program fosters innovation, reduces waste, and expands market opportunities for recycled

materials, contributing to Queensland's circular economy objectives (Amarasinghe et al., 2024).

Australia's Circular Economy Framework aims to double Australia's circularity by 2035, focusing on resource lifecycle management through three key targets. Priorities span four major supply chains and six objectives for economic, environmental, and social benefits. Backed by major investments and policies, this framework sets a 10-year vision for innovation, collaboration, and stewardship (DCCEEW, 2024).

Policy Landscape in Queensland

Recently implemented waste management initiatives and policies by the Queensland government have attempted to address aspects of circular economy but so far lack the scope and coordination to have the desired effect and required impact of comprehensive circular economy practices (Queensland Government, 2011, 2019b, 2019a, 2021, 2024b, 2024c, 2024a).

Current initiatives, such as the *RRIDP* and the waste levy (Queensland Government, 2024b, 2024c), address waste reduction and have helped exceed construction and demolition (C&D) waste recovery targets through recycling, but they fall short of supporting higher-order circular practices like deconstruction and material adaptive reuse in the construction sector.

Findings

Circularity Policy Gaps in Queensland's C&D Sector

This research evaluates Queensland's policies in supporting a circular built environment and facilitating the construction sector's transition to a circular economy. While significant progress has been made in waste management and recovery, current policies primarily focus on

recycling and lack direct measures to promote higher-order circularity practices such as deconstruction and reuse. Queensland's initiatives aim to reduce landfill use but emphasize lower-order circular strategies like recycling. Despite the state achieving an 81.2% recovery rate for construction and demolition waste in 2022–23, this milestone has been reached through recycling rather than practices that enable systemic change, such as reuse. These gaps highlight the need for Queensland to adopt more explicit and ambitious policies that promote deconstruction, reuse, and other sustainable practices. A shift toward supporting higher-value circular strategies is essential to achieve a genuine transition to a circular economy in the construction sector and overcome existing barriers to progress.

Barriers to High-Order Circular Strategies

Progress in high-value circular strategies, such as deconstruction and material reuse, has been hindered by several barriers in Queensland. Institutional and regulatory challenges, including fragmented policy frameworks and weak enforcement mechanisms, limit the effectiveness of circular initiatives. Economic disincentives, such as high upfront costs and financial risks, discourage businesses from adopting circular models. Additionally, cultural resistance and industry inertia, driven by longstanding reliance on linear economy practices, further slow the transition to more sustainable construction methods.

Opportunities For Queensland

Queensland has significant opportunities to enhance circularity in the built environment through deconstruction, adaptive reuse, and material recovery. The circular economy market in Australia is projected to create up to 25760 new jobs every year (Commonwealth of Australia, 2021).

Expanding deconstruction and adaptive reuse could drive green job creation in material salvaging, refurbishment, and repurposing. Research shows that diverting 10,000 tonnes of waste from landfills creates 9.2 jobs through recycling and 36 jobs through reuse and remanufacturing (Commonwealth of Australia, 2021; CSIRO, 2022). Targeted incentives for architects, developers, and recyclers would accelerate industry adoption of circular principles, reducing reliance on virgin materials. To unlock these opportunities, financial incentives such as tax benefits for sustainable construction and grants for circular business models are essential. Workforce training programs can further develop expertise in material recovery, fostering economic resilience. By implementing these strategies, Queensland can position itself as a leader in circular economy innovation, driving both environmental and economic benefits within the construction sector.

References

Amarasinghe, I., Hong, Y., & Stewart, R. A. (2024). Visualising a framework for enhancing material circularity in building construction projects: Drivers, barriers, and strategies. Building and Environment, 111359–111359. https://doi.org/10.1016/j.buildenv.2024.111359

DCCEEW (2024), Australia's Circular Economy Framework, Department of Climate Change, Energy, the Environment and Water, Canberra, December. CC BY 4.0.

Commonwealth of Australia, (2021). *National Waste Policy Action Plan 2019.* Retrieved from https://www.dcceew.gov.au

CSIRO, (2022). *Australia's Circular Economy: Economic, Environmental, and Social Opportunities.* Retrieved from https://www.csiro.au

Mollaei, A., Bachmann, C., & Haas, C. (2023). Assessing the impact of policy tools on building material recovery: Resources, Conservation & Recycling. Resources, Conservation & Recycling, 198, N.PAG–N.PAG.https://doi.org/10.1016/j.resconrec.2023.107188

Queensland Government. (2024). *What is a circular economy?* State Development, Infrastructure and Planning. Retrieved November 9, 12, 2024, https://www.statedevelopment.qld.gov.au/news-and-events/what-is-a-circular-economy

Foth, M., Kamols, N., Turner, T., Kovachevich, A., & Hearn, G. (2022). Brisbane 2032: The Promise of the First Climate-positive Olympics for Regenerative Cities. *Design for Regenerative Cities and Landscapes*, 227–248. https://doi.org/10.1007/978-3-030-97023-9_10

Marsh, F., & Stilwell, F. (2023). Housing affordability, inequality and the asset economy: A study of Queensland regions. The Journal of Australian Political Economy, (91), 83–106. https://search.informit.org/doi/10.3316/informit.245962499825682

Evans, J. (2022, June 16). Australia's Paris Agreement commitment lifted to 43 per cent emissions reduction by 2030. ABC News. https://www.abc.net.au/news/2022-06-

Queensland Government. (2011). *Waste Reduction and Recycling Act 2011*. Retrieved November 27, 2024, from https://www.legislation.qld.gov.au/view/html/inforce/current/act-2011-031

Queensland Government. (2019). *Waste management and resource recovery strategy*. Retrieved November 27, 2024, from https://www.qld.gov.au/__data/assets/pdf_file/0028/103798/qld-waste-management-resource-recovery-strategy.pdf

Queensland Government. (2019). *Queensland resource recovery industries 10-year roadmap and action plan*. Retrieved November 27, 2024, from https://www.statedevelopment.qld.gov.au/__data/assets/pdf_file/0014/17204/resource-recovery-roadmap.pdf

Queensland Government. (2024a). *Resource recovery industry development program*. Retrieved November 27, 2024, from https://www.statedevelopment.qld.gov.au/industry/critical-industry-support/resource-recovery/industry-development-program

Queensland Government. (2024b). *Waste disposal levy overview*. Retrieved November 27, 2024,https://www.qld.gov.au/environment/circular-economy-waste-reduction/disposal-levy/about/overview

Queensland Government. (2024c). *Queensland waste strategy review report 2019–2023*. Retrieved November 27, 2024, from https://www.qld.gov.au/__data/assets/pdf_file/0023/506327/waste-strategy-review-report.pdf

Queensland Government. (2021). ReMade in Queensland. Department of Regional Development, Manufacturing and Water. https://www.rdmw.qld.gov.au/manufacturing/manufacturing-assistance-programs/remade-in-queensland

Sufficiency and Design for Less



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Leveraging social norms for sustainable behaviour: How the exposure to static-and-dynamic-norm communications encourage sustainable behaviour towards reduction of fashion consumption

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Keywords: Social norms; sufficient-based consumption, fashion, sustainable behaviour; over-consumption.

Abstract: Communication channels from social media to newspapers abound with examples where static norms, reflecting established behaviours (e.g., eating meat, drinking alcohol at parties) are combined with dynamic norms, illustrating emerging societal trends (e.g., adopting more plant-based diets, attending alcohol-free events). Despite widespread exposure to these combined static-and-dynamic-norm communications, their impact on consumer behaviour remains unexplored. Through two lab experiments, this research investigates how static-and-dynamic-norm communications influence sustainable behaviour towards a reduction of fast fashion consumption. Our findings show that consumers exposed to the combination of unsustainable static and unsustainable dynamic norm purchased significantly fewer fashion items compared to other experimental conditions. This effect is driven by social moral cleansing, as consumers, confronted with widespread unsustainable behaviour of others, felt a highlighted motivation to clean and compensate for the normalized bad behaviour of others by behaving more sustainably in return. This research advances the understanding of social normative influences on sustainable consumption and offers valuable insights for researchers, designers and policy makers. By identifying an effective social norm communication to encourage consumption reduction, it lays the groundwork for future research and policy initiatives aimed at promoting sufficiency in the context of sustainable behavioural change.

Introduction

In our increasingly digital world, we find ourselves exposed, almost constantly, to others' people lives, including how they commonly behave and what they believe as standard, typical and appropriate behaviour in many situations. Contemporary media environments are dense not only of "current behaviours", of how people behave in a particular moment in time, but also of "future trends", of how people are changing their behaviour over time. From omnivorous influencers engaging in "veganism for a month" to alcohol lovers engaging in strict alcohol-free "dry parties" (documenting their transition day by day to their audience), social media platforms are increasingly responsible in making certain behaviours more visible, more accepted and more normalized (Geber & Hefner, 2019).

Beyond social media, also the more traditional communication channels, such as newspapers and newscasts, are full of examples where static practices, showing the norm up to now are combined with dynamic trends in society, showing which behaviour is becoming more common between consumers. In this regard, recent examples from the newspaper The Guardian, include: "*Until recently, 67% of Brits have engaged in monthly drinking…young adults would reach for a drink at parties to fit in socially* (static norm). *However, more and more young people are choosing not to drink, increasingly engaging in dry events. Welcome to the era of sober-curious…(*dynamic norm*)*" (Segalov, 2023) or "*Up to now, full-time in-office work was the norm, with face-to-face meetings and set hours (*static norm*). Now, more companies and employees are embracing flexible, remote work options as part of a new standard, with hybrid models becoming the preferred choice…(*dynamic norm*)"* (Aratani, 2024).

Such narratives are also reflected in sustainability discussions, where, past, present and future practices are combined, in the same message, to raise awareness on the impact of human behaviour on the environment. An example for all is represented by the popular BBC documentary (and homonymous book) "*A*

Life on Our planet" where current unsustainable behaviours (e.g., *for decades, people used coal and oil to power their homes)* are emphasized in combination with more sustainable dynamic trends (e.g., *society is embracing renewable energy solutions which are becoming more and more common*) (Attenborough, 2020). From a theoretical point of view, all the above mentioned examples combine the so-called static and dynamic social norms. While static social norms indicate those sets of values, beliefs and behaviours that are perceived as typical and acceptable at a particular moment in time or up to now, dynamic norms signal behaviours that are becoming increasingly popular over time (Loschelder et al., 2019; Sparkman & Walton, 2017).

Despite frequent exposure to these combined static-and-dynamic-norm communications, no scientific research has investigated the effect of this exposure on our behaviour, exploring, for instance, how the combination of static and dynamic social norm messages influence consumer sustainable behaviour. While in the context of environmental research, studies on the effects of static-only or dynamic-only messages on pro-environmental decisions have been flourishing (Borg et al., 2020; Loschelder et al., 2019; Pristl et al., 2021; Sparkman & Walton, 2017; Thomas & Sharp, 2013; Yamin et al., 2019), up to our knowledge, no research has been focused on the combined effect of static-and-dynamic-norm information. This understanding holds crucial importance, particularly when promoting sustainable behaviour. In a world where encounters with forms of unsustainable behaviours (e.g., littering, prematurely discarding of still functional items, or engaging in fast fashion consumption etc..) are common, normalized and often accepted, it becomes important to understand how the exposure to others' unsustainable behaviours or communications about that, influences the likelihood of conforming to or diverging from these established norms. Furthermore, since, these unsustainable behaviours can be framed as both the static and the dynamic norm (thus creating a matching alignment between the two norms) or as the dynamic norm alone compared to a more sustainable static norm and vice versa (creating a mismatch), it is essential to explore how these different combinations of static and dynamic norms influence consumer behaviour. In fact, different types of norm combinations with a matching or mismatching sustainability framing may lead to varying effects on pro-environmental decision making and sustainable behaviour.

Therefore, this research aims to explore the effect of combining (sustainable or unsustainable) static and (sustainable or unsustainable) dynamic norms in promoting more sustainable behaviour, and in particular, in promoting sufficiency (often associated with "buy less', " buy parsimoniously", "buy only what you need"), rather than over-consumption of fashion items (Allaby & Park, 2013; Ehrlich & Goulder, 2007). By using this rather overlooked but crucial context of sufficient (vs over-) consumption for its societal implications, this research aims to answer the following research questions: *How does the exposure to static and dynamic social norm communications with a matching or mismatching sustainability framing influence sustainable behaviour towards sufficiency in fashion?"* and "*Which combinations of static and dynamic social norms are more effective in promoting more sustainable practices*?".

By doing so, this research provides several theoretical and practical implications. Theoretically, this research advances the understanding of the combined impact of static and dynamic norm communications on consumer behaviour, filling a critical gap in prior studies that largely examine static-only or dynamic-only normative influences (Aldoh et al., 2024; Loschelder et al., 2019; Sparkman & Walton, 2017). At a practical level, this research underscores the influence of norm-based communications on immediate consumer decisions, a finding that holds particular relevance for the rapidly growing field of social commerce. In this regard, nearly 40 million users are expected to participate in social commerce, where purchasing decisions are directly integrated with social interactions (Azhar et al., 2023; Leong et al., 2024). This setup allows shopping choices to occur almost simultaneously (or right after) to the perceived normative behaviour (e.g., to choose and purchase an outfit right after being exposed to a normalized fashion behaviour). Furthermore, by differentiating the effects of various combinations of (sustainable/unsustainable) static and dynamic norms and by suggesting which combinations of normative messages may be more effective in promoting sustainable practices, this research provides substantial societal implications. Specifically, it may offer actionable insights for policymakers focused on

fostering sustainable practices in the fashion industry which stands as the second-most polluting industry globally, after the oil and gas sector (Choi & Lee, 2024).

Studies overview

The current research aims to explore the effect of exposing consumers to static-and-dynamic social norm communications with a matching and mismatching sustainability framing on an actual real-life sustainable behaviour, namely sufficient behaviour in the context of fashion. By doing that, this research also demonstrates which combinations of (sustainable/unsustainable) static and (sustainable/unsustainable) dynamic norm are more effective in promoting sustainable practices and the reasons for this effectiveness. This paper tested these effects through two lab studies. Study 1 tested the main effect of static and dynamic norm communications on the number of fashion items chosen by respondents in a fictitious web-shop of clothes, as proxy of (un)sustainable behaviour. Study 2 replicates these effects with different manipulations of static and dynamic norms and different measures for the dependent variables. Additionally, study 2 explores the potential mediating role of social moral cleansing and social moral licensing as two related strategies of norm-behaviour regulation.

The experiments for Study 1 and 2 run across four days in January and December 2024, respectively, and followed the same procedure: upon entering the lab, participants were asked to sit at a computer desk, read and agree to an inform consent and were randomly assigned to one condition in a 2 (static norm: unsustainable vs sustainable) x 2 (dynamic norm: unsustainable vs sustainable) between-subjects experiment, containing the combination of static and dynamic social norms. They were instructed to evaluate a web shop of clothes, after being exposed to the manipulation of social norms and to shop as they would have normally done. Upon completion of the experiment, participants were offered a chocolate bar as a thank-you gift for study 1 and chocolate bar and 5 euro voucher for study 2.

Methods – Study 1

Participants

A total of 292 participants were recruited from [blinded for reviewers] University. After excluding 19 participants who did not pass both attention checks integrated in the study, a final sample of 273 respondents was used for the data analysis (54.9% female; Mage=22.8 years old; 78.4% Dutch).

Manipulations of the static and dynamic norms

To study how the combination of static and dynamic norms affected respondents' (over)consumption practices of fashion items, a fictitious web shop of clothes was created containing a 40 seconds movie that represented the manipulation of static and dynamic norms. Respondents were asked to watch the movie before answering a series of questions. Four different movies for the four different experimental conditions were created that systematically differed for a series of elements presented: text (with voice recorded on top), colour, pictures and animations. The videos started with the presentation of the static norm, following the dynamic norm on a follow-up page/animation. The text for the sustainable (unsustainable) static norm included the following sentences (with voice recorded): "*Recent research has shown that currently 80% of consumers (do not) make an effort to limit the amount of clothes they buy, purchasing only the clothes they need (more clothes than they need)"*. This text was followed by a second text in a second page, representing the sustainable (vs unsustainable) dynamic norm: "*And (but) they are changing their behaviour; more and more consumers are engaging in sufficient consumption (over-consumption), purchasing less (more) clothes than before and only (more than) what they really need*" (Figure 1). All the texts were adapted from previous manipulations of social norms (Yamin et al., 2019).

Procedure and main measures

After being exposed to the manipulation of static and dynamic norms, respondents were asked to engage in a fictitious web shop of clothes and to shop as they would have normally done, with a specific event in mind (e.g., a job interview, a party, a day out etc..). Participants were first asked whether they wanted to shop in the men's or women's section and were presented with an assortment of clothes corresponding with their gender selection.

Condition 1: unsustainable static + unsustainable dynamic

Screenshot 1 (unsustainable static)



Screenshot 2 (unsustainable dynamic)



Condition 2: unsustainable static + sustainable dynamic

Screenshot 1 (unsustainable static)



Screenshot 1 (sustainable dynamic)



Figure 1: screenshots of the movie, representing the manipulation of static and dynamic norms for condition 1 (unsustainable static + unsustainable dynamic) and condition 2 (unsustainable static + sustainable dynamic). Text, images (depicting over-consumption vs sufficient- based consumption in fashion for the static and dynamic norm) animations (with wardrobe of clothes becoming fuller or emptier and shoppers holding more vs less shopping bags) for the respective conditions are presented.

A large assortment of clothes was created to guarantee variety, including a total of 54 pieces of clothes for each gender, divided in six pages (one page of t-shirt, one of jeans, one of blouses, one of skirts etc..). Every item selected was recorded as a primary measure of (over)consumption practices. Selecting fewer items indicated a more parsimonious and sustainable behaviour compared to selecting a larger number of items. Second, participants were informed that they had €50 leftover, and they were asked whether they wanted to donate (some of) the leftover budget to the WWF (defined as "*a non-profit organization that fights for conservation of nature and the environment")* or keep it and continue shopping (Van Horen et al., 2018). Personal traits (environmental concern and tendency to overconsume), manipulation and attention checks, control variables and demographic questions were also asked and recorded.

Results – Study 1

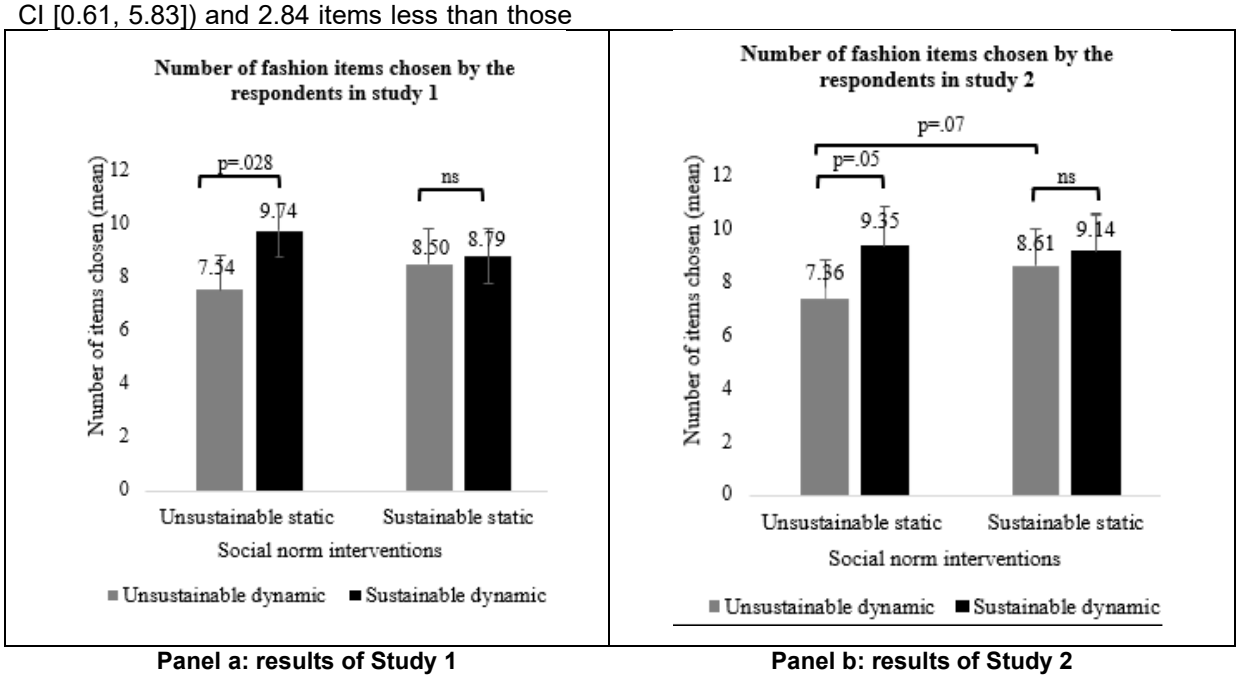
The effect of static-and-dynamic norm communications on sustainable behaviour towards reduction of fashion consumption

Results of an ANOVA and post-hoc test showed that respondents chose a lower number of items when exposed to the combination of an unsustainable static and unsustainable dynamic norm (M=7.54; SD=4.79) than when exposed to the combination of an unsustainable static and sustainable dynamic norm (M=9.74; SD=6.10; p=.02, Figure 2, panel a).

In addition, results of an ANCOVA showed that the individual's tendency to overconsume (F (1,273) = 10.72; p=.001; part η^2 =.04) and age (F (1,273) = 4.98; p=.03; part η^2 =.02)

significantly affected the number of items chosen by the respondents, independently from the social norm intervention. Specifically, the higher the tendency to overconsume, the higher was the number of items chosen (β=.19; t=3.28; p=.001). Similarly, the younger the respondents, the higher was the number of items chosen (β= -.13; t= -2.22; p=.03).

A spotlight analysis was conducted to examine the effects of the different social norm interventions on the number of fashion items chosen by the respondents at specific levels of the moderator (-1SD for low level, mean and +1SD for high level), namely people tendency to overconsume. Additionally a floodlight analysis was performed to explore range of the moderator values at which these effects are statistically different. Both analysis were conducted with the SPSS PROCESS macro, Model 1 (Spiller et al., 2013). The results showed that, for people with a low tendency to overconsume, the exposure to the "unsustainable static + unsustainable dynamic" intervention was very effective in reducing the number of fashion items chosen, as those people selected, on average, 3.22 items less than those exposed to the "unsustainable static + sustainable dynamic" (t= 2.43, p = .01; 95% CI [0.61, 5.83]) and 2.84 items less than those exposed to "the sustainable static + sustainable dynamic" intervention (t= 2.11, p = .03; 95% CI [0.19, 5.48]). For people with an average level of tendency to overconsume the exposure to an unsustainable static and unsustainable dynamic norm was still very effective in reducing the number of fashion items chosen (on average, 2.04 pieces of items less), but only more effective than the "unsustainable static + sustainable dynamic" (t= 2.20, p = .03; 95% CI [0.21, 3.86]). For people with high tendency to overconsume, no significant differences were observed across interventions. Overall, the results suggest that a rather "catastrophic" scenario, signalling that the majority of consumers behave unsustainably (unsustainable static norm) and that this trend is changing for the worst (unsustainable dynamic norm), is more effective than a scenario that opens a window of positivity and hope, where the dynamic norm signals a change for the better ("…*but more and more consumers are changing their behaviour, reducing the number of clothes they buy* etc..). In particular the intervention is effective for people with a low to medium tendency to overconsume (with values below 3.70- results from the Floodlight analysis).



Panel a: results of Study 1 **Panel b: results of Study 2**

Figure 2: Number of fashion items chosen by the respondents across the four static and dynamic norm communications in study 1 (panel a) and study 2 (panel b). NS= non significant. Error bars indicate 95% confidence interval.

Methods – Study 2

Study 2 further studies (and replicates) the effects of Study 1 and delve into a potential mediating factor. Rather than with a movie, study 2 manipulated static-and-dynamic-norm communications through a series of digital and newspaper news. For each condition, respondents were exposed to two news, one from a digital newspaper and one from a paper newspaper. This was done to strengthen the effect of the manipulation, for replication purposes only. Each news included a piece of text and an image representing the information included in the news. The two texts for the unsustainable (vs sustainable) static norm included the following: "*Currently, 80% of Western consumers engage in over-consumption (sufficient consumption): they commonly purchase excessive (parsimonious) amounts of clothes, far more than (only) what they really use and need"* and *"Recent research indicates over-consumption (sufficient consumption) of fashion items as an accepted and standard trend in today's western society, where buying excessively (parsimoniously) is the norm".* The two texts for the unsustainable (vs sustainable) dynamic norm included the following: "*Consumer behaviour is changing for the worst (the better): more and more consumers are engaging in over-consumption (sufficient consumption), purchasing more (less) clothes than before"* and *"Consumption practices are getting worst (better): overconsumption (sufficient consumption) is expected to be the norm by 2030, when buying excessively (parsimoniously) will become more common between consumers"* (Figure 3).

Procedure and main measures

Same procedure and instructions as Study 1 were applied for study 2.

Main measurements: Four main measurements were recorded and analysed to measure sustainable behaviour. First, the number of fashion items chosen by the respondents was measured and recorded, as in Study 1. In addition to that, as sufficient behaviour has been identified not only in the practice of reduced consumption, but also in the practice of reusing and second-hand purchases (Lage, 2022; Speck & Hasselkuss, 2015), willingness to switch to a second-hand item was added in study 2 as a second measurement for sufficiency. For this purpose, respondents received the following instructions: "You have just selected some brand-new clothes. The web-shop presents you with an option to switch to a second-hand version of the same product. How much cheaper does the second-hand item need to be for you to consider switching? Please use the slider to indicate the percentage discount you would need". The slider included values from 0% discount (second hand and new item have the same price) to 100% discount (the second hand item is for free) with increments of 10%. This was based on the switching behaviour typical of choice-based conjoint analysis or forced choice scales (Guiot & Roux, 2010; Roux & Korchia, 2006; Train, 2009).

In addition, to measure whether the social norm interventions triggered some consumption restraints, limiting respondents from buying all the items they liked, a multi-items question was used, adapted from the Frugality Scale (Lastovicka et al., 1999) and the Brief self-control scale (Malouf et al., 2014). Items and reliability analysis are included in Table B.1, Appendix B. Last, respondents were asked their intention to support a policy for consumption reduction by answering the question: "How strongly would you support or oppose a government policy that limits the number of fashion items consumers can purchase in a year to reduce the environmental impact?". This was measured through a 1-7 scale (1: I would strongly oppose, 4: I would neither oppose, nor support, 7: I would strongly support).

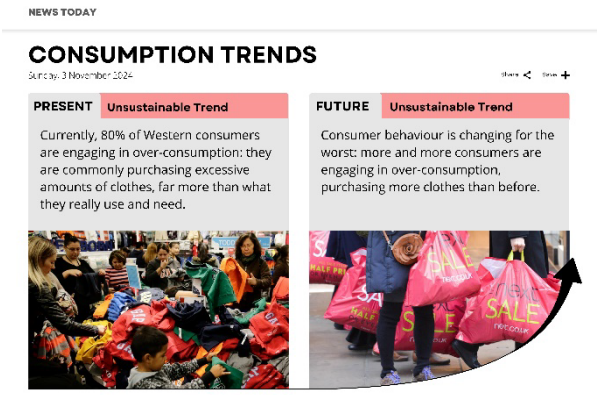
Mediator: To explore whether and to what social moral licensing and its reversed effect of social moral cleansing mediate the effects of the social norm interventions on sustainable behaviour, respondents were asked to reply to two scales measuring social moral cleansing (example of item: "After reading about other's behaviour, I feel the need to act quickly to reduce consumption") and social moral licensing (example item: "Reading about other's behaviour makes me feel I can relax a bit my own efforts) in a 7 point scale (1: strongly disagree; 7: strongly agree) and the emotional context related to social moral licensing (feelings of indifference, unconcern and discouragement) and cleansing (feelings of anxiety, stress or frustration), respectfully [1]. These emotions can be used to understand the emotional context that might lead to social

[1] Opposite poles labelled (1: very relaxed…7: very anxious; 1: very calm…7: very stressed; etc..). Manipulation of social norms was re-presented to the respondents before the mediator variables.

moral licensing/cleansing, allowing for a deeper understanding not only of whether and to what extent social moral licensing/cleansing influence the effects of static and dynamic norms on sustainable consumption practices, but also how this influence occurs (Cyders & Smith, 2008; Fisher-Fox et al., 2024).

Condition 1 : Unsustainable static + unsustainable dynamic

Digital news



Newspaper news



Condition 2 : Unsustainable static + sustainable dynamic

Digital news



Newspaper news



Figure 3: Example stimuli material for study 2, where the two versions of the same condition (1 and 2) is presented: the digital news and the newspapers news combining the static and dynamic norm information.

Discussion Study 1

Results of study 1 showed initial and promising insights into how exposing consumers to static and dynamic norm communications influences sustainable behaviour, towards a reduction in fashion consumption. In particular, consumers in our experiment chose on average a lower number of fashion items when exposed to the combination of an unsustainable static and unsustainable dynamic norm than consumers in other conditions. Despite the significant differences found, consumers still selected a high number of items across conditions, highlighting a crucial challenge: while reducing consumption is a relatively attainable behavioural shift, achieving true sufficiency-

consuming only what is necessary- remains a far more difficult step in the context of sustainable behavioural change.

Results of study 1 enrich the current understanding on social norm effects by supporting the hypothesis of norm-behaviour differentiation, rather than conformity, theoretically grounded on the principle of social proof (Bicchieri, 2016; Cialdini et al., 1990; Lahlou, 2018). In this regard, our results showed that consumers do not follow the presented normalized behaviour of others but deviate from that, if exposed to a very strong signal that others are behaving unsustainably. The combination of an unsustainable static and unsustainable dynamic norm function as such a strong signal that seems to motivate consumers to take action and behave differently and more positively than others. In study 2, we aim to replicate this effect and to investigate whether such norm-behaviour differentiation, found in study 1, is due to the norm-behaviour regulation strategies of social moral licensing and cleansing (Lasarov & Hoffmann, 2020; Brañas-Garza et al., 2013).
Adding beyond study 1, study 2 uses a sample of online shoppers, rather than a mixed sample of online and exclusively in-store shoppers and a different manipulation of social norm communications with digital and traditional newspapers news. In addition, study 2 adds variety to the dependent variable measurements, by investigating the effect on sustainable and sufficient practices from multiple lens: the one on reduction, by measuring how many items consumers purchase (replication from study 1), the one on reusing, by investigating switching behaviour to second-hand fashion practices, and the one on policy support, by investigating willingness to support to a policy for fashion reduction.

Results- study 2

The effect of static-and-dynamic norm communications on sustainable behaviour towards reduction of fashion consumption

Results of an ANOVA and post-hoc test confirmed the results of study 1: respondents chose a lower number of items when exposed to the combination of an unsustainable static and unsustainable dynamic norm communication (M=7.36; SD=45.20) than when exposed to the combination of an unsustainable static and sustainable dynamic norm (M=9.34; SD=5.34; p=.05, Figure 2, panel b). In addition, marginal significance was found between the condition “unsustainable static + unsustainable dynamic” and its opposite, “sustainable static + sustainable dynamic” (M= 9.14; SD= 5.16; p=.07) (Figure 2, panel b).
In addition, results of an ANCOVA showed that the individual’s environmental concern (F (1,230) = 6.40; p=.01; part η2 =.03) significantly affected the number of items chosen by the respondents, independently from the social norm intervention. Specifically, the higher the environmental concern, the lower was the number of items chosen (β=-.17; t=-2.63; p=.009). No significant effects were observed for other personal traits (tendency to overconsume). Gender significantly affected the number of items chosen, as female respondents chose on average less items than male respondents (β=-.24; t=-3.71; p=<.001). For female respondents, the effect of the social norm interventions was stronger and variances between conditions larger (p-values become smaller).
Results on the effect of social norm interventions on second hand switching behaviour (F(1, 230)=0.30; p=.83) and reflection on restrictive parsimonious behaviour (F(1,230)=0.77; p=.51) did not show significant effects.

The effect of static-and-dynamic norm communications on policy support for reduction

Results of an ANOVA and post-hoc test (LSD corrected) showed that respondents who were exposed to the combination of an unsustainable static and an unsustainable dynamic norm indicated to be more willing to support a government policy that limits the number of fashion items consumers can purchase in a year to reduce the environmental impact (M= 4.03; SD= 1.87) in comparison to the respondents exposed to its opposite, the combination of a sustainable static and sustainable dynamic norm (M=3.21; SD= 1.83; p=.01).
Thus, this result shows that a behaviour related measurement (N of items chosen) and an intention behaviour measurement (intention to support a policy) are in line: the social norm intervention which combines an unsustainable static norm with an unsustainable dynamic norm seems to be the most effective in promoting sustainable behaviour, which gets reflected into both consumer intentions for

policy support and actual purchasing behaviour towards reduction.

4.2.4 The role of social moral cleansing and social moral licensing (and the related emotional context)

To check whether social moral cleansing and licensing mediates the effect of social norm communications on sustainable behaviour towards reduction in fashion (i.e., number of fashion items selected and on policy support for reduction), a series of mediation analysis were conducted with PROCESS MACRO in SPSS, Model 4 with multi-categorical independent variable (Spiller et al., 2013). As social moral cleansing and licensing effects are related to certain emotions that may anticipate or co-occur with these effects, these emotions were added in the analysis (anxiety, stress, frustration related with social moral cleansing and indifference, unconcern and discouragement related with social moral licensing).

The mediation analysis with social moral cleansing showed that different static and dynamic norm communications differently triggered the emotional context related with social moral cleansing (t=-1.97; SE=0.41; p=.050; LLCI=-1.642; ULCI=-0.001). In fact, those consumers exposed to the "unsustainable static + unsustainable dynamic" condition experienced a higher level of social moral cleansing related emotions (M=4.86), in comparison to consumers exposed to the "sustainable static + sustainable dynamic" condition (M=3.52; p<.001; LLCI=-1.687; ULCI=-0.98) and "unsustainable static and sustainable dynamic" condition (M=4.49; p=.045; LLCI=-0.733; ULCI=-0.008). As a result, consumers felt the urge to "clean" and compensate for the unsustainable behaviour of others, behaving more sustainably in return (social moral cleansing effect). In fact, higher levels of stress, frustration and anxiety were associated with 1) stronger social moral cleansing effect (B=0.57; SE=0.07; β= 0.50; t=8.68; p<.001), 2) lower number of fashion items selected by respondents (B=- 0.72; SE=0.33; β= - 0.14; t= -2.18; p=.03), and 3) greater support for policies aimed at consumption reduction (B=0.48; SE=0.11; β= 0.28; t=4.49; p<.001). While the social moral cleansing related emotions mediate the effect of social norm communications on the number of items chosen by respondents, the cleansing effect per se (measured through the 4-item scale) leads to greater willingness to policy support for reduction (B=0.60; SE=0.09; β= 0.41; t=6.81; p<.001; LLCI=0.329; ULCI=0.729), but does not result in actual sustainable behaviour, purchasing fewer items (B=- 0.06; SE=0.29; β= - 0.014; t= -0.21; p=.84; LLCI=-0.329; ULCI=0.978).

The mediation analysis with social moral licensing showed no significant effect on sustainable behaviour, neither on the number of fashion items chosen by respondents, nor on policy support for consumption reduction. In addition, no variations were observed across interventions on social moral licensing. Despite that, results showed that higher levels of social moral licensing related emotions (indifference, unconcern and discouragement) had two main consequences: 1) significantly increased the social moral licensing effect (B=0.33; SE=0.08; β= 0.26; t=4.15; p<.001), and 2) significantly decreased consumer support to policies aimed at consumption reduction (B=- 0.49; SE=0.13; β= - 0.24; t= -3.79; p<.001).

Discussion Study 2

Results of study 2 replicate and confirm results of study 1, demonstrating that consumers exposed to the combination of unsustainable static and unsustainable dynamic norm communications behaved more sustainably than consumers exposed to other conditions. In fact, those consumers selected a lower number of items in the shopping task and indicated a higher willingness to support a policy aimed at consumption reduction. Adding beyond study 1, the results of study 2 suggest an underlying mechanism driving these effects, centred on the norm-behaviour regulation strategy of social moral cleansing. In this regard, results demonstrate that the communication of an unsustainable behaviour of others, like the one of excessive consumption, reflected both in the static and dynamic norm, can function as a strong signal driving action rather than inaction and norm- behaviour differentiation rather than conformity. In fact, after being exposed to the unsustainable static and unsustainable dynamic norm communication, respondents in study 2 felt more anxious, stressed and frustrated in regard to the normalized unsustainable behaviour of others, than respondents in the other conditions. As a result, respondents felt the urgency to take action and "clean" the bad behaviour of others, behaving more sustainably in return (social moral cleansing effect).

References

Allaby, M., & Park, C. (2013). *A dictionary of environment and conservation*. OUP Oxford.

Aratani, L. (2024, 12 July 2024). The new normal': work from home is here to stay, US data shows. *The Guardian*. https://www.theguardian.com/money/article/2024/jul/12/working-from-home-data

Attenborough, D. (2020). *A life on our planet: My witness statement and a vision for the future*. Random House.

Azhar, M., Akhtar, M. J., Rahman, M. N., & Khan, F. A. (2023). Measuring buying intention of generation Z on social networking sites: an application of social commerce adoption model. *Journal of Economic and Administrative Sciences*. https://doi.org/10.1108/JEAS-02-2022-0047

Borg, K., Curtis, J., & Lindsay, J. (2020). Social norms and plastic avoidance: Testing the theory of normative social behaviour on an environmental behaviour. *Journal of Consumer Behaviour*, *19*(6), 594-607. https://doi.org/10.1002/cb.1842

Choi, Y.-H., & Lee, S. (2024). Climate change messages in the fashion industry discussed at COP28. *The Research Journal of the Costume Culture*, *32*(4), 517-546. DOI: 10.29049/rjcc.2024.32.4.517

Ehrlich, P. R., & Goulder, L. H. (2007). Is current consumption excessive? A general framework and some indications for the United States. *Conservation Biology*, *21*(5), 1145-1154. https://doi.org/10.1111/j.1523-1739.2007.00779.x

Geber, S., & Hefner, D. (2019). Social norms as communicative phenomena: A communication perspective on the theory of normative social behavior. *SCM Studies in Communication and Media*, *8*(1), 6-28. DOI: 10.5771/2192-4007-2019-1-6

Hogg, M. A., & Reid, S. A. (2006). Social identity, self-categorization, and the communication of group norms. *Communication Theory*, *16*(1), 7-30. https://doi.org/10.1111/j.1468-2885.2006.00003.x

Leong, L.-Y., Hew, T. S., Ooi, K.-B., Hajli, N., & Tan, G. W.-H. (2024). Revisiting the social commerce paradigm: The social commerce (SC) framework and a research agenda. *Internet Research*, *34*(4), 1346-1393. https://doi.org/10.1108/INTR-08-2022-0657

Loschelder, D. D., Siepelmeyer, H., Fischer, D., & Rubel, J. A. (2019). Dynamic norms drive sustainable consumption: Norm-based nudging helps café customers to avoid disposable to-go-cups. *Journal of Economic Psychology*, *75*, 102146. https://doi.org/10.1016/j.joep.2019.02.002

Pristl, A. C., Kilian, S., & Mann, A. (2021). When does a social norm catch the worm? Disentangling social normative influences on sustainable consumption behaviour. *Journal of Consumer Behaviour*, *20*(3), 635-654. https://doi.org/10.1002/cb.1890

Rimal, R. N., & Lapinski, M. K. (2015). A re-explication of social norms, ten years later. *Communication Theory*, *25*(4), 393-409. https://doi.org/10.1111/comt.12080

Segalov, M. (2023, 15 January 2023). Last orders: how we fell out of love with alcohol [November 2024]. *The Guardian*. https://www.theguardian.com/society/2023/jan/15/last-orders-how-we-fell-out-of-love-with-alcohol

Sparkman, G., & Walton, G. M. (2017). Dynamic norms promote sustainable behavior, even if it is counternormative. *Psychological science*, *28*(11), 1663-1674. https://doi.org/10.1177/0956797617719950

Spiller, S. A., Fitzsimons, G. J., Lynch Jr, J. G., & McClelland, G. H. (2013). Spotlights, floodlights, and the magic number zero: Simple effects tests in moderated regression. *Journal of Marketing Research*, *50*(2), 277-288. https://doi.org/10.1509/jmr.12.0420

Thomas, C., & Sharp, V. (2013). Understanding the normalisation of recycling behaviour and its implications for other pro-environmental behaviours: A review of social norms and recycling. *Resources, Conservation and Recycling*, *79*, 11-20. https://doi.org/10.1016/j.resconrec.2013.04.010

Van Horen, F., van der Wal, A., & Grinstein, A. (2018). Green, greener, greenest: Can competition increase sustainable behavior? *Journal of Environmental Psychology*, *59*, 16-25. https://doi.org/10.1016/j.jenvp.2018.08.007

Yamin, P., Fei, M., Lahlou, S., & Levy, S. (2019). Using social norms to change behavior and increase sustainability in the real world: A systematic review of the literature. *Sustainability*, *11*(20), 5847. https://doi.org/10.3390/su11205847

Yanovitzky, I., & Rimal, R. N. (2006). Communication and normative influence: An introduction to the special issue. *Communication Theory*, *16*(1), 1-6. https://doi.org/10.1111/j.1468-2885.2006.00002.x

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One man's trash is another man's treasure: Actor constellations to prolong the life of 'new waste' resources

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Keywords: pre-consumer waste, new waste, multiple case study, ARA model

Abstract: The overconsumption of finite resources and the growing climate crisis necessitate innovative manufacturing waste management approaches. This study investigates the untapped potential of redesigning waste materials—specifically, pre-consumer waste or "new waste"—to create value while mitigating environmental impact. Unlike recycling or disposal, this approach leverages the inherent qualities of discarded manufacturing materials derived from virgin resources, aligning with the European Union's waste hierarchy principles. Using a multiple case study methodology, we analysed eight collaborations between manufacturing companies and industrial designers. The actor-resources-activities model was employed to understand how these partnerships foster redesign and prolong material lifespans. Our findings reveal that strategic actor roles and interactions are crucial in activating redesign potential, enabling the transformation of waste materials into new products. The crucial actor roles consist of an industrial designer, a waste owner, a waste processor, and a sales & distribution actor. The results highlight significant business and environmental opportunities, including cost reductions and waste diversion from landfills. However, realising this potential requires targeted interventions to facilitate cross-disciplinary collaborations and align objectives among stakeholders. By illustrating successful constellations of actors and processes, this research provides actionable insights into unlocking new avenues for circular economy practices in manufacturing.

Introduction

The amount of waste materials generated by manufacturing companies is too high, considering our limited resources and the growing climate crisis. Overconsumption of the planet's finite resources severely risks ecosystems, human health, and economies worldwide (Intergovernmental Panel On Climate Change (Ipcc), 2023). Data presented by the World Bank highlights the staggering scale of global waste generation, with projections estimating that, without intervention, waste generation will increase by 70% by 2050 (Kaza et al., 2018). When this projection is combined with the fact that 40% of global waste ends up in landfills (33% in open landfills, Kaza et al., 2018), the environmental impact of waste becomes palpable. This calls for better sufficiency, a concept described as "meeting human needs within planetary limits by curbing excessive consumption levels", (Niessen & Bocken, 2021). In the past, sufficiency has primarily been a consumer-based concept (Jungell-Michelsson & Heikkurinen, 2022). However, there has been a limited focus on sufficiency from a manufacturers point of view e.g., retaining and utilising the value of what may be defined as unavoidable waste from industry. This is also termed pre-consumer waste or 'new waste' materials. New waste, typically viewed as a burden, holds significant opportunities for simultaneous value generation and environmental impact reduction, e.g., by focusing on reusing and remanufacturing (Du et al., 2013; Pacelli et al., 2015). Such recommendations are also laid out in the European Union's five-step waste hierarchy: waste prevention, reuse, recycling, recovery (herein also energy recovery), and safe disposal (Directive 2008/98/EC, 2024). Studies show that recycling new waste can significantly reduce energy consumption and cost (reductions of up to 67% and 40%, respectively, Ali et al., 2019). Thus, there is a considerable untapped value potential in utilising the generated waste materials as *new products* rather than for recycling, energy, or waste dumps.

For example, it is possible to consider such discarded scraps from manufacturing as new waste derived from virgin materials, which opens the possibility of designing products with

what is essentially leftover virgin material. Normalising products made from new waste tackle the primarily consumer-based sufficiency concept from a different angle. By offering consumers easy, alternative new waste products to products made from traditional virgin materials, it may be possible to curb over consumption through better resource use.

Designing products with waste is a new but growing field. It has been described as an inverted process, where one starts from the material and defines a relevant use case/user need based on the qualities of the material, rather than starting from a consumer need and then defining the most suitable materials for the product. Ways to structure such a design process have been described before (Jensen et al., 2024; Pacelli et al., 2015). However, there is a lack of transparency and empirical evidence showcasing how to successfully prolong material lifetime in an industry setting, going beyond singular demonstration cases.

This work aims to study actor constellations and interactions that promote redesigning and reshaping waste resources. For this, a multiple case study methodology has been applied to study 8 cases where manufacturing companies were paired with industrial designers. We examine how different actor constellations interact to advance the redesign process with waste materials, and the conditions for creating new products using waste materials are explored using an *actor*, *resources,* and *activities* model (Ford et al., 2008; Håkansson & Snehota, 1995, p. 35).

Theory

The view on what is considered waste is starting to change, e.g., revealing the role of design in reducing the overall material consumption for consumer products by designing with waste (Feast & Laursen, 2023; Jensen et al., 2024; Pacelli et al., 2015). Waste materials have also been used in the design towards creative applications to create novel and unique aesthetics (Sampah et al., 2024), which in turn may serve as examples of how to elevate the perceived value of the final product. External legislation, such as directives from the European Union regarding environmental, social, and governance (ESG) initiatives, adds further pressure to tackle waste handling and reporting requirements. The European Commission has increased its focus on reducing the environmental impact of consumer products, as evidenced by the European Green Deal (European Commission, 2021). These directives compel organisations to reevaluate their approaches to waste management and explore innovative solutions. Among possible solutions lie the option to design new products from discarded materials.

However, designing with new waste (scraps) has proven difficult. For example, waste typically differs in quantity and size (Pacelli et al., 2015), and one does not necessarily know the end-user or area of application up front, which complicates the product design process. Pacelli et al. focus on designing with waste (defined as scraps) and presented a 3 phase process consisting of i) reducing the occurrence of production waste, ii) identifying the unavoidable waste, iii) starting a design process using the unavoidable waste to find relevant use cases or to create new products (Pacelli et al., 2015). During these phases, one must consider the *production setup* (e.g., how reliably one can expect the flow of material to be), conduct *waste material analysis* (functional, dimensional, mechanical, and physical properties), and consider the *sensorial qualities* (e.g., tactile or visual).

However, using design competencies to help solve issues regarding waste materials in manufacturing environments is an underexplored approach, with only a few examples (See Feast & Laursen, 2023; Jensen, 2024; Pacelli et al., 2015). One notable challenge when designing products using waste materials lies in shifting the traditional paradigm of product development thinking. Typically, product ideation begins with identifying a need or problem and then specifying materials and processes to address it. However, this process is inverted when working with waste materials (Jensen et al., 2024). Thus, material specifications are predetermined, and designers must creatively adapt these materials to fit emerging use cases, e.g. by applying an effectual approach to design (Feast & Laursen, 2023). This reversal poses a significant challenge to traditional product development methodologies.

Jensen et al. (2024) dove deeper into Pacelli's phases ii) and iii) by investigating how to assess potential use cases of waste materials properly. They posit that a linear understanding of the designerly material assessment of waste is viable and proposes that four modes of iteratively converging and diverging methods aid the process once a material's reuse potential: Mode 1 - Material sorting, mode 2 -

material potentials, mode 3 - areas of application, mode 4 - value-ranking utilisations. Moreover, they hint that the outcome of the waste reuse potential seems dependent on the assessors' competencies. Therefore, a deeper understanding of the actors collaborating in the design process of reshaping waste materials is currently missing from the discussions.

The ARA model

In business research, a model describing interactions between *actors, resources,* and *activities* (ARA) has been developed (Håkansson, 1995), which not only stipulates how important the interactions *within* a company are but also the interactions *between* companies (or actors), (Ford et al., 2008). See Figure 1. Ford et al. expressed: *"Interaction can be interpreted as a confrontation process that occurs* between *companies and which* changes *and* transforms *aspects of the resources and activities of the involved companies themselves"* (Ford et al., 2008, p. 3).

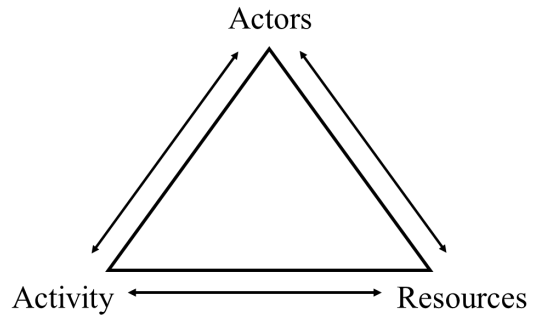


Figure 1 ARA Model from (Håkansson & Snehota, 1995)

In our case, this interaction occurs between different actor roles as *waste owners*, *design professionals*, *waste processors*, and *sale & distributors*, see Figure 2.



Figure 2 Actor roles when designing with waste intended for new consumer products

- **Designer**: The industrial designer paired with the manufacturer based on their experience with either the waste materials or core business area of the manufacturing company.
- **Waste Owner**: The manufacturing company typically generates production waste during their everyday activities.
- **Waste Processor**: Once a waste material is identified, this actor role is responsible for any additional material processing or waste handling to transform the new waste into the proposed product design. It could be the original manufacturing company or a third-party collaborator.
- **Sales & Distribution**: Once the proposed product design has been produced, this actor is responsible for selling and distributing the product. It could be the original manufacturing company or a third-party collaborator.

The *resources* and *activities* relate to waste materials in manufacturing processes and the production processes surrounding those materials. When the right partners are put together, as Håkansson & Johansson put it, a "team effect" occurs, which allows companies to perform activities and use resources that would otherwise not be possible to do alone (Håkansson & Snehota, 1995, p. 37).
To the authors' knowledge, when it comes to designing viable products with waste materials, such a team effect caused by the interactions between these actor roles has not been investigated previously, as the research focus is very nascent and there is a lack of empirical studies.

Methodology

We collaborated with manufacturing companies interested in reducing their waste and were open to new business opportunities, e.g., a product designed from new waste. The manufacturing companies were paired with industrial designers, where the researchers acted as matchmakers and project managers. The rest of the actor constellation emerged (hence the field experiment methodology). As shown in interactive research communities, such a constellation between industry and research has previously garnered rigorous and relevant outcomes for academicians and practitioners alike (Ellström et al., 2020). As such, the research project provided the basis for conducting empirical case studies to research suitable interactions between the actor roles presented in Figure 2.

Data collection

Over 3 years, eight design field experiments were carried out to analyse waste reuse potentials in different manufacturing fields and to arrive at viable product design proposals.

The data collected spans observations at manufacturing plants, voice recordings of initial start-up meetings, preliminary design proposals/ideas, the final design proposals, and closing semi-structured interviews with the involved representatives from the manufacturing company and the industrial designer to capture their experiences and reflections on the process.

Once the collaboration between the design firm and waste owner was concluded with a handover meeting, semi-structured interviews were conducted with the lead designers and the contact person from the manufacturer (typically a production manager or CEO). In total, 14 hours of interviews were conducted after the design phase ended, and on-site field notes, photos, and waste samples were collected. See Table 1.

Table 1 Overview of cases, actors interviewed, and data collected

Method	Cases and informants	Data and processing
Interview	1. Kitchens, 2. Apparel and footwear, 3. Furniture, 4. Powder coated steel, 5. Concrete, 6. Furniture upholstery, 7. Acoustic panels, 8. Mechanical equipment. (7x) Senior Designer, (3x) Technical manager, head of production, CEO, Architect, (2x) Environment and sustainability manager, sales and product manager.	+14 hrs interview data, transcriptions
On-site		Field notes, photos, waste samples

The interviews were conducted using a semi-structured interview guide centred around their participation in the project, their approach to designing with waste materials, the manufacturer's view on waste materials, and their reflections. Where possible, the interviews were conducted straight after the handover meeting. During the research interviews, the waste materials and a process report of their project curated by the research team were provided in front of them according to the artifact elicitation method to make sure to capture finer details otherwise easily omitted when relying on memory alone (Douglas et al., 2015; Wallwey & Kajfez, 2023).

The interviews were coded thematically using a qualitative approach inspired by Braun & Clarke's thematic analysis approach (Braun & Clarke, 2006, 2019).) For the data analysis, we used the ARA model of activities, resources, and actors as an analytical framework and codebook, which made it an abductive approach.

Findings

The outcomes from the field experiments formed different actor constellations between four different actor roles. Our analysis revealed eight different business constellations (more may be possible) and has been mapped out in Figure 3. The grey boundaries represent actor

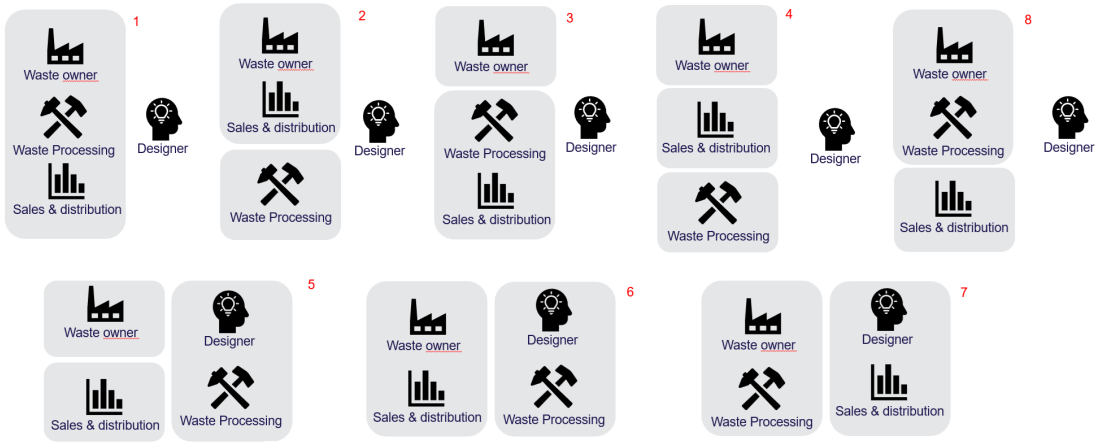


Figure 3. Actor roles and their observed constellation. The grey denotes actor roles within the same company

roles within the same company. For example, constellation 1 explains a situation where the designer works on a product proposal that is targeted to be processed and sold by the waste owner. In contrast, constellation 2 requires a third party to help process/manufacture the product proposal before the waste owner handles product sales and distribution.
Table 2 presents an overview of the cases and which designs went to market. The material-driven process forces designers and businesses to explore alternatives instead of working within existing actor constellations and value chains. Everything is turned upside down and driven by the material, as a designer describes:*"... It's not like I had a list of limitations thrown my way from the companies. That is what one needs to explore. And I think it's in the way that the approach is not 'I need to make a table'. No, it's 'I need to work with concrete'. It turns the design process upside down completely because materials are often some of the last points we decide upon",* Lead Designer, Case 5.

Table 2 Case overview, design proposals, if they have gone to market (GTM), and actor constellations.

Case	Waste material (type)	Design suggestions	Description	GTM?	#
1. Kitchens	Wood, compact laminate Kitchen sink table cutouts	Bedside table	Good product portfolio fit, combined two large waste fractions; is scalable due to a steady supply of standardised sink cutouts.	Y	3
2. Apparel and footwear	Textile, returned pants (customer defects)	Branded Shopper	Good product portfolio fit, fit existing market and sales channels, good fit between actor roles (described as symbiotic)	Y	2
		Travel case for small items	Semi-product portfolio fit, but lacked a proper business case. Good fit between actor roles.	N	
		Wardrobe organiser	Organiser lined with pant-textile material for watches, or a pouch for belts	N	
3. Furniture	Textile, leftover material from furniture upholstery	Cushion	Good product portfolio fit. Idea works in current form. Not able to enter production as is, but possible with additional resources.	Y/N	1
		LED lamp cover	Bad product portfolio fit, required additional materials outside of existing product categories and market. *Missing Sales & Distribution actor role*	N	2
		Wall-hung storage	Semi product portfolio fit. Idea does not work in current form but able to be adapted to their core products. Not able to enter production as is, but possible with additional resources.	Y/N	1
		Foldable stool	Product portfolio fit but required additional materials outside of existing product categories in an already competitive market. *Missing Sales & Distribution actor role*	N	2
4. Powder coated steel	Steel, leftover perforated plates from punch holes/lasercut	Weighted bags with scraps	Bad product portfolio fit. Intended for internal use, not enough scale, and business case not clear. *Missing Sales & Distribution actor role*	N	3
		Interior decoration	Bad product portfolio fit. Would require new sales channels outside of core business. The business case was unclear. *Missing Sales & Distribution actor role*	N	8
		Acoustic panels	Bad product portfolio fit. Would require new sales channels outside of core business. The business case was not clear. *Missing Sales & Distribution actor role*	N	8
5. Concrete		Shelves	Good fit between waste owner, waste processor, and sales & distribution, but the	N	

	Concrete test pour / texture sample		product did not match the scale of the waste stream. Waste volume and product did not match.		3
		Outdoor picnic table set	Good fit between waste owner, waste processor, and sales & distribution and a good fit between waste volume and product.	Y	
6. Furniture upholstery	Leather, scraps from furniture upholstery	Add-ons for door handles – stitched	Good product portfolio fit the waste owner. The designer processed waste but with possibility for outsourcing production. *Missing sales & distribution actor role. Missing waste processor at scale.*	N	5
		Add-ons for door handles – woven	Good product portfolio fit for the waste owner. The designer processed the waste but the product requires specialised skillsets to manufacture. *Missing sales & distribution actor role. Missing waste processor at scale.*	N	
		Weaved leather cushion	Good product portfolio fit for the waste owner. The designer processed waste but with possibility for outsourcing production. *Missing sales & distribution actor role. Missing waste processor at scale.*	N	
		Notebook cover	External sales & distribution channel found, and a good product portfolio fit was reached.	Y	
		Napkin rings	External sales & distribution channel found, and a good product portfolio fit was reached.	Y	
7. Acoustic panels	Wood-cement boards, Damaged acoustic panels	Acoustic/decorative panels in small modular shapes: *rhombus, jagged,* and *squares* with milled patterns	Bad product portfolio fit. Required a new production line with dedicated personnel *(missing resources)*. The business case was not clear. *Missing sales & distribution actor role. Missing waste processor at scale.*	N	3
		Small Acoustic panels for hidden placement under tables	Bad product fit, the solution would not provide enough area to contribute to any real noise dampening *Missing sales & distribution actor role. Missing waste processor at scale.*	N	
		Decorative wall-hung letters or tetris shapes	Bad product fit. Would require a new production line with dedicated personnel. The business case was not clear. *Missing sales & distribution actor role. Missing waste processor at scale.*	N	
8. Mechanical equipment	Steel scraps	Roller table	Bad product fit. Required new sales channels in areas where competition is already high and would not be able to compete on price. *Missing sales & distribution actor role. Missing waste processor at scale.*	N	4
		Car creeper	Bad product fit. Required new sales channels in areas where competition is already high and would not be able to compete on price. *Missing sales & distribution actor role. Missing waste processor at scale.*	N	

Discussion and conclusions

The successful realisation of products made from reshaped waste depends on the alignment and collaboration of four critical actor roles: Designer, Waste Owner, Waste Processor, and Sales & Distribution. The interplay between these roles directly influences the proposed products' feasibility, scalability, and market fit.

This study's analysis of eight cases highlights the pivotal factors, challenges, and opportunities in leveraging waste materials for innovative product development without drawing on virgin material supply chains.

Material-Driven Design and Portfolio fit

The material-driven design approach demands designers start with waste materials rather than predefined product ideas. This reversal of traditional design processes is both a challenge and an opportunity. Such open-ended exploration fosters creativity but requires strong alignment with Waste Owners and Waste Processors to ensure scalability and practicality.

Several cases demonstrate how product proposals achieved a good portfolio fit and went to market, such as Case 1's bedside table, Case 2's branded shopper, Case 5's concrete table, and Case 6's notebook cover and napkin rings. These products shared key characteristics:

- They aligned with the Waste Owner's core product categories.
- They fit seamlessly into existing sales channels or identified new distribution opportunities.
- The waste material supply was steady, standardised, or scalable.

Challenges in Actor Role Alignment

Despite these successes, many cases faced significant challenges due to misaligned or missing actor roles:

- **Waste Processor Role:** The absence of an efficient Waste Processor was a recurring bottleneck. For example, **Case 6**'s woven leather door handle add-ons and cushions required specialised processing skills and scalable operations that were unavailable during the project. Similarly, **Case 7**'s acoustic panels and **Case 8**'s steel products lacked processing capabilities that matched the product proposal's needs.
- **Sales & Distribution Role:** Products with strong design potential often fail to progress due to missing sales and distribution pathways. Examples include **Case 3's LED lamp cover** and **Case 4's acoustic panels**, which required entirely new sales channels or significant investment in distribution, making them commercially unviable.
- **Strategic Alignment:** In some instances, the lead contact from the Waste Owner did not have the decision-making power or strategic alignment to move the project forward. In **Case 8**, this led to proposals like the roller table and car creeper that did not fit the company's market focus or competitive strengths.

Critical Activities and Resources

The success of reshaped waste products hinges on specific activities and the efficient use of resources by the actor roles:

- **Market Analysis and User Testing:** Identifying potential customers and testing product functionalities (e.g., **Case 2**) ensures market readiness.
- **Standardisation:** Defining standard sizes and properties of waste materials, as seen in **Case 1's sink cutouts**, helps integrate the waste into scalable production processes.
- **Waste Dating and Partnering:** Finding suitable collaborators for waste design and production was instrumental in several cases.
- **Leveraging Existing Supply Chains:** Case 5 demonstrated how minimal changes to existing processes (e.g., using a transportable mould) can reduce costs and simplify scaling.

Portfolio Fit and Business Constellation

The strategic fit of a product proposal is a key determinant of its success. Products with good portfolio fit often align with the Waste Owner's existing offerings and leverage established sales channels, as seen in Cases 1 and 2. In contrast, products like Case 4's acoustic panels or Case 8's car creeper struggled due to misalignment with core business areas and the need for entirely new sales and distribution strategies.

The "right" business constellation is context-dependent and requires early involvement from all actor roles. In Case 3, including Sales & Distribution actors earlier in the process could have expedited the adaptation of wall-hung storage to align with the company's core offerings.

For products to succeed in conventional product design, there must be a so-called strategic fit between the available competencies, the market and end-users, and the company strategy (Møller & Laursen, 2023,

p. 51). Møller & Laursen, 2023 investigated the design challenges between these influencing factors before creating a strategic fit that created long-lasting and successful products. However, past examples of strategic fit did not focus on how one might better utilise available resources, e.g., how existing waste materials could be considered in the product design. This work implies that collaboration between different actors from different disciplines could be very beneficial in better exploiting the untapped potentials for optimising material use, e.g., in the form of products designed from waste materials. The chosen (or available) actor constellations can predict how well the reshaped waste product is positioned for the consumer market. More data is needed to determine whether such a material-driven design approach using new waste materials succeed in offering consumers convenient alternatives to linear, more environmentally harmful products, or, if they only manage to increase overall production volume of products with limited use.

Suggestions for Further Research

1. **Exploring 'Waste Symbiosis':** Developing business models in which Waste Owners achieve higher returns for waste materials and Waste Processors gain affordable resources could enhance valorisation of waste materials. E.g., could this be explored from a sufficiency perspective through a microeconomic lens on business collaboration.
2. **The effect of new waste products in a take-make-waste environment:** How well new waste products perform or succeed over traditional products from virgin materials need further investigation. As a minimum, user needs have to be met before such new waste products are a viable replacement of traditional products.
3. **Actor Role Optimisation:** Understanding how to better integrate Waste Processors and Sales & Distribution roles in the development process, particularly in scaling waste-based products, is critical for successful future projects.

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References

Ali, A. K., Wang, Y., & Alvarado, J. L. (2019). Facilitating industrial symbiosis to achieve circular economy using value-added by design: A case study in transforming the automobile industry sheet metal waste-flow into Voronoi facade systems. *Journal of Cleaner Production*, *234*, 1033–1044. https://doi.org/10.1016/j.jclepro.2019.06.202

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Directive 2008/98/EC (2024). http://data.europa.eu/eli/dir/2008/98/2024-02-18/eng

Douglas, E. P., Jordan, S., Lande, M., & Bumbaco, A. (2015). Artifact elicitation as a method of qualitative inquiry in engineering education. In *ASEE Annual Conference and Exposition, Conference Proceedings* (Vol. 122).

Du, Y., Cao, H., Chen, X., & Wang, B. (2013). Reuse-oriented redesign method of used products based on axiomatic design theory and QFD. *Journal of Cleaner Production*, *39*, 79–86. https://doi.org/10.1016/j.jclepro.2012.08.032

Ellström, P.-E., Elg, M., Wallo, A., Berglund, M., & Kock, H. (2020). Interactive research: Concepts, contributions and challenges. *Journal of Manufacturing Technology Management*, *31*(8), 1517–1537. https://doi.org/10.1108/JMTM-09-2018-0304

European Commission. (2021, July 14). *The European Green Deal*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

Feast, L., & Laursen, L. (2023). Design from Waste Materials: Situation, Problem, and Solution. *Learn X Design Conference Series*. https://dl.designresearchsociety.org/learnxdesign/learnxdesign2023/fullpaper/16. https://doi.org/10.21606/drslxd.2024.056

Ford, D., Gadde, L.-E., Håkansson, H., Snehota, I., & Waluszewski, A. (2008). *Analysing Business Interaction*. 24th IMP Conference. https://doi.org/10.20935/AcadEng7407

Håkansson, H., & Snehota, I. (Eds.). (1995). *Developing relationships in business networks*. Routledge.

Intergovernmental Panel On Climate Change (Ipcc). (2023). *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009157896

Jensen, N. S., Laursen, L. N., Bak, B. L. V., & Damgaard-Møller, E. (2024, June 24). Starting from Scraps: Designerly Assessment of Waste Materials. *Design Research Society*. DRS 2024 Boston. Resistance, Recovery, Reflection, Reimagination, Northeastern University, Boston, MA USA. https://doi.org/10.21606/drs.2024.888

Jungell-Michelsson, J., & Heikkurinen, P. (2022). Sufficiency: A systematic literature review. *Ecological Economics*, *195*, 107380. https://doi.org/10.1016/j.ecolecon.2022.107380

Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. https://doi.org/10.1596/978-1-4648-1329-0

Møller, L., & Laursen, L. N. (2023). *Designing for longevity: Expert strategies for creating long-lasting products*. Routledge.

Niessen, L., & Bocken, N. M. P. (2021). How can businesses drive sufficiency? The business for sufficiency framework. *Sustainable Production and Consumption*, *28*, 1090–1103. https://doi.org/10.1016/j.spc.2021.07.030

Pacelli, F., Ostuzzi, F., & Levi, M. (2015). Reducing and reusing industrial scraps: A proposed method for industrial designers. *Journal of Cleaner Production*, *86*, 78–87. https://doi.org/10.1016/j.jclepro.2014.08.088

Sampah, S. N. A., Barfi-Mensah, H. M., Mensah, E. F., Vicku, C., Adja-Koadade, M., & Junior, A.-A. (2024). Exploring sustainable aesthetics through repurposed studio waste materials for unorthodox finishes. *Cleaner Waste Systems*, *8*, 100147. https://doi.org/10.1016/j.clwas.2024.100147

Wallwey, C., & Kajfez, R. L. (2023). Quantitative research artifacts as qualitative data collection techniques in a mixed methods research study. *Methods in Psychology*, *8*, 100115. https://doi.org/10.1016/j.metip.2023.100115

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Perceptions of sacrifice in the pursuit of sufficient consumption

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Keywords: Clothing; sufficiency; perceived sacrifice; sustainable consumption.

Abstract: This study investigates the role of perceived sacrifice in the adoption of behaviours of sufficiency in clothing consumption. With the urgent need to reduce carbon emissions and consumption to stay within planetary boundaries, this research explores how consumers perceive and are willing to make sacrifices for sustainable consumption. The paper examines seven types of perceived sacrifices—functional, emotional, social, epistemic, conditional, financial, and time/effort—and their impact on the intention to adopt sufficiency behaviours such as reducing purchases, extending clothing longevity, shifting to second-hand items, and sharing clothes. The findings reveal that perceived sacrifices significantly and negatively influence the willingness to adopt these behaviours, with variations across different types of sacrifices and behaviours. This research contributes to the literature on sustainable consumer behaviour and offers insights for policy-makers, marketers and designers to promote sufficiency in consumption.

Introduction

Current consumption and production patterns cannot be maintained within the planetary boundaries (O'Neill et al., 2018). For example, it has been estimated that to comply with the Paris Agreement, the carbon budget per capita in the Netherlands should decrease 89% by 2050 in comparison to 1990, representing individual emissions between 1 and 2 tonnes CO2 eq. yearly (Olivier, Schure, & Peters; 2017). In 2021, these emissions were equal to 15.4T CO2 eq., which suggests that substantial efforts have to be undertaken to reduce carbon emissions and especially that of the high consuming-classes. Therefore, next to technological innovations based on efficiency and carbon removal, we have to develop approaches to change behaviour, involving radical reduction of material and energy consumption (Wynes & Nicholas, 2017).

Sufficiency in consumption entails reassessing personal needs to avoid excess consumption (Gossen et al., 2019), reducing overall resource usage, waste, and other negative impacts to contribute to staying within planetary limits while improving human well-being and fighting social inequalities (Garcia-Ortega et al. 2023). The term sufficiency relates to a lower and an upper limit of consumption. The lower limit warrants a decent quality of life while the upper limit ensures the well-being of the planet and thus future generations (Spengler, 2016). Consumers can adopt sufficient lifestyles either by necessity (i.e. lack of financial means to consume more) or by choice (i.e. conscious decision to reduce impact of one's consumption). Our focus is on the latter as this is necessary for just sustainability given the huge gap between consumption footprints of countries (Wiedmann et al., 2020) and individuals with low/high income (Ivanova & Wood, 2020). From a consumer perspective, sufficiency for high-consuming classes results in substantial changes in consumption patterns, which may entail absolute reductions in consumption, modal shifts, product longevity, and sharing practices (Sandberg, 2021).

This study specifically focusses on sufficiency in clothing consumption. The clothing domain is a compelling focus due to its significant environmental impact (Muthu & Gardetti, 2020), the potential for behavioural change, and the symbolic value of clothing in consumer culture (Niinimäki et al. 2020). In this context, changes in consumption patterns may entail behaviours such as assessing the number of clothes that are truly needed, reducing the number of items bought, buying these items second-hand, sharing or renting some clothes or ensuring that these are kept for as long as possible, and may lead to perceived loss of value for consumers.

Akbar et al. (2016, p.4222) indeed highlight that "consumers who want to reduce their general consumption patterns (e.g., to save resources) sometimes make painful sacrifices". Thus, sufficient behaviours can result in discomfort which might prevent consumers from making these necessary sacrifices.

Perceived sacrifice has previously been defined in the consumer behaviour literature as what would be given up in acquisition (Cronin, Brady, & Hult, 2000). However, in daily language we would not call this a sacrifice, but rather an exchange. In other fields, different conceptualisations of sacrifice can be found. For example, in multiple ethical theories, sacrifice is seen as an essential component of the moral agent when self-transcendence and self-interest conflict (Halbertal, 2012). Hence, sacrifice means somebody gives something up of high value for a greater cause (Bélanger et al. 2014). In literature on romantic relationships, sacrifice is conceptualised as costly prosocial behaviour in favour of the relationship (Righetti, Visserman, & Impett, 2022). Based on these definitions, we understand sacrifices for sufficiency as perceived personal losses of value that consumers experience when they voluntarily reduce their consumption for the greater good. Perceived sacrifices are likely highly subjective, dependent on the consumer, lifestyle, and values. Thus what one consumer perceives as an exchange another might perceive as a sacrifice. Unsurprisingly, the extent to which individuals are willing to make sacrifices in their consumption behaviours may differ greatly (Hutter and Hoffmann, 2013).

Despite the potential of perceived sacrifices to explain willingness to adopt sufficient behaviours, perceived sacrifice as an antecedent of adoption of 'strong sustainable behaviours' has so far been overlooked in the literature (Chwialkowska & Flicinska - Turkiewicz, 2021). We therefore investigate the role of perceived sacrifice in predicting the willingness to adopt sufficient consumption behaviours. More specifically, we explore seven types of sacrifice, namely functional, emotional, social, epistemic, conditional, financial, time/effort (Sheth, Newman & Gross, 1991; Zeithaml, 1988). This study contributes to the literature in design for sustainable behaviour change by highlighting the significant role of perceived sacrifices in the willingness to adopt sufficient consumption behaviours. Furthermore, the findings also highlight the perceived benefits of the sufficient consumption behaviours and potential incentives that could make it easier for consumers to change their behaviours.

Method

We created a survey to explore the extent to which different types of value are perceived to be sacrificed when adopting sufficiency behaviours for clothing consumption, how perceived sacrifice influences the intention to adopt behaviours of sufficiency, as well as the perceived benefits of sufficient consumption behaviours and potential incentives to help individuals to adopt these behaviours.

Participants

Two hundred six participants from the Netherlands were recruited via Prolific to participate in this online study. Among these, two participants were deleted from our dataset because they failed the attention check. The final sample consists of 204 individuals aged 18 and above (Mage = 34.31 years, SD = 11.27 years; Age range = 19-75 years), with a diverse representation in terms of gender (Male = 52.9%, Female = 46.1%, nonbinary / third gender : .5%, prefer not to say : .5%), socioeconomic status, and educational background. Ethical approval was received to conduct this study and informed consent was obtained prior to participation. The survey took approximately 13 minutes to complete and participants received a small financial compensation (GPB1.8) for their participation.

Procedure and measurements

Participants started the questionnaire, which was available both in Dutch and in English, by indicating their current level of consumption expressed in clothing items bought in the last three months (Frick, et al. 2021). They were also asked about their aspiration levels in terms of clothing consumption and more specifically how many items per year would be ideal and how many items per year would be sufficient in their opinion (Frick et al. 2021).
Next, to prevent participants' fatigue due to too lengthy questionnaires, they were randomly presented with three out of four behaviours of clothing sufficiency. The four behaviours were based on the categorisation of the sufficiency behaviours by Sandberg (2021). Absolute reduction was represented by "Reducing the purchase of new clothing to on average 5 items

per year (excluding underwear and socks)"; longevity was represented by "Only buying quality clothes, repair and maintain and repair to use until completely worn out"; modal shift was represented by "Only buying second-hand clothing items (excluding underwear and socks)"; sharing was represented by "Only renting clothes that you do not need very often (e.g. via renting or sharing platforms)".
For each behaviour, participants were asked to evaluate the extent to which they would be likely to adopt the behaviour (1: very unlikely - 7: very likely, and 8: I already behave as such). If participants did not respond that they had already adopted the behaviour, they were presented with a list of sacrifices or losses. For each sacrifice, they were asked to evaluate how much sacrifice they thought the behaviour would involve. The sacrifice items (Table 1) were developed based on the theory of consumption values (Sheth et al., 1991), and related to functional, emotional, social, epistemic and conditional value sacrifices), furthermore two items of sacrifice related to financial and time/effort sacrifices were added (Zeithaml, 1988). All items were rated on 7-point Likert scales (1 = no sacrifice to 7 = very big sacrifice). In addition, participants were asked to explain their ratings on the different items in an open question.

Furthermore, participants rated their overall perceived sacrifice on two 7-point Likert scales ('How do you rate the overall sacrifice that this behaviour leads to?' and 'Overall, how hard would it be for you to perform this behaviour?'; Spearman-Brown's ρ's: Absolute reduction = .851; Longevity = .695; Modal shift = .808; Sharing = .839). Then, they had to answer two open questions related to the perceived positive aspects / benefits of the behaviours ('Can you think of the benefits / positive effects related to this behaviour?) and incentives to adopt these behaviours ('What would make it easier for you to adopt this behaviour').
Subsequently, we measured various psychographic variables: Personal Norm for Sufficiency (Frick et al., 2021; Spearman-Brown's ρ = .811), Response Efficacy (Bradley et al., 2020; α =.734), reduced NEP scale (Whitmarsch, 2008; α =.757), a general measure on the Willingness to Sacrifice for the Environment (Davis et al., 2011; α =.954) and involvement with clothing as a product category (Chandrasekaran, 2004; α =.848).
Finally, we collected demographic information and more specifically participants' age, gender, education level, and income.

Results

Descriptive statistics

On average, participants indicated that they had bought 4.37 items (min = 0, max = 30) in the last three months (SD = 4.4). Furthermore, the average ideal level of consumption was 26.2 items (min = 0, max = 500) per year (SD = 44.2) and the average sufficient level of consumption was 9.3 items (min = 0, max = 100) per year (SD = 11.9), indicating discrepancies in participants consumption and aspiration levels. For each behaviour, a number of participants (20% for the absolute reduction behaviour, 19.6% for the longevity behaviour, 7 % for the modal shift behaviour, and 1.3% for the sharing behaviour) indicated that they had already adopted the behaviour. These results give an indication of the proclivity of individuals to adopt these behaviours of sufficiency.

Aspect of sacrifice	**Operationalisation for clothing**
Functional	The ability of your clothes to provide their functional and practical benefits.
Emotional	The ability of your clothes to make you feel good.
Social	The ability of your clothes to help you fit in with social expectations or norms.
Epistemic	The ability of your clothes to satisfy your desire for novelty and curiosity.
Conditional	The ability of your clothes to help you to adapt to different or changing circumstances of use (e.g. work, leisure, weather conditions).
Financial	The cost of this behaviour in terms of money.
Time/effort	The cost of this behaviour in terms of time or effort.

Table 1. Aspects of sacrifices and operationalisation.

Among the participants who had not adopted the behaviours, on average, participants rated their intention to adopt the behaviours below the midpoint of the scales ($M_{absolute_reduction}$ = 3.95, SD = 1.94; M_{modal_shift} = 2.93, SD = 1.92; $M_{sharing}$ = 2.44, SD = 1.90) indicating moderate to low intention to adopt these behaviours. Only for longevity, participants rated their intention to adopt this behaviour on average above the midpoint of the scale ($M_{longevity}$ = 4.60, SD = 1.87). Interestingly, the overall perceived sacrifice related to these behaviours were on average rated as moderate ($M_{absolute_reduction}$ = 3.95, SD = 1.72; $M_{longevity}$ = 3.79, SD = 1.40; M_{modal_shift} = 4.22, SD = 1.68; $M_{sharing}$ = 4.56, SD = 1.58). Table 2 displays the means and standard deviations for the four types of clothing sufficiency behaviours.

Influence of overall perceived sacrifice on intention to adopt sufficiency behaviours

Linear regressions were conducted to investigate the influence of the overall perceived sacrifice on the intention to adopt each of the four sufficiency behaviours. The regressions showed significant and negative relationships between the perceived overall sacrifice and the intention to adopt each of the sufficiency behaviour. For the absolute reduction behaviour, $F(1, 118) = 100.01$, $p < .001$, the model explained 46% of the variance in the intention to adopt the behaviour ($R^2 = .459$; $b = -.77$, $p < .001$). For the longevity behaviour, the regression was also significant $F(1, 123) = 32.36$, $p < .001$, explaining 21% of the variance in the intention to adopt the behaviour ($R^2 = .208$; $b = -.61$, $p < .001$). For the modal shift behaviour, $F(1, 144) = 74.649$, $p < .001$, the model explained 34% of the variance ($R^2 = .341$; $b = -.67$, $p < .001$). Finally, for the sharing behaviour, $F(1, 148) = 54.19$, $p < .001$, the model explained 27% of the variance in the intention to adopt the behaviour ($R^2 = .268$; $b = -.62$, $p < .001$).

Influence of specific sacrifices on overall perceived sacrifices

Stepwise regressions were conducted to investigate the influences of the seven perceived sacrifices on the overall sacrifice for each of the four sufficiency behaviours.

Absolute reduction

The first stepwise regression was conducted to determine the most useful perceived sacrifices to predict the overall sacrifice to adopt a behaviour of absolute reduction (i.e., buying maximum five clothing items per year). This first regression model was significant ($F(4, 115) = 43.03$, $p < .001$), and explained 59.9% of the variance in the overall perceived sacrifice. Four variables positively and significantly influenced perceived overall sacrifice: functional sacrifice ($b = .470$, $p < .001$), emotional sacrifice ($b = .231$, $p = .001$), time and effort sacrifice ($b = .167$, $p < .05$) and epistemic sacrifice ($b = .158$, $p < .05$).

Longevity

Second, we analysed the most useful perceived sacrifices to predict the overall sacrifice to adopt a behaviour of longevity (i.e. only buying quality clothes, repair and maintain and repair to use until completely worn out). This second regression was also significant ($F(4, 120) = 17.59$, $p < .001$) and explained 37% of the variance in the overall perceived sacrifice for this behaviour. Here again, four variables significantly influenced the overall perceived sacrifice. Specifically, time and effort sacrifice ($b = .288$, $p < .001$), epistemic sacrifice ($b = .152$, $p < .05$), financial sacrifice ($b = .140$, $p < .05$), and emotional sacrifice ($b = .150$, $p < .05$) were all significantly and positively contributing to the overall perceived sacrifice.

Modal shift

The third stepwise regression was conducted to determine which specific sacrifices best predict the overall perceived sacrifice to adopt a behaviour of modal shift (i.e. only buying second-hand clothing items). This regression was significant ($F(3, 141) = 30.17$, $p < .001$) and explained 39% of the variance in the overall perceived sacrifice for this behaviour. Here, three variables significantly influenced the overall perceived sacrifice. These variables were emotional sacrifice ($b = .337$, $p < .001$), time and effort sacrifice ($b = .201$, $p = .001$) and epistemic sacrifice ($b = .195$, p , .01).

Sharing

Finally, the fourth stepwise regression was conducted to determine which specific sacrifices best predict the overall perceived sacrifice to adopt a sharing behaviour of modal shift (i.e. only renting clothes that you do not need very often (e.g. via renting or sharing platforms)). This regression was significant ($F(3, 146) = 26.886$, $p < .001$) and explained 36% of the variance in the overall perceived sacrifice for this behaviour. For this specific behaviour, three variables significantly

influenced the overall perceived sacrifice. These variables were emotional sacrifice (b = .278, p <.001), time and effort sacrifice (b = .238, p < .001) and functional sacrifice (b = .158, p < .01).

	Absolute reduction		Longevity		Modal shifts		Sharing	
	M	SD	M	SD	M	SD	M	SD
Overall sacrifice	3.95	1.72	3.79	1.40	4.23	1.68	4.56	1.58
Intention to adop	3.95	1.94	4.60	1.87	2.93	1.92	2.44	1.89
Functional sacrifice	3.73	1.82	2.76	1.53	3.32	1.84	3.49	2.02
Emotional sacrifice	3.99	1.87	2.98	1.68	3.84	1.99	4.14	1.93
Social sacrifice	3.43	1.73	2.90	1.53	3.15	1.68	3.21	1.90
Epistemic sacrifice	3.90	1.85	3.54	1.83	3.44	1.93	3.31	1.95
Conditional sacrifice	4.48	1.59	3.49	1.64	3.34	1.67	3.63	1.91
Financial sacrifice	2.08	1.28	3.46	1.83	2.15	1.48	3.77	1.78
Time/Effort sacrifice	2.50	1.63	4.33	1.78	4.09	1.88	4.90	1.74

M: Means; SD: Standard deviations

Table 2. Descriptive statistics

Qualitative results

To better understand respondents' perceptions of the sufficiency behaviours, we analysed the qualitative comments. We extracted the perceived benefits, most prominent sacrifices and suggestions for making the sufficiency behaviours easier to adopt. Respondents did see benefits in all sufficiency behaviours but clearly compared these with their current practices which resulted in concerns about the convenience and cost of integrating these behaviours in daily life. More insights per behaviour are presented in Table 3.

Discussion and Conclusions

To achieve the reductions in per capita consumption necessary to stay within the planetary boundaries, major changes in consumption and production patterns are required (Wiedmann et al., 2020). Sufficient behaviours could contribute to this but are not yet widely adopted. With this study, we contribute to the literature on sufficient consumption (Sandberg, 2021) by demonstrating the influence of perceived sacrifice on willingness to adopt four sufficiency behaviours in the context of clothing. We contribute to the literature on sacrifice by showing that different values involved in consumption (Sheth, 1991; Zeithaml, 1988) are affected when individuals adopt sufficient consumption behaviours for the greater good (Chwialkowska & Flicinska - Turkiewicz, 2021). Regarding the specific aspects of sacrifice, we show that time and effort sacrifice and emotional sacrifice contributed to the overall sacrifice for all four behaviours. For some behaviours epistemic, functional and financial sacrifice also played a significant role. In other words, different sufficiency behaviours lead to different perceived sacrifices. Interestingly, the social and conditional sacrifice aspects did not significantly influence the overall sacrifice for any sufficiency behaviour, while participants mentioned the risk of not being 'able to adapt to different circumstances' and not 'meeting social expectations' when qualitatively elaborating on their ratings of the sacrifices. The fact that participants might have downplayed the social sacrifice could be explained by the fact that people often perceive themselves as less susceptible to social norms, advertising, or peer influences compared to others. Future research should study how different segments of consumers vary in their perceived sacrifices. Furthermore, the study should be replicated in other consumption domains such as electronic products and food. Overall, our results can be used by designers and policy-makers to address the perceived sacrifices that sufficiency behaviours entail by proposing interventions that reframe the behaviours more positively.

Sufficiency behaviour	Perceived benefit(s)	Most prominent sacrifice(s)	Suggestion for making behaviour easier
Absolute reduction	Many respondents see reducing the purchase of new clothing as a way to save money and live more sustainably.	The greatest sacrifices are seen in adapting to different circumstances and meeting social expectations.	-
Longevity	Respondents appreciate the durability and longevity of quality clothing.	The cost and effort of repairs are seen as major sacrifices.	More Accessible Repair Services: Offering easily accessible and affordable repair services can help promote the adoption of quality clothing.
Modal shift	Second-hand clothing is seen as a cost-saving and environmentally friendly option.	There are concerns about the availability of appropriate sizes and styles.	Expansion of second-hand Options: More second-hand stores and online platforms can increase the accessibility and acceptance of second-hand clothing.
Sharing	Renting clothing is seen as a good option for special occasions.	The difficulty and cost of the rental process are cited as drawbacks.	Improved Rental Platforms: Developing user-friendly and affordable rental platforms can lower the barrier to renting clothing.

Table 3. Respondents' perceptions of the sacrifices, benefits and incentives related to the sufficiency behaviours

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References

Kashkoush, M., & El Maraghy, H. (2016). Optimum Overall Product Modularity, 6th CIRP Conference on Assembly Technologies and Systems (CATS) Procedia CIRP 44, p. 55 – 60 DOI: 10.1016/j.procir.2016.01.023

Akbar, P., Mai, R., & Hoffmann, S. (2016). When do materialistic consumers join commercial sharing systems. Journal of Business Research, 69(10), 4215-4224. https://doi.org/10.1016/j.jbusres.2016.03.003

Bélanger, J. J., Caouette, J., Sharvit, K., & Dugas, M. (2014). The psychology of martyrdom: making the ultimate sacrifice in the name of a cause. Journal of Personality and Social Psychology, 107(3), 494. DOI: 10.1037/a0036855

Bradley, G. L., Babutsidze, Z., Chai, A., & Reser, J. P. (2020). The role of climate change risk perception, response efficacy, and psychological adaptation in pro-environmental behavior: A two nation study. Journal of Environmental Psychology, 68, 101410. https://doi.org/10.1016/j.jenvp.2020.101410

Chandrashekaran, R. (2004). The influence of redundant comparison prices and other price presentation formats on consumers' evaluations and purchase intentions. Journal of Retailing, 80(1), 53-66. DOI: 10.1016/j.jretai.2004.01.004

Chwialkowska, A., & Flicinska - Turkiewicz, J. (2021). Overcoming perceived sacrifice as a barrier to the adoption of green non - purchase behaviours. International Journal of Consumer Studies, 45(2), 205-220. DOI: 10.1111/ijcs.12615

Cronin Jr, J. J., Brady, M. K., & Hult, G. T. M. (2000). Assessing the effects of quality, value, and customer satisfaction on consumer behavioral intentions in service environments. Journal of Retailing, 76(2), 193-218. https://doi.org/10.1016/S0022-4359(00)00028-2

Davis, J. L., Le, B., & Coy, A. E. (2011). Building a model of commitment to the natural environment to predict ecological behavior and willingness to sacrifice. Journal of Environmental Psychology, 31(3), 257-265. https://doi.org/10.1016/j.jenvp.2011.01.004

Frick, V., Matthies, E., Thøgersen, J., & Santarius, T. (2021). Do online environments promote sufficiency or overconsumption? Online advertisement and social media effects on clothing, digital devices, and air travel consumption. Journal of Consumer Behaviour, 20(2), 288-308.

Garcia-Ortega, B., Galan-Cubillo, J., Llorens-Montes, F. J., & de-Miguel-Molina, B.

(2023). Sufficient consumption as a missing link toward sustainability: The case of fast fashion. Journal of Cleaner Production, 399, 136678 DOI: 10.1016/j.jclepro.2023.136678

Gossen, M., Ziesemer, F., & Schrader, U. (2019). Why and how commercial marketing should promote sufficient consumption: a systematic literature review. Journal of Macromarketing, 39(3), 252-269. DOI: 10.1177/0276146719866238

Halbertal, M. (2012). On sacrifice. Princeton University Press.

Hutter, K., & Hoffmann, S. (2013). Carrotmob and anti-consumption: Same motives but different willingness to make sacrifices?. Journal of Macromarketing, 33(3), 217-231.

Ivanova, D., & Wood, R. (2020). The unequal distribution of household carbon footprints in Europe and its link to sustainability. Global Sustainability, 3, e18. DOI: 10.1017/sus.2020.12

Muthu, S. S., & Gardetti, M. A. (Eds.). (2020). Sustainability in the textile and apparel industries (pp. 163-187). Cham: Springer. DOI: 10.1007/978-3-030-38545-3

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. Nature Reviews Earth & Environment, 1(4), 189-200. DOI: 10.1038/s43017-020-0039-9

Olivier, J. G., Schure, K. M., & Peters, J. A. H. W. (2017). Trends in global CO2 and total greenhouse gas emissions. PBL Netherlands Environmental Assessment Agency, 5, 1-11.

O'Neill, D.W., Fanning, A.L., Lamb, W.F. and Steinberger, J.K., 2018. A good life for all within planetary boundaries. Nature sustainability, 1(2), pp.88-95. DOI: 10.1038/s41893-018-0021-4

Righetti, F., Visserman, M. L., & Impett, E. A. (2022). Sacrifices: Costly prosocial behaviors in romantic relationships. Current Opinion in Psychology, 44, 74-79. https://doi.org/10.1016/j.copsyc.2021.08.031

Sandberg, M. (2021). Sufficiency transitions: A review of consumption changes for environmental sustainability. Journal of Cleaner Production, 293, 126097. https://doi.org/10.1016/j.jclepro.2021.126097

Sheth, J. N., Newman, B. I., & Gross, B. L. (1991). Why we buy what we buy: A theory of consumption values. Journal of Business Research, 22(2), 159-170. https://doi.org/10.1016/0148-2963(91)90050-8

Spengler, L. (2016). Two types of 'enough': sufficiency as minimum and maximum. Environmental Politics, 25(5), 921-940. DOI: 10.1080/09644016.2016.1164355

Whitmarsh, L. (2008). Are flood victims more concerned about climate change than other people? The role of direct experience in risk perception and behavioural response. Journal of Risk Research, 11(3), 351-374. https://doi.org/10.1080/13669870701552235

Wiedmann, T., Lenzen, M., Keyßer, L. T., & Steinberger, J. K. (2020). Scientists' warning on affluence. Nature communications, 11(1), 3107. https://doi.org/10.1038/s41467-020-16941-y

Wynes, S., & Nicholas, K. A. (2017). The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters, 12(7), 074024. DOI: 10.1088/1748-9326/aa7541

Zeithaml, V. A. (1988). Consumer perceptions of price, quality, and value: a means-end model and synthesis of evidence. Journal of Marketing, 52(3), 2-22. https://doi.org/10.2307/1251446

Research paper
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From excess to essential – Exploring the Potential of Adopting Smaller Wardrobes

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Keywords: wardrobe study; wardrobe size; wardrobe reduction; sustainable fashion; sufficiency.

Abstract: The overproduction and overconsumption of clothing have substantial environmental impacts. Shifting to smaller wardrobes containing fewer, durable, and frequently used garments is a key strategy in transitioning to a sustainable system. Understanding the size and composition of wardrobes is an essential first step to assess the potential of adopting smaller wardrobes. This study maps the current size of individuals' wardrobes, the fraction actively used, and the fraction individuals deemed essential to meet their needs. It moreover investigates the characteristics of essential garments and identifies barriers to adopting an essential wardrobe. To examine this, participants' wardrobes were first audited and then reduced to only those items deemed essential to meet their needs for the coming year. The wardrobe audit of 30 individuals in Flanders (Belgium) reveals that participants owned, on average, 169 garments, of which 138 were used in the past year (81%), and 90 were considered essential (53%). Participants' perceived essential clothing needs varied strongly, ranging from 36 to 275 garments, or alternatively, 28% to 98% of their current wardrobe. Combinability emerged as the most important criterion for selecting essential garments. Both practical (i.e., shortages) and emotional considerations (i.e., loss of joy) were anticipated as obstacles to adopting an essential wardrobe. This study highlights the considerable variation in how individuals meet their clothing needs and what they deem essential. Our findings provide an initial range for the minimum number of garments required to meet clothing needs and offer valuable insights for establishing sufficiency thresholds in apparel consumption.

Introduction

The clothing value chain has become increasingly scrutinized for its adverse environmental impacts (Niinimäki et al., 2020). In response, governments and companies are taking action to address this, such as the European Union Strategy for Sustainable and Circular Textiles. However, most proposed initiatives focus on innovations in the clothing value chain's beginning (production) or end (waste management), with little attention paid to the use phase (Bardey et al., 2022; Maguire & Fahy, 2023). Yet, more intensive and longer use of garments in the use phase holds significant potential to slow the flow of garments, reducing the adverse environmental impacts associated with production and waste treatment processes (Roos et al., 2017).
Shifting to smaller wardrobes containing fewer, long-lasting, and intensely used garments is proposed as a key strategy in the transition towards a more sustainable system (Rhee & Johnson, 2019; Vladimirova, 2021). However, despite the importance of understanding consumer behavior in shaping sustainable practices (Piontek et al., 2019; Polizzi di Sorrentino et al., 2016), there is a scarcity of studies that delve into wardrobe dynamics at the individual level. Insight into the relation between the size of individuals' wardrobes, the fraction of the wardrobe actively used, and the fraction required to meet personal needs is necessary to assess the true potential of wardrobe reduction as a sustainable strategy. Such bottom-up research facilitates a more comprehensive and holistic understanding of clothing needs. This is required in sufficiency-oriented frameworks, such as consumption corridors, to determine lower-bound limits to apparel consumption (Vladimirova, 2021).
This paper first gives background information on what is known about wardrobe size, garment use, and wardrobe reduction. Next, the methods are outlined. The results are reported

and discussed with regard to (i) wardrobe size, (ii) the characteristics of essential garments, and (iii) the barriers to adopting essential wardrobes. The paper finishes with a general conclusion.

Background

Wardrobe Size and Use of Garments

There is a lack of systematic, empirical research on individuals' clothing stock, as well as, on how, when or why clothes enter, remain in, and leave wardrobes (Maldini et al., 2023). Few studies provide representative results, and methodological disparities complicate comparisons and generalizations (Vermeyen et al., 2025). Yet, wardrobe size seems to vary strongly between individuals. For example, Vermeyen et al. (2025) found wardrobe sizes ranging from 44 to 434 among 156 Belgian individuals. Similarly, de Wagenaar et al. (2022) observed a wide range from 30 to 713 garments in a global sample of 520 individuals. In studies differentiating between genders, the general observation is that, on average, women own more garments than men (de Wagenaar et al., 2022; Maldini et al., 2017; Vermeyen et al., 2025). The findings related to age and wardrobe size are inconsistent (de Wagenaar et al., 2022; Maldini et al., 2017; Vermeyen et al., 2025). The above underscore the need for further research to better understand the size of individuals' wardrobes and the factors that influence this variation.

There is also limited understanding of how individuals use the garments in their wardrobes. Tracking clothing lifespans is challenging since most garments lack identifiers like serial numbers to trace their production date. Moreover, the lifetime of a product should be linked to its actual use, as dormant garments provide no functional benefit (Corona et al., 2019). Existing quantitative research on wardrobe size typically focuses on the proportion of a wardrobe that has not been used in the past 12 months—i.e., dormant garments. Early studies suggest that roughly one-fourth of an individual's wardrobe remains dormant (de Wagenaar et al., 2022; Maldini et al., 2017; Vermeyen et al., 2025; WRAP, 2022). These garments are retained primarily because individuals believe they will still prove useful in the future (Vermeyen et al., 2025; WRAP, 2022).

The results above suggest clothing needs are inefficiently met, with many garments remaining underused. Consequently, wardrobe reduction seems a viable strategy for addressing clothing needs more sustainably, reducing resource consumption and waste generation.

Wardrobe Reduction

Wardrobe reduction could begin by eliminating dormant garments from wardrobes. A change in ownership – for instance, through gifting, resale, or donation - can find new users for garments no longer suited to the current owner. Further, access to temporary ownership – for instance, through rental or clothing libraries - can eliminate the need to keep garments only worn on scarce occasions. Successful implementation of these strategies could reduce the total flow of garments, as suggested by Coscieme et al. (2022).

However, it is worth investigating whether wardrobe reduction can go beyond simply eliminating dormant garments. Concepts such as minimalism or sufficiency are gaining traction as deeper solutions to overproduction and overconsumption in affluent societies. One manifestation of this is slow fashion, which aims to reduce the negative environmental and societal impacts of fast fashion by encouraging mindful consumption and production practices (Štefko & Steffek, 2018). The focus is on creating and consuming long-lasting clothes, emphasizing durability and timeless design. The concept of a capsule wardrobe takes this further by embracing the minimalist idea of owning only what is deemed essential (Bardey et al., 2022). The Cambridge Dictionary defines a capsule wardrobe as "a small collection of clothes that can be put together in different ways and includes everything you would normally need to wear.". There is no prescribed size for a capsule wardrobe, with the ideal size differing from person to person due to individual preferences, lifestyle choices, and personal needs (Bardey et al., 2022; Vladimirova, 2021). The goal is not just to minimize the wardrobe's size, but to maximize the use of each item and reduce the need for new purchases. To support the transition to a smaller wardrobe, specific selection criteria such as quality, comfort, timelessness, and combinability are recommended (Bardey et al., 2022). However, even with these guidelines, the shift to a smaller wardrobe can be challenging. Martin-Woodhead (2023) identified several drawbacks people experienced when reducing their wardrobe, such as boredom with the limited selection of clothing, not having the right outfit

for specific occasions, and the high initial cost of high-quality garments.

The existing research on wardrobe reduction tends to be centered around (voluntary) participation in minimal fashion challenges (Bardey et al., 2022; Martindale & Lee, 2019; Martin-Woodhead, 2023; Rhee & Johnson, 2019; Ruppert-Stroescu et al., 2015; Vladimirova, 2021; Wu et al., 2013). These challenges entail an extreme form of wardrobe reduction with the adoption of a capsule wardrobe of 30 to 55 items per season (Bardey et al., 2022; Vladimirova, 2021). However, individuals in affluent societies are unlikely to embrace such a drastic reduction. Vladimirova (2021) notes that bottom-up research on the minimum levels of apparel consumption is currently lacking, yet is essential for identifying the need for apparel. The present study, therefore, flips the script by asking participants to identify the minimum number of garments they consider necessary. This approach offers deeper insights into individuals' varying (perceived) clothing needs. Additionally, no research has explored the composition of smaller wardrobes and what criteria participants consider when composing their reduced wardrobes. In this context three research questions are addressed: (i) 'What number of garments do individuals perceive as essential to meet their clothing need?', (ii) 'What are the characteristics of essential garments?', and (iii) 'What are the main barriers individuals perceive when adopting an essential wardrobe?'.

Method

To address these questions, a two-step method was used: Firstly, a wardrobe audit was conducted to quantify the total wardrobe size and dormant fraction. Secondly, participants were guided through an exercise to downsize their wardrobes to include only essential pieces. An overview of the sample with respect to gender and age is given in Table 1. All the data was collected between January and March 2024 in either Flanders, the northern region of Belgium, or the capital region of Brussels.

Wardrobe Audit

A wardrobe audit is a type of wardrobe study, which uses quantitative or qualitative methods to systematically analyze the content of individuals' wardrobes (Maldini et al., 2023). In this study, the wardrobe audit consisted of a systematic count of all the garments within the scope of the study at the participant's home with a researcher present to guide the process. Per garment type, the researcher noted the total amount of garments, as well as the number of active/dormant garments (i.e. used/unused in the last 12 months). Underwear, swimwear, and accessories such as gloves, scarves, hats, bags, and shoes are outside the scope of this study. The wardrobe audits discussed in this manuscript were part of a broader audit conducted by Vermeyen et al. (2025), a detailed description of the methodology and general results can be found there. This manuscript only discusses the 30 audits of the participants who also took part in the wardrobe reduction exercise.

men	16-34	8
	35-54	3
	55+	4
women	16-34	5
	35-54	5
	55+	5

Table 1. number of participants by gender and age

Wardrobe reduction Exercise

Following the wardrobe audit, participants were asked to assess which garments in their wardrobes they considered essential to meet their clothing needs for the coming year. After an initial selection of garments for their essential wardrobe, participants were asked to consider whether they had accounted for all seasons and specific occasions. This allowed participants to reflect on their decisions and make final adjustments. The composition of the resulting essential wardrobe was recorded by clothing category.

Next, participants were asked to identify the factors they considered when selecting garments. Initially, they were encouraged to freely mention any relevant aspects, allowing for a broad range of answers. Subsequently, participants were asked to rate the importance given to four key criteria commonly associated with garments in capsule wardrobes: quality, comfort, timelessness, and combinability.

Finally, participants were asked: "Imagine that this is now your real wardrobe for a whole year, and you are not allowed to buy anything else for an entire year. What do you think would be some of the difficulties that might arise during that year?" This question aimed to provide insights into the barriers to adopting an essential wardrobe.

Results and Discussion

Wardrobe Size: Total – Active - Essential

Figure 1 shows the quantitative results of the wardrobe audit and wardrobe reduction exercise. The total wardrobe size of participants in the subsample spans from 44 to 315 garments, with an average of 169 and a median of 160. The active wardrobe size ranges from 36 to 275 garments, with an average of 138 and median of 134. Lastly, the essential wardrobe size ranges from 36 to 275 garments, with an average of 90 and median of 77.

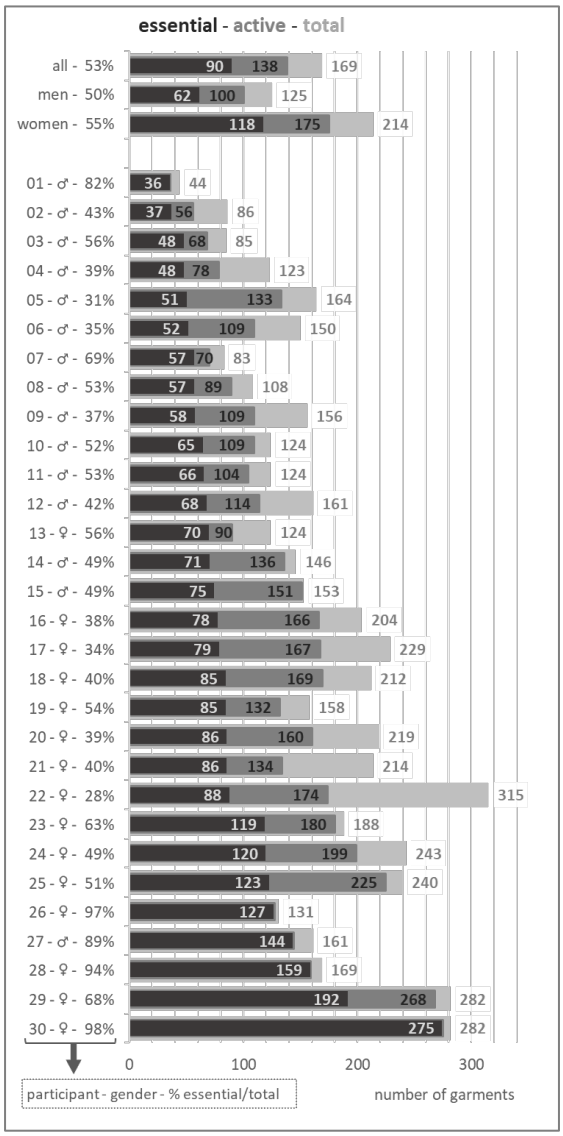


Figure 1. Number of garments in essential, active, and total wardrobe, and percentage essential (n=30).

For all three, indicators, women's wardrobe size is notably larger than men's. Hence, women seem to possess more clothing, use more pieces actively, and consider more pieces essential. However, all gender related findings warrant some caution due to the limited sample size.

The fraction of the wardrobe that individuals actively use varies between 55% to 98%, with an average of 81% and a median of 82%. The fraction of the wardrobe deemed essential ranges from 28% to 98%, with an average of 54% and a median of 50%. This means only half of the garments in wardrobes were deemed essential. Men and women consider a similar percentage to be essential. This is interesting, as it indicates that both genders need a comparable proportion of their total wardrobe to meet their essential needs.

Figure 2 shows the average wardrobe disaggregated by garment category and gender. The active and essential fraction is quite consistent across the different garment categories and between genders.

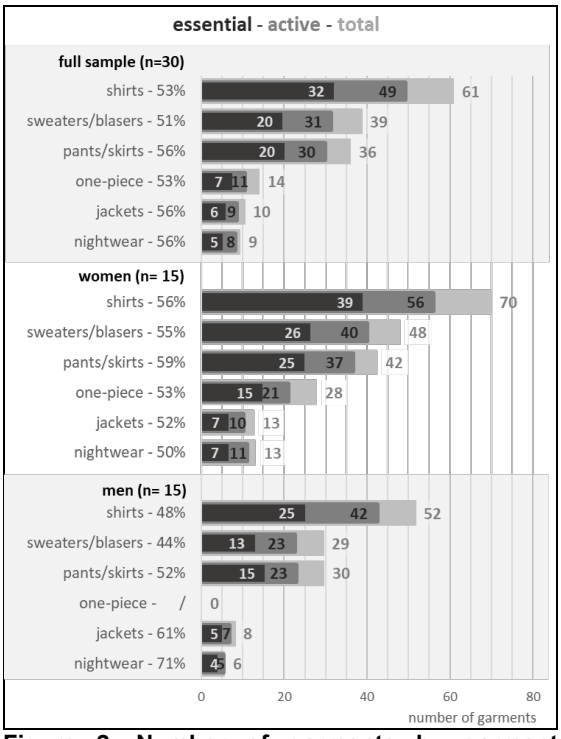


Figure 2. Number of garments by garment category and gender in average essential, active, and total wardrobe, and percentage essential (n=30).

Yet, substantial differences are observed between individual participants (Figure 1). Five of the 30 participants did not see the possibility of reducing their wardrobe size beyond their active wardrobe (participant 1, 26, 27, 28, and 30 in Figure 1). Participant 1 already had the sample's smallest total and active wardrobe, comprising 44 and 36 garments respectively. Hence, his unwillingness can be attributed to him already possessing a limited number of garments. Conversely, the remaining four participants have relatively extensive total and active wardrobes. Their reluctance to further reduce stemmed from a desire for a diverse range of clothing options and the habit of regularly varying outfits, as is reflected in the low share of dormant clothing in their wardrobes. When looking at the other extreme, three of the 30 participants concluded it would be possible to meet their needs with only a third or less of their current wardrobe (participant 5, 17, and 22 in Figure 1).
The results in this section are an initial step to a broader understanding of the potential of wardrobe reduction in society. The findings shed light on the difference between (groups) of individuals, underscoring the importance of considering the varying (perceived) needs of groups across society when designing interventions.

Characteristics of essential garments

The 25 participants who reduced their wardrobe beyond their active wardrobe were asked to indicate to what extent they considered combinability, comfort, timelessness, and quality of garments when selecting items for their essential wardrobe. Figure 3 shows the distribution for each criteria.

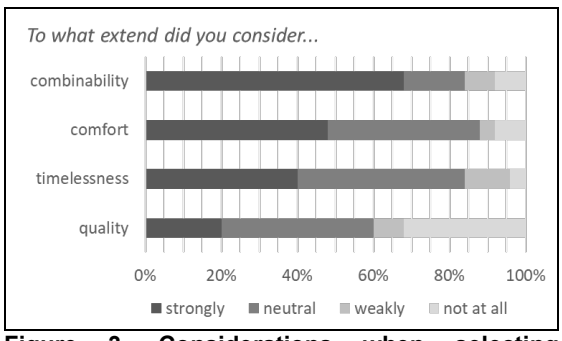


Figure 3. Considerations when selecting garments for an essential wardrobe (n=25).

Combinability stands out as the most important factor, with nearly 70% of participants giving it strong consideration when selecting garments. This suggests that people highly value easily mix-and-matchable garments as essential pieces in their wardrobe. Quality emerged as the least prioritized selection criterion.
Additionally, the open-ended question about the factors participants considered revealed that all of them focused on selecting their favorite pieces. This demonstrates the importance of a strong emotional connection in ensuring active garment use. Further, four participants mentioned excluding garments resembling each other, indicating that one such garment is sufficient. This implies that these participants prioritize garments that offer distinct styling options, enhancing the versatility of their essential wardrobe. Furthermore, two participants emphasized the importance of choosing garments that do not require extensive ironing. Lastly, two participants indicated they selected their most expensive garments.

Barriers to adopting essential wardrobes

Finally, the 25 participants who reduced their wardrobe were asked to describe potential obstacles they anticipated encountering if they would transition to their essential wardrobe. Three participants stated they saw no issues. All three are men and indicated that clothing was unimportant to them. After screening the responses of the remaining 22 participants, the anticipated barriers could be categorized into two main groups: ‘practical barriers’ and ‘emotional barriers’.
13 Participants mentioned at least one practical barrier. These were mainly related to worries about shortages. Participants expressed concerns about not having access to garments due to a defect (n=8), a poor fit due to changing bodies (n=3), or garments being in the laundry (n=2). Hence, the size of current wardrobes can likely be partly explained by individuals wishing to have a buffer so that when garments become defective, are in the laundry, or no longer fit, alternatives are readily available.
18 Participants mentioned at least one emotional barrier. These barriers related mainly to a loss of joy. This can take on various forms, such as a thwarted desire for newness (n=9), frustrations from being unable to keep up with trends or change style (n=6), loss of shopping as a joyful activity (n=5), or boredom with current pieces (n=4). One participant mentioned anticipating social pressure to change outfits regularly.

Rhee & Johnson (2019) observed similar apprehensions amongst students which had to participate in a minimalist wardrobe challenge. However, initial negative feelings shifted over the course of the challenge, with most participants ultimately reflecting positively on the experience. This suggests that some concerns may be unfounded. The real challenge then lies in encouraging the general public to let go of unwarranted beliefs rooted in consumer culture.

Limitations of the study

The present paper presents a pilot study based on a relatively small sample, aimed at providing initial insights into the little-researched topic of wardrobe reduction. This study explores the potential of wardrobe studies as a methodology to investigate the feasibility of wardrobe reduction in a diverse sample of individuals. The findings offer preliminary insights that can serve as a foundation for further research.

When evaluating the current methodology, it is important to note that while the initial count of total wardrobe size can be measured objectively, the subsequent steps rely on participants' subjective judgments. For determining the active fraction of the wardrobe, issues related to poor recall may arise. Additionally, when defining their essential wardrobe, participants may struggle to accurately assess what they will truly need or anticipate the challenges they might face. An interesting extension to address this would be to ask participants to use only their selected essential wardrobe over a period of time. However, finding a diverse sample of participants willing to commit to such a study may prove difficult.

Conclusion

Addressing the environmental impact of the clothing value chain requires a system-wide transformation. Strategies focused on the use phase should receive due attention as clothing is currently used inefficiently. This study offers initial insights into the relationship between total wardrobe size, active wardrobe (i.e., garments used in the past 12 months), and essential wardrobe (i.e., the minimum amount required to meet the participant's needs in the coming year). Among the 30 participants, we found that the average wardrobe contained 169 garments, of which 138 were active, and 90 were deemed essential. Hence, on average, one-fifth of garments were not used in the past year and approximately half were considered non-essential to meeting the minimum clothing needs. Our findings indicate that significant wardrobe reduction is likely feasible in affluent societies. However, substantial variation exists between individuals in the way they meet their need for clothing, as well as, in what they consider as essential, highlighting the importance of considering diverse perspectives in developing sustainable wardrobe practices.

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References

Bardey, A., Booth, M., Heger, G., & Larsson, J. (2022). Finding yourself in your wardrobe: An exploratory study of lived experiences with a capsule wardrobe. *International Journal of Market Research*, *64*(1), 113–131. https://doi.org/10.1177/1470785321993743

Corona, B., Shen, L., Reike, D., Rosales Carreón, J., & Worrell, E. (2019). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources, Conservation and Recycling*, *151*, 104498. https://doi.org/10.1016/j.resconrec.2019.104498

Coscieme, L., Akenji, L., Latva-Hakuni, E., Vladimirova, K. , N. K. , H. C. , J.-M. C., Nielsen, K., Iran, S., & D´Itria, E. (2022). *Unfit, Unfair, Unfashionable: Resizing Fashion for a Fair Consumption Space.* Hot or Cool Institute.

de Wagenaar, D., Galama, J., & Sijtsema, S. J. (2022). Exploring Worldwide Wardrobes to Support Reuse in Consumers' Clothing Systems. *Sustainability*. https://doi.org/10.3390/su14010487

Maguire, H., & Fahy, F. (2023). Unlocking insights in the everyday: Exploring practices to foster sustainable maximum use of clothing. *Cleaner and Responsible Consumption*. https://doi.org/10.1016/j.clrc.2022.100095

Maldini, I., Duncker, L., Bregman, L., Piltz, G., Duscha, L., Cunningham, G., Vooges, M., Grevinga, T., Tap, R., & van Balgooi, F. (2017). *Measuring the Dutch Clothing Mountain*. Amsterdam: Publishing Lab. http://www.hva.nl/bibliotheek/contact/contactformulier/contact.html,

Maldini, I., Haugrønning, V., & De León, L. (2023). Studying clothing consumption volumes through wardrobe studies: a methodological reflection. *Procedia PLATE – Product Lifetimes And The Environment*. https://aaltodoc.aalto.fi/handle/123456789/122687

Martindale, A., & Lee, Y. A. (2019). Students' perceptions of adopting minimal transformable wardrobes. *International Journal of Fashion Design, Technology and Education*, *12*(1), 76–85. https://doi.org/10.1080/17543266.2018.1477998

Martin-Woodhead, A. (2023). Making wardrobe space: The sustainable potential of minimalist-inspired fashion challenges. *Area*, *55*(2), 274–283. https://doi.org/10.1111/area.12848

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*. https://doi.org/10.1038/s43017-020-0039-9

Piontek, F. M., Rapaport, M., & Müller, M. (2019). One year of Clothing Consumption of a German Female Consumer. *Procedia CIRP*, *80*, 417–421. https://doi.org/10.1016/j.procir.2019.01.055

Polizzi di Sorrentino, E., Woelbert, E., & Sala, S. (2016). Consumers and their behavior: state of the art in behavioral science supporting use phase modeling in LCA and ecodesign. *The International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-015-1016-2

Rhee, J., & Johnson, K. K. P. (2019). 'The wardrobe diet': teaching sustainable consumption through experience with undergraduates in the USA. *International Journal of Fashion Design, Technology and Education*. https://doi.org/10.1080/17543266.2019.1590864

Roos, S., Sandin, G., Zamani, B., Peters, G., & Svanström, M. (2017). *Will Clothing Be Sustainable? Clarifying Sustainable Fashion* (pp. 1–45). https://doi.org/10.1007/978-981-10-2182-4_1

Ruppert-Stroescu, M., LeHew, M. L. A., Connell, K. Y. H., & Armstrong, C. M. (2015). Creativity and Sustainable Fashion Apparel Consumption: The Fashion Detox. *Clothing and Textiles Research Journal*, *33*(3), 167–182. https://doi.org/10.1177/0887302X15579990

Štefko, R., & Steffek, V. (2018). Key issues in Slow Fashion: Current challenges and future perspectives. *Sustainability (Switzerland)*, *10*(7). https://doi.org/10.3390/su10072270

Vermeyen, V., Alaerts, L., Worrell, E., Van Acker, K., & Germeys, F. (2025). Behind Closed Doors: Examining the Stock of Clothing in Individuals' Wardrobes. *Journal of Circular Economy*, *3*(1). https://doi.org/10.55845/OQEE5977

Vladimirova, K. (2021). Consumption corridors in fashion: deliberations on upper consumption limits in minimalist fashion challenges. *Sustainability: Science, Practice, and Policy*, *17*(1), 103–117. https://doi.org/10.1080/15487733.2021.1891673

WRAP. (2022). *Citizen Insights: Clothing Longevity and Circular Business Models receptivity in the UK. November 2021*.

Wu, D. E., Thomas, J. B., Moore, M., & Carroll, K. (2013). Voluntary simplicity: The Great American Apparel Diet. *Journal of Fashion Marketing and Management*, *17*(3), 294–305. https://doi.org/10.1108/JFMM-05-2012-0020

Extended Abstract
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Creative research methods for engagement with nature, positive activism and the aesthetics of degrowth

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Keywords: creative research methods; positive activism; degrowth aesthetics; engagement with nature; response-ability.

Introduction

In this paper we will present six creative research methods that empower the dialogical partnership with nature and reconsider our ways of doing, in order to move towards cultural, environmental and social resilience. We will discuss how the role of creative practices can be rethought based on our own practice as a visual artist and a textile designer. Six out of nine planetary boundaries, which regulate the stability and resilience and human existence on the Earth, have been transgressed by 2023. World's biodiversity is shrinking – millions of species are at risk of extinction, diversity is decreasing, and human habitats are also deteriorating. (IPBES, 2019) In the time of multifaceted crises artists and designers among others face the questions of the meaning and impact of their practices. The collective engagement with the rest of nature (Mackay & Schmitt 2019) and emotional attachment towards both, nature and human-made objects is lacking. Therefore our patterns of thought and relations tend to be superficial, decisions are too often based on habits which are developed at the times of industrialisation. We ask how creative research methods promote our **engagement with the rest of nature** and support meaningful actions in the context of degrowth. We aim to shift the aesthetic perception toward focusing on relations, patterns that welcome change, layers of meaning and embodied relationships to be seen as possible degrowth aesthetics.

We propose the notion of positive activism – initiating and conducting creative community formulation, action learning, craftivism (Greer, 2003) and gardening for hope and approachable change.

The Garden – A Framework

We invite you to perceive the garden as a metaphor for the entire planet or your current field of practice. A gardener can be someone who takes care of a defined area – be it a design project, exhibition, or a garden plot, a mental territory, or a territory of action. Here humans are actors within a complex system of living beings (Clement, 2021). There are many other agents in the garden besides humans with whom we co-create the garden and the garden is always multiperspective. “The planetary garden protects and develops diversity with all its form, while globalization erases it in the name of market forces”. (Clement, 2021) Many of our ancestors common ways of doing, like mending, have fallen out of practice with the rise of capitalism (Taul, 2021) We resonate with the concept of degrowth – movement which criticises the current growth-oriented economy and develops sustainable alternatives (Degrowth Estonia, s.a.).

The Gardeners´ Dialogue as Research Methodology

The methods developed in a dialogue of an artist and a designer are meant for other designers, artists, researchers and to be applied on other fields and gardens as well. One of the developed methods – Dialogue of gardeners` – worked also as the research method.

The dialogue manifests directly – between us in co-writing and conversations, and metaphorically – in the gardener's dialogue with the garden. We curated experiences and facilitated workshops to promote dialogue and support data collection. Dialogical approach in the metaphorical sense can be applied in words as well as actions, images and objects (Figure 1), the important thing is that the counterparts

react to each other. This reminds us of our response-ability (Haraway, 2016). More generally, this method aims to support co-creation and action learning.

The methods are based on two case-studies. The artist´s "Interspecies social sculpture" focuses on garden and forest as an environment for interspecies communication. The designer´s practice focuses on hand stitched textile repair and initiating natural processes where textiles and clothes welcome change in their physical form and appearance.

The research was carried out using a qualitative multi-method approach including both ethnographic and autoethnographic data collection (visual documentation, diary, reflections). In our approach objects were agents in facilitating dialogue and dialogue is embodied in the objects. Data was decoded to a written form and analysed using qualitative content analysis in three steps. During data analyses three categories were formed from the codes: 1) representations of nature experience, 2) textile objects and their work in process, 3) meetings and collaboration.

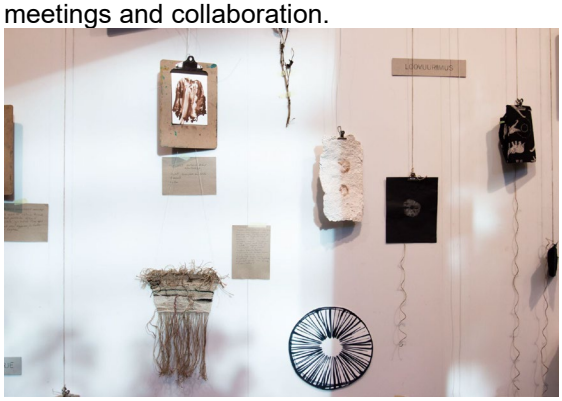


Figure 1. The creative practice of an artist and a designer set in a dialogue. Photo: Aurelia Minev.

Results. The Creative Research Methods

As a result of the analysis we learned that the bond with nature is strengthened by involving people into active creative engagement with nature. Focusing and co-creation facilitated by art and design creates a connection with place, people and nature and helps to see the meaning in less. Rethinking existing knowledge can take place through creative activities in a dialogic environment. An environmentally conscious creative process is facilitated by experiential participation and considering the possibilities of the environment. The role of the artist and designer becomes the initiator and mediator of dialogic processes.

Based on this knowledge we developed six creative research methods.

- Dialogue of gardeners´
- Decomposing the resource-intensive patterns of action supports critically analising our ways of doing and decomposing them into nourishing compost
- Ritual slowing down in the garden aims to notice and value activities that will not give immediate fruit, but help to contribute to the future flourishing.
- Exercises for interspecies co-creation
- Interweaving with the rest of nature
- Valuing the aesthetics of randomness, decay and wearing out

They work the best if combined, interwoven and influenced by each other.

On the method cards we open up on how we applied the methods in our creative practice.

Conclusions

We propose that one of the contributions of the methods is proposing possibilities of how to not do anything new but add layers of meaning to the existing. The role of the creative practitioner shifts from being the producer to being the facilitator of the dialogue.

We the creative practitioners can become the decomposers of resource intensive patterns, agents of degrowth and positive activism.Through the methods we invite you to a dialogue.

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References

Clement, G. (2021). In practice: Gilles Clément on the planetary garden. The Architectural Review. https://www.architectural-review.com/essays/in-practice/in-practice-gilles-clement-on-the-planetary-garden. (Accessed 31.03.2024)

Degrowth Estonia. Mis on tasaareng, https://tasaareng.info/mis-on-tasaareng/. (Accessed 19.04.2023)

Greer, B. (2003). Craftivism Manifesto. https://craftivism.com/wp-content/uploads/2017/04/craftivism-manifesto-2.0.pdf (Accessed 26.03.2025)

Haraway, D. J. (2016). Staying with the Trouble – Making Kin in the Chthulucene. Duke University press. Durham and London. DOI: 10.1080/14649365.2017.1421042

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. https://files.ipbes.net/ipbes-web-prod-public-files/inline/files/ipbes_global_assessment_report_summary_for_policymakers.pdf (Accessed 08.12.2024)

Mackay, C. & Schmitt, M. (2019). Do People Who Feel Connected to Nature Do More to Protect It? A Meta-Analysis", Journal of Environmental Psychology, Volume 65, October 2019, 101323. Elsevier, 2019, https://doi.org/https://doi.org/10.1016/j.jenvp.2019.10132.

Taul, M. (2021). Parandamise tehnoloogiad 20. sajandi alguse kirjanduse ja Eesti Rahva Muuseumi kogus olevate 19. sajandist ja 20. sajandi algusest pärit linaste rahvarõivapükste näitel. University of Tartu Viljandi Culture Academy. Seminar work.

Rebound effects and critical views on product durability

Research paper
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Hygiene practices in everyday Life: Exploring the adoption and environmental implications of disposable gloves

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Keywords: Disposable gloves; single use products; social practice theory; practices for longevity; focus groups.

Abstract: The COVID-19 pandemic has led to increased use of disposable products, notably face masks and disposable gloves. While these items serve as a protective barriers against health hazards, they also pose significant environmental risks due to their resource-intensive production and waste generation. This study explores the adoption of disposable gloves beyond healthcare, probing their use and significance in the daily lives of Norwegian consumers. Employing social practice theory, the research investigates the underlying reasons and ways Norwegian consumers incorporate disposable gloves into various practices, and how more sustainable alternatives could be promoted. The methods encompass mobile ethnography and focus groups with Norwegian consumers. The findings demonstrate that disposable gloves are used to reduce health risk and enhance hygiene in daily life conveniently, consequently increasing waste. Alternative methods for increasing hygiene, such as reusable and longer lasting products or hand washing, are perceived as less hygienic and less convenient. Conclusively, the study sheds light on the complexities of changing material-practice entanglements and offers insights for developing more sustainable hand hygiene practices.

Introduction

This paper explores the use and understanding of disposable gloves, a subject that has become increasingly relevant during and after the COVID-19 pandemic. While previous research primarily examined their role in healthcare (e.g. Dodamani et al., 2020), the pandemic has heightened scrutiny of their environmental and health implications (Kutralam-Muniasamy et al., 2022; Singh et al., 2020). The study examines their adoption and meaning in the everyday lives of Norwegian consumers.

Disposable gloves are multifaceted artifacts. They symbolise and provide physical protection against health and social risks, yet they also present environmental challenges due to resource-intensive production and waste creation. Discarded gloves can release pollutants like microparticles, organic matter, and heavy metals, potentially affecting water and soil quality (Jędruchniewicz et al., 2021; Wang et al., 2022). Furthermore, allergies to disposable gloves have become increasingly common among individuals in occupations requiring frequent glove use (Hunt et al., 1995; Rose et al., 2009), a trend that may extend to consumers as glove usage rises.

This complexity makes disposable gloves an intriguing artifact for social science research, complementing the predominantly natural science-oriented research on the topic. By adopting a social practice perspective, this study aims to contribute to broader discussions on sustainable and alternative hand hygiene practices, offering insights for social innovation.

The initial idea for studying disposable gloves first emerged over 15 years ago, inspired by an observation during one of the authors' daily commutes past a small bakery. He noticed that in the mornings, workers handled bread and cakes without gloves, but in the afternoons, they consistently wore disposable gloves. This sparked curiosity about the rationale behind such usage outside the healthcare sector - were gloves being used to protect the food, the workers, the customers, or for another reason altogether?

The topic re-emerged during the COVID-19 pandemic when the use of disposable gloves spread from the healthcare into everyday life

practices, resulting in increased usage. Consequently, the topic was included in the research project REDUCE, which aims to identify how plastic products are intertwined in everyday practices and measures to reduce unnecessary plastic use.

This study explores the broader implications of disposable glove usage, focusing on their transition from specialised healthcare settings to integral elements of everyday practices. By investigating the factors driving this shift and the various contexts in which disposable gloves are used, the research aims to address the environmental challenges associated with these products and inform policy for increasing the use of more sustainable alternatives.

The study is guided by the following research questions:

1. How do Norwegian consumers use disposable gloves in everyday life?
2. How can we promote the use of more sustainable alternatives?

The study employs mobile ethnography, where participants photographed everyday plastic objects, followed by visual focus groups discussing the functional, social, aesthetic, and economic roles of plastics. Before detailing the method, the paper briefly reviews practice-theoretical framework that contextualises disposable gloves as an everyday product, and their dual roles as health risk reducer and environmental risk producer. The results demonstrate that disposable gloves are used to increase hygiene and convenience, reducing health risks and giving consumers a sense of protection. Performing alternative practices, such as washing hands, using reusable gloves, or reducing use, are perceived as less convenient. The paper concludes with recommendations for policy interventions to promote hygiene practices that are more sustainable yet convenient and effective.

Social practice theory

The transition of disposable gloves from the health care sector to everyday life, and their use in daily activities, can be explored through social practice theory, which considers the social, cultural and material aspects of disposable glove use.

Social practice theory provides a holistic conceptual framework for analysing everyday life through the entanglements of material and social elements, defined as practices. A practice is a socially constituted and shared way of doing something, like washing your hands, that individuals perform (Cetina et al., 2001; Reckwitz, 2002). In practice-based analyses, the practice itself is the analytical point of departure, looking at what sort of materials (e.g., disposable and reusable gloves), forms of knowledge (expert knowledge about hygiene or routinised enactments of hygiene) and general understandings (e.g. social norms on hygiene) are used in performing actions.

We can differentiate between dispersed and integrative practices. Dispersed practices are widely spread across different sectors of social life, such as describing, ordering, following rules, explaining, or questioning (Schatzki, 1996, p. 91). Integrative practices, on the other hand, are more complex and are found in and constitutive of particular domains of social life, such as farming, cooking, business, or teaching practices (Schatzki, 1996, p. 98). In this context, hygiene is a dispersed practice, while disposable glove use is an integrative practice.

Focusing on practices as the primary unit of analysis allows us to explore their elements, relations, and interdependencies. For example, in our analysis, we demonstrate that hand hygiene and disposable glove use intertwine with various everyday activities like personal hygiene, cooking, eating, and childcare. According to Shove et al. (2012, p. 13), the elements of these practices change over time, and that the introduction of disposable gloves represents a new materiality in the evolution of these practices. The increase in the use of disposable gloves implies a change in hand hygiene practices across different and integrated practices. When practices and materialities are deeply entangled, it becomes even more challenging to enact change, such as re-introducing less environmentally damaging and longer lasting materials like reusable gloves or reducing the consumption of disposable gloves.

Disposable gloves as health risk reducer and environmental risk producer

Many single-use hygiene products, including gloves, are multifaceted in their function. They reduce risk by protecting the body from

potential contaminants that pose health risks, such as bacteria and viruses, substances that are culturally perceived as unpleasant or unclean (Douglas, 2003[1966]), such as decaying food, soil or mud, as well as materials undesirable on the skin, such as paint or glue. On the other hand, these products pose environmental risks due to massive waste generation and resource-intensive production, as well as health risk due to allergies. Moreover, incorrect disposal might lead to nature pollution or in some cases microplastics pollution.

The use of disposable gloves has expanded over time, influenced by broader societal changes, and increasing emphasis on hygiene and risk management. The evolution of gloves in modernity might be understood within the context of a 'civilized risk society' (Beck, 1992). Disposable gloves were first introduced in the health sector with well-defined and strict rules aimed at protecting against infection. Later, they became common consumer goods in supermarkets, kindergartens and homes. Global production increased from 213 billion products consumed in 2017 to 420 billion pieces in 2021 (Koncept Analytics, 2013; Jędruchniewicz et al., 2021). During the pandemic, the demand for gloves in the health sector exceeded the supply, leading to over 700% increase in prices (Dolonen & Hernæs, 2021). In Norway, the increased use during the pandemic has led to initiatives from the official health authorities to reduce usage to only specific situations, and suggesting alternative ways of securing hand hygiene protection, mainly by washing hands. The slogan for 2024 hand hygiene day information campaign was "Gloves - only when needed!" (FHI, 2024).

Previous research (Wakefield-Rann et al., 2020a, b) highlights the importance of understanding how practices structure interactions between humans, microbes, and chemicals at home. However, there's a gap in understanding how disposable gloves have been integrated into everyday life—especially through the lens of social practice theory. This study fills this gap by examining the use and significance of disposable gloves consumers' daily lives, offering new insights into their roles in hygiene, leisure, and beyond.

Method

The study employs a qualitative research methodology that combines mobile ethnography with focus groups to explore the use and understanding of disposable gloves. In November 2022, three focus group interviews were conducted involving 10 Norwegian men and 15 women aged 17 to 74 years (average 42 years). Each group comprised a diverse mix of participants, including both women and men from single and multi-member households, with and without children. The primary objective of the study was to explore the use of plastic products in daily life and assess opportunities for their reduction. Before the focus group interview, each of the participants was asked to photograph plastic products they used in their daily lives within the three themes, childhood, hygiene and leisure. These photos were used to relate the discussions to concrete use situations. All the participants signed a written consent form, and the interviews were fully transcribed.

The interviews were designed to capture the participants' understandings of and experiences with using plastic products in various everyday contexts. During discussions on hygiene-related plastic use, the participants were divided into sub-groups based on gender to account for differences in hygiene product usage, particularly the use of menstrual products among women. In the men's sub-group, the conversation revolved around different types of hygiene products, including disposable gloves. The following analysis is primarily based on the discussions among the male participants.

Results

The below analysis of the focus group data demonstrates that consumers' understanding, and use of, disposable gloves is characterised by inherent conflict between hygiene benefits and environmental risks.

Protection and health risk reduction

Using gloves creates a physical barrier between the skin and the objects we touch. In the case of disposable gloves, the pollution on the outside of the gloves can easily be dealt with by discarding the gloves after using them. However, there is a risk of contamination when taking the gloves on or off, and the gloves themselves must be packaged in a way that prevents pollution. One of the participants talks about the complexities of hygiene practices: *"They [hygiene products] don't have to be packaged in plastics but they must be*

hygienically clean, so that no impurities enter the package. Otherwise, it won't work as it is supposed to" (Man, Focus group 1). The quote exemplifies the layers of product and actions that are needed to ensure a sufficient level of hygiene.

Although the level of hygiene varies between a medical setting, such as a hospital, and at home, we find that after the COVID-19 pandemic, there has been an increased focus on hygiene also at home, producing new forms of 'risk work' (Horlick-Jones, 2005). This concept involves negotiating risk levels, competing risks, and risk reduction within everyday life practices. The pandemic significantly complicated hygiene practices, and disposable gloves have emerged as one solution to manage this complexity. We find that there are mainly two shared meanings or understandings that frame the hygiene risk negotiations in the focus groups: convenience and disgust.

Several of the focus group participants said that they previously used reusable rubber gloves but had recently switched to disposable gloves, which was understood to be convenient. One of the participants said that *"I have a package lying on the kitchen counter at home. (…) I use them to clean the bathroom, the drain",* which was confirmed by another participant who added: *"Yes, it's much nicer to use gloves for that"* (Men, Focus group 1). The group goes on discussing situations where gloves are convenient, such as giving children and pets medicine, dealing with bodily fluids, and using strong detergents and paint. Convenience is the state of being able to proceed with something without difficulty, often also without reflection, thus reducing the work needed to consider hygiene when performing these practices.

In addition to convenience, gloves are used to avoid what one of the participants frame as follows: *"you use it for hygiene stuff, like, the stuff that's a bit nasty"* (Man, Focus group 1). Avoidance of disease has long been theorised as the principal function of disgust (Oaten et al., 2009). Thus, experiencing disgust promotes the rejection of potential health threats, such as microbes found in spoiled food. Several of the participants framed their use of gloves as avoiding dirt, using them as "*protective equipment*".

Danger and environmental risk production

The negative environmental effect of disposable gloves was secondary to the hygiene benefits of using them. One of the participants expressed this view: *"It think with hygiene, like, I think it's difficult using plastic, but it's for hygiene, and your hygiene is more important than being really sustainable (…)"* (Man, Focus group 2). Still, all three groups discussed reduction in use either by proposing multiple use products or alternative ways of performing the task.

Longer-lasting washable rubber gloves were discussed as an alternative; however, it was perceived to be less convenient and riskier because washing them might not get rid of all the pollutants. One participant said that *"The alternative is rubber gloves that you have to disinfect afterwards, and if you look at the carbon footprint of disinfecting, it might be just as good to wear a disposable glove that you throw away"* (Man, Focus Group 3), while another was asked why he did not use rubber gloves to which he answered that *"I've become more sensitive to it recently (laughs)"* (Man, Focus group 2). These quotes exemplify the moral struggle between convenient and environmentally friendly products. The literature on sustainable consumption has shown that convenience is often prioritised over sustainability, producing unsustainable consumption patterns (Shove, 2003).

Several participants were still positive that the increased use of disposable products during and after the pandemic would be countered by more environmentally friendly products with replaceable parts, as expressed by one participant: *There could come a counter reaction, though, as we saw with the reusable face mask, like; listen here, what we did during the start of the pandemic, we created a massive environmental foodprint by preventing COVID-19, it was huge, and now we have to replace some of the products we started out using* (Man, Focus group 2). The group continued to discuss the potential of more reusable hygiene products, including gloves made of different materials.

An alternative practice of reducing health risk without producing the environmental pollution that comes from disposable gloves is to wash your hands. The participants agreed that after

COVID-19, using disposable gloves had become more common, like this participant said: *"I think it's a bit funny, but after corona it has become really common to use rubber gloves"*, followed up by another who replied that *"washing your hands is as effective, nearly, right, you wash your hands after using the gloves as well. But I think the gloves have returned, I can't remember using so many single use products before corona, maybe the culture…"* (Men, Focus group 2). Some of the participants had never worn disposable gloves, and surprisingly, during the discussions they became interested in where the other participants had bought them and how and why they used them, aiming to adopt similar practices at home. During these discussions, the underlying rationale seemed to be that those who used them wanted to be clean and be perceived as clean by others. Washing hands was not a sufficient measure to create the perception of cleanliness, like this discussion shows:
Man 1: If I'm making dinner for more people and they see that you wear gloves, they might feel that, okay, he is very hygienic and…
Man 2: I follow you, I totally agree
Man 3: It's just become like that
Interviewer: To show that…
Man 1: It's important to appear proper. It's important to be hygienic [when cooking] (Men, Focus group 3).

The increase in single-used hygiene products during the COVID-19 pandemic has resulted in a negotiation between health and environmental risks in everyday hygiene practices. As the analysis shows, consumers use gloves to deal with pollutants in a convenient way and to avoid disgust. Alternative products with longer lifespans, such as rubber gloves, and alternative practices such as washing hands, are seen as insufficient to that end. This indicates that a change in the material element of hygiene practices, the introduction of gloves, has changed the general hygiene understanding. A suggestion taken from our material is to further examine the role of single and multiple use products for changing overall societal understandings of hygiene.

Discussion and conclusions

This paper has explored the journey of disposable gloves from their origins in the healthcare sector to their adoption in everyday consumer practices, examining how they are integrated into various routinised actions. By unpacking this shift, we provide insight into why disposable gloves are often preferred over reusable alternatives with longer lifespans. The focus group data shows that disposable gloves are preferred above both longer lasting materials and more environmentally friendly practices such as washing hands mainly due to convenience and avoidance of disgust.

On a general level, the evolution of disposable gloves from a specialised medical tool to a common household item reflects a shift in social and cultural norms of what it means to be clean and hygienic. There is thus a need for alternative products or competences that are more sustainable yet convenient and hygienic.

Policy interventions could include:

- Public education that highlights the shortcomings of improper use of disposable gloves
- Promoting and easing access to reusable gloves, hand washing, or sanitisers
- Extend policies against single-use plastics to limit sales of disposable gloves to specific stores like pharmacies
- Labelling to inform about the plastic content, risk of allergic reactions and proper disposal for recycling
- Introducing waste management, recycling and clean-up obligations for producers.
- Offer grants for companies to develop and promote more sustainable single use alternatives to disposable gloves

Importantly, efforts to reduce disposable gloves use must consider the broader context in which this product is embedded. Simply promoting alternatives to disposable gloves might not be sufficient; instead, it may be necessary to address the underlying practices, and the understandings attached to them – in this case the understanding of proper hygiene. By understanding and combining the factors that drive the use of disposable gloves and the contexts in which they are used, policymakers and practitioners can develop targeted interventions that encourage more sustainable hand hygiene practices.

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References

Beck, U. (1992). *Risk Society: Towards a New Modernity*. Sage Publications.

Cetina, K. K., Schatzki, T. R., & Von Savigny, E. (2001). *The Practice Turn in Contemporary Theory*. Routledge.

Dodamani, A. S., Jadhav, H. C., Khairnar, M. R., & Naik, R. G. (2020). Dental professionals' knowledge and behavior towards utilization of gloves: a cross-sectional survey. *J Prev Med Hyg,* 61(4), E636-e641. DOI:10.15167/2421-4248/jpmh2020.61.4.1291

Dolonen, K. A., & Hernæs, N. (2021, 17.3.2021). Det produseres for få hansker: Usikkert om Norge får nok. *Sykepleien*. https://sykepleien.no/2021/03/det-produseres-fa-hansker-usikkert-om-norge-far-nok

Douglas, M. (2003[1966]). *Purity and Danger: An Analysis of Concepts of Pollution and Taboo*. Routledge.

FHI. (2024). Markering av 5. mai - håndhygienens dag. Erfaringsoppsummering fra 2024. Folkehelseinstituttet.

Horlick-Jones, T. (2005). On 'risk work': Professional discourse, accountability, and everyday action. *Health, risk & society*, 7(3), 293-307. https://doi.org/10.1080/13698570500229820

Hunt, L. W., Fransway, A. F., Reed, C. E., Miller, L. K., Jones, R. T., Swanson, M. C., & Yunginger, J. W. (1995). An epidemic of occupational allergy to latex involving health care workers. *J Occup Environ Med*, 37(10), 1204-1209. DOI:10.1097/00043764-199510000-00011

Jędruchniewicz, K., Ok, Y. S., & Oleszczuk, P. (2021). COVID-19 discarded disposable gloves as a source and a vector of pollutants in the environment. *Journal of hazardous materials*, 417, 125938. DOI: 10.1016/j.jhazmat.2021.125938

Koncept Analytics. (2013). *Global Rubber Gloves Market Report*. https://issuu.com/prkonceptanalytics/docs/global_rubber_gloves__market

Kutralam-Muniasamy, G., Pérez-Guevara, F., & Shruti, V. C. (2022). A critical synthesis of current peer-reviewed literature on the environmental and human health impacts of COVID-19 PPE litter: New findings and next steps. *Journal of Hazardous Materials*, 422, 126945. DOI:10.1016/j.jhazmat.2021.126945

Oaten, M., Stevenson, R. J., & Case, T. I. (2009). Disgust as a disease-avoidance mechanism. *Psychological bulletin*, 135(2), 303. DOI: 10.1037/a0014823

Reckwitz, A. (2002). Toward a theory of social practices. A development in culturalist theorizing. *European journal of social theory*, 5(2), 243-263. https://doi.org/10.1177/13684310222225432

Rose, R. F., Lyons, P., Horne, H., & Mark Wilkinson, S. (2009). A review of the materials and allergens in protective gloves. *Contact Dermatitis*, 61(3), 129-137. DOI:10.1111/j.1600-0536.2009.01580.x

Schatzki, T. (1996). *Social practices: A Wittgensteinian Approach to Human Activity and the Social*. Cambridge University Press. https://doi.org/10.1017/CBO9780511527470

Shove, E. (2003). *Comfort, Cleanliness and Convenience: The Social Organization of Normality*. Berg.

Shove, E., Pantzar, M., & Watson, M. (2012). *The Dynamics of Social Practice: Everyday Life and How it Changes.* Sage Publications. DOI: https://doi.org/10.4135/9781446250655

Singh, N., Tang, Y., & Ogunseitan, O. A. (2020). Environmentally Sustainable Management of Used Personal Protective Equipment. *Environmental Science & Technology*, 54(14), 8500-8502. DOI:10.1021/acs.est.0c03022

Wakefield-Rann, R., Fam, D., & Stewart, S. (2020a). Microbes, chemicals and the health of homes: integrating theories to account for more-than-human entanglements. *BioSocieties*, 15(2), 182-206. DOI:10.1057/s41292-019-00147-7

Wakefield-Rann, R., Fam, D., & Stewart, S. (2020b). Routine exposure: social practices and environmental health risks in the home. *Social Theory & Health,* 18(4), 299-316. DOI:10.1057/s41285-018-00084-8

Wang, Z., An, C., Lee, K., Chen, X., Zhang, B., Yin, J., & Feng, Q. (2022). Physicochemical change and microparticle release from disposable gloves in the aqueous environment impacted by accelerated weathering. *Science of The Total Environment*, 832, 154986. DOI:10.1016/j.scitotenv.2022.154986

Welch, D., & Yates, L. (2018). The practices of collective action: Practice theory, sustainability transitions and social change. *Journal for the theory of social behaviour*, 48(3), 288-305. DOI: 10.1111/jtsb.12168

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Leverage Points as an Analytical Framework for Preventing Rebound Effects: An Exploratory Study

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Keywords: Rebound Effects; Design Thinking; Systems Thinking; Leverage points; Systemic Design.

Abstract
Despite global efforts toward sustainability, greenhouse gas emissions continue to rise, partly due to rebound effects (RE), i.e., systemic responses that offset the potential sustainability benefits of sustainability interventions. Designers often struggle to prevent RE due to dynamic complexities characterized by non-linearity, feedback loops, and delays. This paper explores how systems thinking, specifically the Leverage Points Framework (LPF), can support design activities in ideating and designing strategies for preventing RE. Through an exploratory case study of an electric car-sharing system, LPF and ideation techniques were applied to devise potential design strategies to prevent RE emerging from five identified RE mechanisms. Our findings suggest that integrating leverage points into the design process encourages a more systemic and comprehensive approach to ideation, expanding design opportunities towards the prevention of RE. We conclude that combining systems thinking with design thinking enhances the potential for creating effective, sustainable interventions and recommend further research to evaluate the practical potential of the proposed framework.

Introduction
Despite global efforts towards sustainability, the total Greenhouse Gases (GHG) emissions continue to rise (UNEP, 2021). The gap between sustainability-oriented actions and the expected reduction in resource use (such as energy and material) is partially explained by the so-called Rebound Effects (RE). RE refers to systemic responses that partially or entirely offset the potential sustainability gains of interventions (Guzzo et al., 2023).
Although RE are widely recognized, fundamental scientific gaps hinder their prevention (Andrew & Pigosso, 2024; Hertwich, 2005). The few studies that offer recommendations to address RE (Reimers et al., 2021) are focused on policy interventions (Azevedo, 2014; Colmenares et al., 2019; Greening et al., n.d.). Additionally, much attention has been given to the effects of RE, while the mechanisms necessary for addressing them remain underexplored (Guzzo et al., 2024; Lange et al., 2021).
Addressing RE requires diving into the dynamic complexities emerging from the nonlinearity, feedback loops, delays, and accumulations inherent of socio-technical systems (Guzzo et al., 2023). Designers often grapple with the dynamic complexities of systems, which leads to a trial-and-error approach for developing and testing design interventions (Scoones, 2007). Often, poor understanding of these dynamic complexities, especially feedback loops and delays, leads to negative consequences that off-set or backfire the initial intentions of the design intervention (de Gooyert et al., 2016; Guzzo et al., 2023). Thus, there is a need for a systemic perspective and toolkit towards understanding the complexity of the designed system towards the prevention of RE (Madlener & Turner, n.d., Oliveira et al., 2024).
By adopting a systemic understanding of social and technical contexts, designers can enhance the effectiveness of their interventions by hedging against or leveraging on higher-order effects (such as RE (Dori et al., 2020))), generated by the interplay of feedback loops (Oliveira et al., 2024).
The Leverage Points Framework (LPF) offers a promising approach for addressing RE by helping to identify intervention variables and supporting system change by showing how small shifts in one point can lead to significant impacts in the system (Meadows, 1999). While LPF has been used to address sustainability challenges (Kieft et al., 2020), it has not yet been applied to RE.
This paper investigates how systems thinking and the concept of leverage points can support

design activities in devising design strategies capable of preventing rebound effects.

Theoretical Background

This section elaborates on two key elements for this study: rebound mechanisms and the Leverage Points Framework (LPF).

Rebound Mechanisms

Causal frameworks for explaining RE via rebound mechanisms are on the rise (Castro et al., 2022; Metic & Pigosso, 2022). Rebound mechanisms refer to the causal pathways (i.e., cause and effect relationships) mediating a given system intervention and the RE (Lange et al., 2021). System interventions will activate rebound mechanisms via the interplay of variables that causally determine its existence and moderated by contextual parameters, resulting in a RE of a given magnitude (Guzzo et al., 2024). To capture the systemic nature of rebound mechanisms, Guzzo et al. (2024) developed a (non-exhaustive) generalizable catalogue of rebound mechanisms utilizing causal-loop diagrams (CLDs). CLDs capture causal relations between variables operating in the system while emphasizing feedback loops and delays.

Figure 1 illustrates a generic rebound mechanism, agnostic of any specific intervention. Starting in the top variable: sustainability actions aiming at reducing local resource consumption at the local level, such as increasing efficiency of consumption or production, may activate a rebound mechanism (by triggering a certain variable that explains consumption or production activities), leading to responses in the social system that increase demand for products and or services. The change in supply or demand is depicted in arrows, *Links in red depict opposite relations (minus sign "-") and green ones represent variables increasing at the same direction (plus sign "+").*

Structural analysis of the rebound mechanisms enables identifying ways to prevent or mitigate RE, identifying leverage points that weaken the

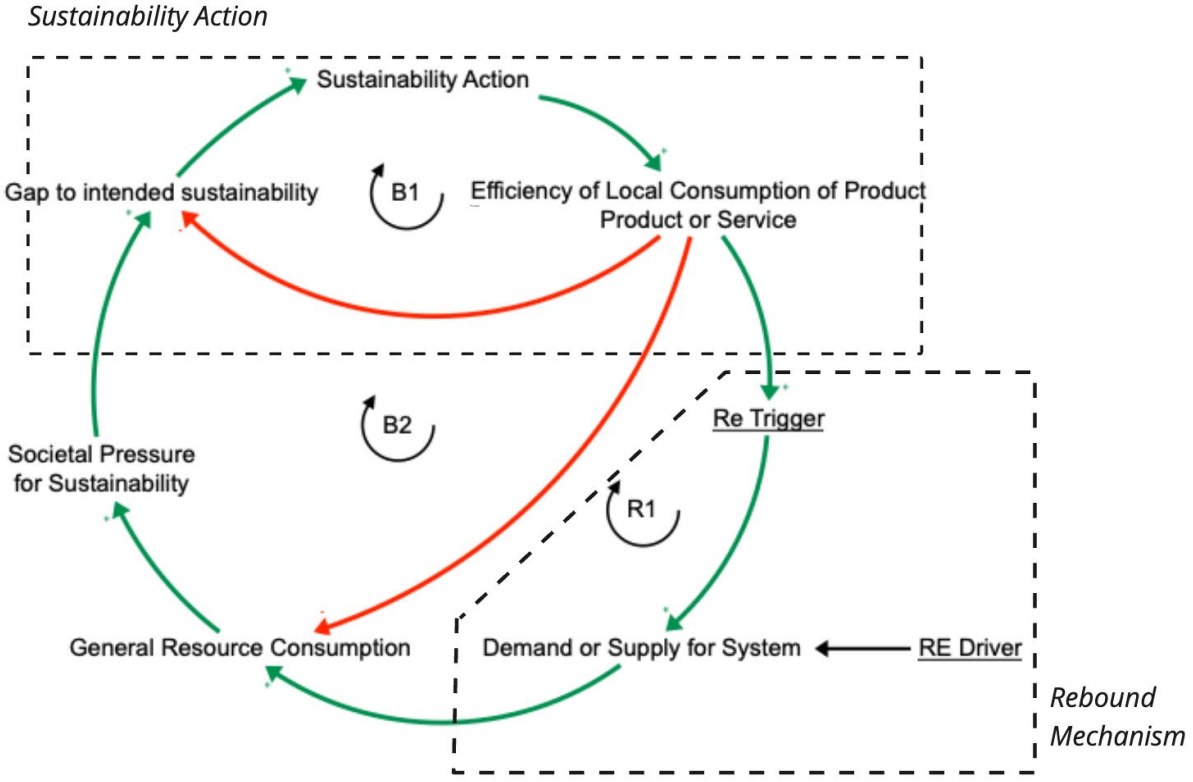


Figure 1 – Generic Rebound Mechanism adapted from (Guzzo et al., 2024).

effects of triggers, drivers, and feedback loops sustaining the rebound mechanisms (Guzzo 2024).

Leverage Points Framework (LPF)

LPF is an analytical framework capable of supporting decision-makers in addressing systemic, dynamic, and complex problems. Meadows postulates a hierarchy of 12 leverage points (LP) of intervention, with increasingly transformative potential in the system (Figure 2). LP is defined as *"places within a complex system where a small change can produce large shifts in the system's behavior"* (Meadows, 1999).
LPs can be arranged into four groups of interventions (Abson et al., 2017):

I. **Parameters**: refer to tangible – often physical – aspects of the system: taxes, prices, sizes of stocks (system accumulations), or rates of change. Intervening at this level is relatively straightforward, but not particularly impactful in driving systemic change. In a car-sharing system, for instance, changes in parameters might be related to the price charged per use (LP 12) or the fleet size of vehicles (LP 11), or setting-up processes for repairing the vehicles (LP 10).

II. **Feedback**: refers to how the information circulates within the system (through processes) and feedback into itself. Intervening on feedback involves, for example, changing the time required to process and deliver a vehicle to a customer (LP 9), decision rules for controlling the fleet size within inventory management (LP 8), or the extent to which profits are reinvested to expand business activities (LP 7).

III. **System structure:** Effectively change how information is shared, as well as those who have access to information (e.g., by adding new processes, accumulations or buffers). Examples of additional system structures in a car sharing system could be enabling users to have live access to fleet availability or monitor the environmental impact induced by their use (LP 6), incentives and punishments rewarding desired behaviors (LP 5), and the power for customers collectively decide the incentives for their behaviors (LP 4).

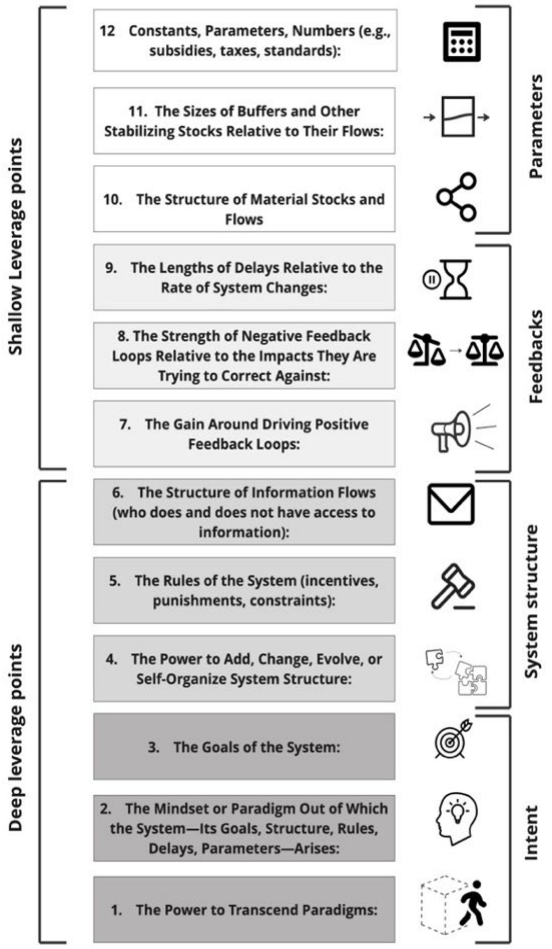


Figure 2 - The Leverage Points framework

IV. **Intent**: refers to the worldview, underlying values, and paradigm in which actors behave within the system, operate, and make decisions. It is the most intangible and difficult-to-change aspect of a system, yet the most determinant of system behavior. Changing the intent of a mobility platform could mean moving from profit maximization towards ensuring sustainable, efficient and effective mobility.
It is important to note that leverage points are at different hierarchical levels and are inherently linked to one another. Shallower interventions contribute to deeper transformations over time, and vice-versa.

Method

The research question guiding this study is: "*How could designers use leverage points in ideation sessions to systematically devise design strategies capable of preventing rebound effects?*".

The main hypothesis is that LP can enhance systems thinking in design by helping to identify ways to tackle RE. LPs are seen as critical elements within a complex system that, when identified, enable designers to implement interventions leading to significant and positive changes in system behavior.
To explore the use of LPF in devising design strategies that can support the prevention of RE, this study uses an inductive approach departing from one specific case towards broader generalizations of the findings in five research steps (Figure 3). The case focuses on a retrospective analysis of an electric car-sharing product-service system (PSS) which is subjected to RE.

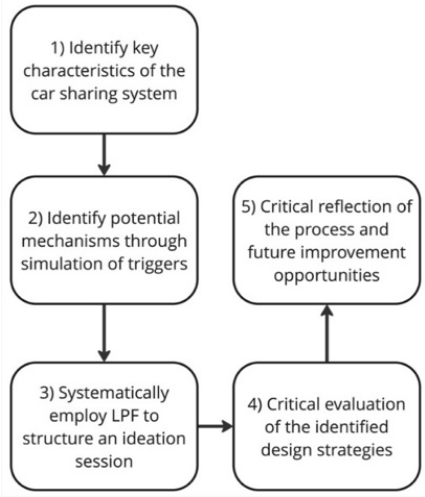


Figure 3: Process overview

Step 1: Identify key characteristics of the car-sharing system

Transitioning to electric vehicles and shifting to shared mobility is seen as an alternative to reduce the negative environmental impacts of mobility, including emissions and resource consumption. However, without careful design, these solutions can inadvertently lead to RE, such as increased overall travel demand or vehicle production – displaying the complexity of the system. The selected car-sharing PSS is GoMore, a Danish company offering three value propositions: leasing, ridesharing, and peer-to-peer car rental services. Our analysis emphasized the intended sustainability gains and induced impacts of GoMore's value propositions in comparison to traditional private-owned mobility. The data was collected from the company's website (www.gomore.dk) and supplemented by the available literature.

Step 2: Identify and select mechanisms through the stimulation of triggers

Departing from the key characteristics of GoMore's value propositions, we systematically examined the extent to which these offerings could activate the rebound mechanisms systematized by Guzzo et al. (2024). For instance, a mobility PSS reduces the cost of consumption of private mobility, leading to a release in the budget for additional consumption. If users re-spend the budget in resource-intensive activities, a RE in total resource consumption would be observed (Guzzo et al., 2024). This process resulted in the identification of five potential rebound mechanisms stimulated by the PSS platform. CLDs representing the identified mechanisms were used to visualize the causal pathway linking triggers, drivers, and potential rebound effects on resource consumption.

Step 3: Systematically employ LPF to structure an ideation session

Based on the results of Step 2, we proceeded to identify actionable elements of the rebound mechanisms that could be influenced through design, at different leverage points. The ideation process started by addressing shallow leverage points (such as parameters, numbers, and numbers) and later deeper leverage points (such as transcending paradigms). As a result, the ideation process resulted on the consolidation of several design strategies that could support in the prevention of rebound effects.

Step 4: Critical evaluation of the identified design strategies

The ideated design strategies were critically evaluated regarding three main criteria: (1) feasibility of implementation; (2) effectiveness to address potential RE; (3) "designability" (i.e., the extent to which the intervention is within designer's decision space).

Step 5: Critical reflection of the process and future improvement opportunities

The final step was to reflect upon the overall process and the use of leverage points to link systems thinking and design thinking for the prevention of rebound effects. This reflection key findings contributed to the generalization of the results obtained in this study. These insights are presented in section 5. Discussion.

Results

This section presents the key findings of research step 1-4.

Step 1: Key characteristics of the car-sharing system

GoMore is a Danish mobility platform that integrates peer-to-peer car rental and ridesharing and provides vehicle leasing contracts. In peer-to-peer modes, customers act as clients on the platform, offering either their vehicles for rent or posting pre-scheduled rides to be shared. Leased vehicles are directly provided by GoMore, who retain their ownership throughout the contract.

Rebound mechanism	LP	Design strategy	Evaluation		
			Feasibility	Effectiveness	Designability
Re-spending Mechanism	12 (I. Parameters)	Enhance product efficiency as a means to counteract additional consumption originating from past REs.	High: Implementation is straightforward.	Low: May strengthen existing rebound effects reliant on product efficiency.	High: Controllable within design parameters.
Income Mechanism	8 (II. Feedback)	Strengthen Price feedback by setting limits on total mileage per trip or per user to reduce overuse, prevent long-distance travel, and encourage intentional use.	Moderate: Requires local adaptation and enforcement. From a business standpoint might not be viable due to market competition.	Moderate: Targets specific behaviors effectively in urban areas.	High: Easily designed.
Motivational consumption	6 (III. System Structure)	Inclusion of new information flows (e.g., estimating emissions for each trip before bookings as well as summaries of usage patterns), and allowing users to set personal sustainability goals.	Moderate: Relies on integrating novel technology for data collection and display.	High: Influences user behavior significantly by promoting awareness.	Moderate: requires collaborations with technical professionals and data providers.
Substitution effect	2 (IV. Intent)	From discussing the design of mobility system to discussing the design of human settlements & urban centers	Low: Complex and long-term process involving multiple stakeholders.	Very High: Addresses systemic causes of rebound effects at the root.	Low: Beyond the typical scope of design; requires interdisciplinary collaboration.

Table 1: Examples of different leverage points, corresponding design strategies and evaluation of strategies.

Participation in peer-to-peer services as a lessor is incentivized.

Through its propositions, GoMore intends to combine increased customer value to reduce the environmental impact of private mobility. Offering product-as-a-service reduces the cost of ownership and increases convenience and flexibility while optimizing efficiency and effectiveness through higher utilization rates and reduced idleness.

Step 2: Identified and selected mechanisms through stimulation of triggers

By linking the outcomes of the company's value proposition and evaluating the extent to which they stimulate rebound triggers, we were able to identify five relevant rebound mechanisms: (1) income, (2) re-spending, (3) substitution (4) motivational, (5) consumption time, and (6) moral hazard. The sixth mechanism, not present in the catalogue was supplemented through the literature (Ackermann & Tunn, 2024)

Reduced costs of consumption may activate three mechanisms simultaneously: (1) income mechanism occurs when savings due to the reduced cost of transportation are reinvested into more driving of the consumer's initial choice, while (2) Re-spending mechanism occurs when released budget is reinvested in additional consumption elsewhere. Lastly, (3) Substitution occurs when consumers change their consumption choice to a less resource effective choice in respect to a change in cost of consumption. (4) Motivational consumption mechanism happens when users perceive a product or service as a sustainable alternative, leading to increased consumption (5) Consumption time mechanism is triggered by easiness of consumption. For instance, enabling users move faster and easier from A to B through a sharing platform might lead to driving more and further.

Step 3: Results of systematically employing LPF to structure an ideation session.

In total, our ideation session resulted in 68 unique potential design strategies that could prevent the occurrence of rebound effects, targeting at different leverage points with

varying degrees of effectiveness. The ideas were widely distributed across the LP. Shallow LPs included 22 ideas from Parameters, often focusing on altering physical system parameters, and 11 ideas from Feedback, mainly eco-feedback. Deeper LPs included 23 ideas from System Structure, emphasizing co-creation with stakeholders, and 12 from Intent, targeting attitude and paradigm shifts.

Table 1 exemplifies the types of results achieved during the ideation process. The table contains strategies for 4 Rebound mechanisms and a critical evaluation based on the parameters set in the methods section.

Figure 4 deepens the example illustrating the income mechanism by representing the design intervention in CLD format. The figure displays how an intervention (LP5) could limit consumption by adding a feedback loop in the system regulating consumption per user. The introduction of dynamic price creates a balancing loop (B3) that limits the strength of (R1) that results in the RE.

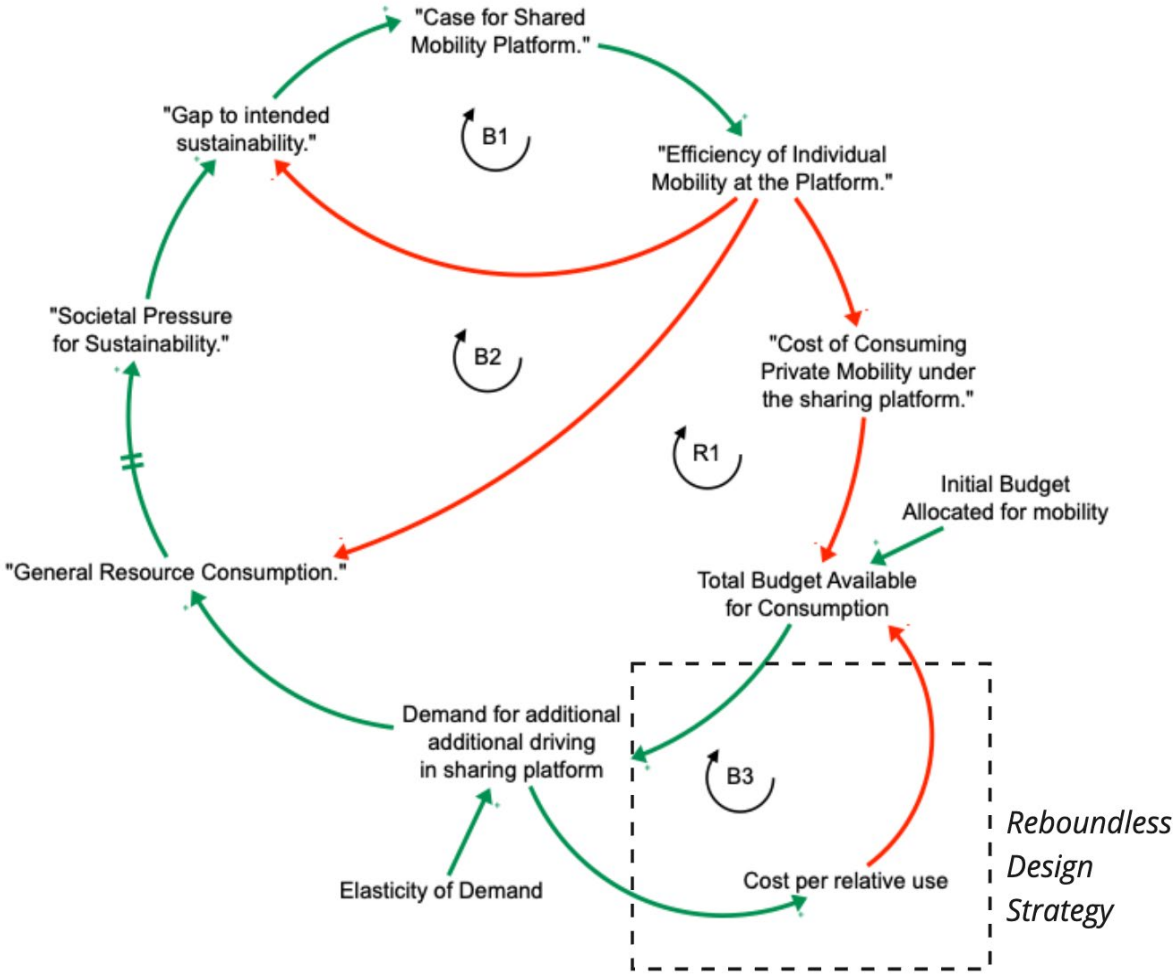


Figure 4. Income mechanism supplemented by an example of reboundless design strategy implementation (LP5) (Guzzo et al., 2024).

Step 4: Critical evaluation of design strategies

Several types of design strategies targeted at the product-, PSS-, and socio-technical system- levels were devised, providing multiple angles to engage with various leverage points. An example of a strategy was the inclusion of new information flows, e.g. estimating emissions for each trip before booking, as well as summaries of usage patterns.

The strategies were evaluated based on the three criteria earlier established (*Feasibility, Effectiveness and Designability*) and is illustrates in Table 1. The table illustrates a trade-off in design strategies: those targeting shallow leverage points, such as parameters and feedback, demonstrate high feasibility and designability due to their straightforward implementation and control within design parameters but exhibit lower effectiveness in addressing RE. Conversely, strategies aimed at deeper leverage points, such as system structures or intent, are more effective in mitigating systemic rebound effects but face challenges in feasibility and designability, requiring long-term, interdisciplinary collaboration and broader systemic changes. This highlights the balance needed between ease of implementation and impact.

The findings also suggest a relationship between the level of design intervention, the depth of leverage points addressed, and the designability between leverage points and design levels. Product-level strategies target shallower leverage points, like buffer sizes (e.g., limiting cars in transit-rich areas), while PSS and STS address deeper points, such as information flows (e.g., feedback before booking), linking intervention levels to leverage depth and designability.

Discussion

LP can guide designers to focus on control variables (aspects that can be manipulated), directing ideation toward interventions that shift the system in a desired direction towards target variables (the aspects we aim to change).

LPF offers a heuristic for identifying leverage points. The systematic analysis of their feasibility, effectiveness and designability helps determine the most points with most potential, nevertheless estimating the effects of the devised strategies to prevent RE proved complex (i.e., some identified strategies were prone to generate additional RE). Addressing this requires two key considerations:

I. Identifying the most impactful design strategies.

Strategies must be assessed for their potential to create meaningful change, which can be achieved through qualitative or quantitative model analysis. Qualitative methods, such as analyzing cause-and-effect relationships using CLDs allow designers to mentally estimate the outcome of design interventions in the system amid feedback loops. For example, the introduction of dynamic pricing would likely be more effective than a linear decrease on price as it weakens the feedback loop sustaining the income mechanism. Quantitative methods, including simulation-aided model analysis, offer deeper insights into determining the magnitude of potential RE (Metic 2024) and also on hidden leverage points and relative strength of feedback loops (Schoenberg et al., 2020). These approaches can support designers by unveiling counterintuitive system behavior, that may pose trade-offs between variables and REs – often arising from system complexity and dynamism.

II. Assessing the Scope and "Designability" of Strategies

Some strategies extended beyond design's immediate influence, requiring policy-level interventions, or raised questions about their "designability." Evaluating strategies across various levels clarifies where design influence is most actionable and where collaboration with policymakers may be necessary. For influencing rebound mechanisms, triggers and drivers were identified as the most actionable elements within a designer's scope.

Lastly, further integrating LP into design processes requires moving further from heuristics to better defined filtering and prioritizing criteria and processes. In that sense, there is space for clearer directions for the applicability of the LPF for RE prevention by attributing existing mitigation strategies to the different leverage point levels. Also, the feasibility, effectiveness and designability analysis can benefit from further reasoning guidance.

Despite the challenges, incorporating LP into the design process proved beneficial. It encouraged a more systemic approach to ideation, expanding the range of design opportunities beyond superficial and simplistic solutions. The diverse strategies highlighted the richness of ideas possible when using systems thinking.

Through an analysis of process reflections, a future process framework is proposed for more effectively integrating LP as an ideation tool in design to address rebound effects (Figure 5). The proposed process framework builds upon the five steps sustaining this research by integrating 3 extra steps: identification of most impactful LP through mental or formal simulation (steps 3 and 4), approaches to assessing and filtering design strategies (steps 6 and 7), and testing the effect of the selected strategies (step 8), indicated by the stippled lines.

Future Research

Rather than using the case study as a reference, future research could focus on mapping the rebound effects associated with the company's service and analyzing the creative process and key considerations that shaped its specific characteristics. Furthermore, the design strategies must be implemented and monitored over time to see whether they are really preventing or to what extent they are preventing the rebound effects from happening.

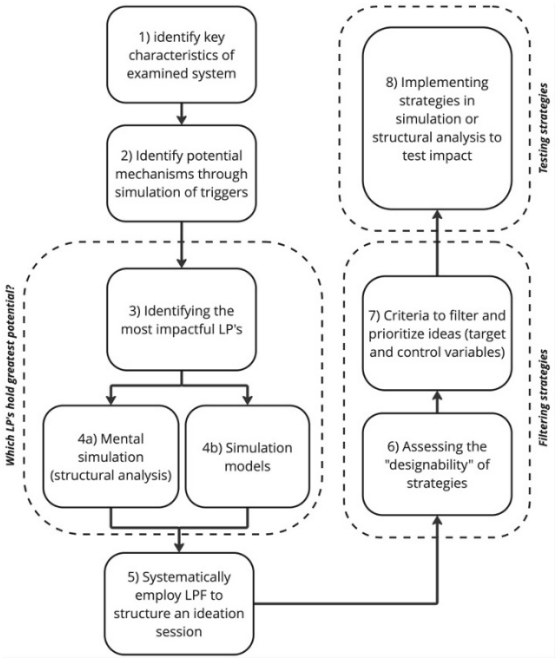


Figure 5: Proposed future process overview for the integration of the leverage points in design for the prevention of rebound effects

Final Remarks

Through an inductive case study of a car sharing system, this paper demonstrated the systematic use of LP (from parameters to deeper systemic paradigms) in design to expanding the range of design strategies for preventing RE beyond immediate and surface-level solutions. Therefore, our contribution to rebound effect prevention focuses on *ex-ante* measures—intervening during the design process, before products or systems are implemented in the market—to address potential rebound effects at their root.

While this approach generated a diverse and insightful set of ideas, the evaluation of their practical potential and "designability" remains an area for future research, as well as the evaluation of their potential to prevent rebound effects.

To support future research, a 10-step approach is proposed for the systematic integration of leverage points in the design process for the prevention of potential rebound effects.

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References

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C. D., Jager, N. W., & Lang, D. J. (2017). Leverage points for sustainability transformation. Ambio, 46(1), 30–39. https://doi.org/10.1007/s13280-016-0800-y

Ackermann, L., & Tunn, V. S. C. (2024). Careless product use in access-based services: A rebound effect and how to address it. Journal of Business Research, 177. https://doi.org/10.1016/j.jbusres.2024.114643

Andrew, E., & Pigosso, D. C. A. (2024). Multidisciplinary perspectives on rebound effects in sustainability: A

systematic review. Journal of Cleaner Production, 470, 143366. https://doi.org/10.1016/J.JCLEPRO.2024.143366

Azevedo, I. M. L. (2014). Consumer end-use energy efficiency and rebound effects. In Annual Review of Environment and Resources (Vol. 39, pp. 393–418). Annual Reviews Inc. https://doi.org/10.1146/annurev-environ-021913-153558

Castro, C. G., Trevisan, A. H., Pigosso, D. C. A., & Mascarenhas, J. (2022). The rebound effect of circular economy: Definitions, mechanisms and a research agenda. Journal of Cleaner Production, 345, 131136. https://doi.org/10.1016/J.JCLEPRO.2022.131136

Colmenares, G., Löschel, A., & Madlener, R. (2019). The rebound effect representation in climate and energy models. In Environmental Research Letters (Vol. 15, Issue 12). IOP Publishing Ltd. https://doi.org/10.1088/1748-9326/abc214

de Gooyert, V., Rouwette, E., van Kranenburg, H., Freeman, E., & van Breen, H. (2016). Sustainability transition dynamics: Towards overcoming policy resistance. Technological Forecasting and Social Change, 111, 135–145. https://doi.org/10.1016/J.TECHFORE.2016.06.019

Dori, D., Sillitto, H., Griego, R. M., McKinney, D., Arnold, E. P., Godfrey, P., Martin, J., Jackson, S., & Krob, D. (2020). System Definition, System Worldviews, and Systemness Characteristics. IEEE Systems Journal, 14(2), 1538–1548. https://doi.org/10.1109/JSYST.2019.2904116

Greening, L. A., Greene, D. L., & Di, C. (n.d.). Energy e$ciency and consumption * the rebound e!ect * a survey.

Guzzo, D., Walrave, B., & Pigosso, D. C. A. (2023). Unveiling the dynamic complexity of rebound effects in sustainability transitions: Towards a system's perspective. In Journal of Cleaner Production (Vol. 405). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2023.137003

Guzzo, D., Walrave, B., Videira, N., Oliveira, I. C., & Pigosso, D. C. A. (2024). Towards a systemic view on rebound effects: Modelling the feedback loops of rebound mechanisms. Ecological Economics, 217, 108050. https://doi.org/10.1016/J.ECOLECON.2023.108050

Hertwich, E. G. (2005). Consumption and the rebound effect: An industrial ecology perspective. Journal of Industrial Ecology, 9(1–2), 85–98. https://doi.org/10.1162/1088198054084635

Lange, S., Kern, F., Peuckert, J., & Santarius, T. (2021). The Jevons paradox unravelled: A multi-level typology of rebound effects and mechanisms. Energy Research & Social Science, 74, 101982. https://doi.org/10.1016/J.ERSS.2021.101982

Meadows, D. (1999). Leverage Points Places to Intervene in a System.

Metic, J., & Pigosso, D. C. A. (2022). Research avenues for uncovering the rebound effects of the circular economy: A systematic literature review. Journal of Cleaner Production, 368, 133133. https://doi.org/10.1016/J.JCLEPRO.2022.133133

Reimers, H., Jacksohn, A., Appenfeller, D., Lasarov, W., Hüttel, A., Rehdanz, K., Balderjahn, I., & Hoffmann, S. (2021). Indirect rebound effects on the consumer level: A state-of-the-art literature review. In Cleaner and Responsible Consumption (Vol. 3). Elsevier Ltd. https://doi.org/10.1016/j.clrc.2021.100032

Schoenberg, W., Davidsen, P., & Eberlein, R. (2020). Understanding model behavior using the Loops that Matter method. System Dynamics Review, 36(2), 158–190. https://doi.org/10.1002/sdr.1658

Scoones, I. , L. M. , S. A. , S. S. , S. A. and T. (2007). Dynamic Systems and the Challenge of Sustainability. www.wave.coop

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Nudging as a strategy to prevent behavioural rebound effects in the early phases of design

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Keywords: Nudging; Rebound effects; Design for sustainability; Sustainable behaviour.

Abstract: Despite the recognition that ca. 50% of the potential environmental gains of sustainability-oriented interventions are offset by rebound effects (RE), effective strategies that can prevent the occurrence of rebound effects are currently missing. To address this gap, this paper explores how nudging can be used to prevent RE during the early phases of design of products, product/service-systems and socio-technical systems. Through a Systematic Literature Review, 23 nudges that have the potential to promote sustainable behaviour were identified and subsequently classified into four categories: 'Decision information' (e.g. descriptive norms), 'Decision structure' (e.g. defaults), 'Decision assistance' (e.g. pre-commitment), and 'Miscellaneous' (e.g. priming). The identified nudges served as the foundation for the development of a novel design tool that can support the selection of nudges to prevent RE in the early phases of design, with indication of potential additional RE emerging from the implementation of the selected nudges. In addition to the development of the tool, this study mapped existing research gaps that can guide further research in the field.

Introduction

While design for sustainability is receiving more attention, the potential sustainability gains are not being achieved due to rebound effects (Otto et al, 2014). Rebound effects (RE) are systemic responses triggered by sustainability-oriented innovations (Guzzo et al, 2024) that offset ca. 50% of their potential environmental gains (Brockway et al, 2021). Up until now, research has mostly focused on examining the effect size of the rebound effects. Nevertheless, knowledge on how to prevent rebound effects is still limited.

As pointed out by Osbaldiston & Schott (2012) and DaSilva (2023) nudges can be an effective tool in enhancing and promoting pro-environmental behaviour. Nudges are simple yet low-cost interventions that can alter people's behaviours without applying a force of hand or significantly changing monetary incentives (Thaler & Sunstein, 2009).

Although nudging has demonstrated success in promoting sustainable behaviours, their application within the field of sustainable design to prevent rebound effects remains unexplored and a comprehensive overview is lacking. Therefore, this paper aims to address the following research question "How to support designers to select nudging strategies to prevent RE in the early phases of design?". Focus on the early phases of design is chosen as approximately 80% of a product's environmental profile is determined in this phase (McAloone & Bey, 2009). The research question is addressed by: (1) identifying and categorising nudges to be applied to sustainable design; (2) evaluating how the nudges relate to behavioural rebound mechanisms (i.e., preventing or increasing); and finally (3) creating a tool to support designers to prevent RE of products, product/service-systems and socio-technical systems.

Methodology

This paper applied the Design Research Methodology of Blessing & Chakrabarti (2009), especially suited for developing academic results applicable to design support (Blessing & Chakrabarti, 2009). The Design Research Methodology includes three main phases: (1) Descriptive Study I (DSI); (2) Prescriptive Study (PS); and (3) Descriptive Study II (DSII).

Descriptive Study I

A Systematic Literature Review (SLR) was conducted to examine how nudging can be used to increase sustainable behaviour. Using Scopus as the scientific database, the following search string was applied: TITLE("nudg*" OR "behavi* design" OR "cognitive psycholog*" OR "behavi* experiment" AND "sustain*" OR "environment*" OR "climate*" OR "circular*" OR "green*"). Studies that were published before 1999, are non-English, and refer to a different domain (e.g. chemistry, medicine, mathematics etc.) were excluded.

The search string provided 138 studies, which were filtered based on two steps (i.e., reading article title, keywords, abstract; and reading full text) while applying **three** inclusion criteria: (1) sustainability relevance; (2) relation to product/system; and (3) nudging and/or behavioural relevance. This resulted in the identification of 51 relevant studies (for full overview see: https://doi.org/10.11583/DTU.28513265.v1.

The 51 studies led to the identification of 174 nudges. After merging duplicate nudges, a final list of 23 nudges were categorised based on the choice architecture categories and techniques of Münscher et al (2016):

- Decision information: nudges that target decision-relevant information without altering options
- Decision structure: nudges that alter the arrangement of options and the decision-making format
- Decision assistance: nudges that provide decision assistance to achieve given intentions

A fourth category, Miscellaneous, was applied to nudges that did not fit into the existing categories.

Lastly, the nudges were categorised based on their effectiveness, amount of evidence and ease of implementation. The effectiveness was evaluated through primary evidence of whether a specific nudge was deemed effective (supported evidence), mixed effective (context specific or uncertain evidence) or ineffective (not supported evidence) (Formula 1). The evidence was calculated as shown in Formula 2. Finally, the ease of implementation of each nudge was estimated based on the expected 'number of stakeholders involved', the 'implementation time' and the 'implementation cost'.

$$\frac{no.of\ effective\ sources + \frac{no.of\ mixed\ effective}{2}}{no.of\ sources\ in\ total} \cdot 100 \qquad \text{(F1)}$$

$$\frac{no.of\ sources\ mentioning\ nudge}{no.of\ sources\ of\ most\ mentioned\ nudge} \cdot 100 \qquad \text{(F2)}$$

The actual percentage was calculated by weighing the nudges against each other; scoring each nudge either 1 or 0 against each other. The higher the score in total, the easier we assumed it is to implement the nudge.

The connection between the identified nudges and behavioural rebound mechanisms was synthesised by answering the underlying question; 'Can the nudge counteract a given behavioural rebound mechanism?' through an initial analysis by the authors and collective workshop. The analysis was carried out based on 15 behavioural rebound mechanisms (Pigosso & Van der Loo, 2024). After which, only the nudges assumed to be most effective in counteracting RE were selected for the final analysis, e.g. 'loss framing' nudges can counteract 'moral licensing' RE by motivating PEBs and preventing moral credit collection.

Prescriptive Study

The Prescriptive Study focused on synthesising the insights from the Descriptive Study I into a design tool for the selection of relevant nudges to prevent RE.

The tool development started with desk research of existing tools and defining a requirement specification. The requirements acted as a base to move into idea generation, where silent brainstorms led to the creation of seven distinct ideas. Ranking these on feasibility vs. fidelity in a matrix, four were deemed promising. Creating a better basis for choosing, the four ideas were conceptualised and evaluated with pros and cons. Considering the requirements, a Pugh matrix was used to weigh the concepts. Once a concept was chosen, detailing begun. The tool was prototyped and finalised in Excel.

Descriptive Study II
The final phase of the study covered an evaluation of the tool. To enable specific feedback from different perspectives, the evaluation involved four researchers in the field of RE, and two design engineer students with no prior knowledge of RE. Feedback was collected with the aid of two tests to evaluate: (1) general usability of the tool; and (2) the usefulness of the tool. In the first test, the users were asked to use the tool to identify relevant nudges, after a product/service-system within clothing and the related RE's were provided. The second test additionally examined the user's ability to select relevant RE before choosing the nudges appropriately for the same design case. After both tests, a survey to evaluate usability and usefulness was administered. The results of the evaluations were used to iterate on the functionality and content of the tool.

Results

Descriptive Study I – Data analysis and synthesis

Strengths and gaps in literature
The systematic literature review provided an overview of the tendencies in research on nudging and sustainability, along with the strengths and gaps. The majority of research on nudging consisted of articles with experimental studies based on quantitative data (Figure 1). This provides a good foundation of evidence from primary sources, although doubts could arise whether the conclusions are generalisable due to the typical isolated nature of experiments.

The selected studies were also evaluated based on the addressed context (Figure 2). Existing research mostly covered the 'Food' sector on a product level (i.e., 17%). The most addressed sustainability type was 'efficiency', which means that there exists a gap in research on 'sufficiency' and 'effectiveness' that still remains relatively untouched. The total number of sources represented in this model covered 45 of the 64 reviewed in the SLR, as the other 19 sources did not examine specific design process or research strategies, indicating a gap.

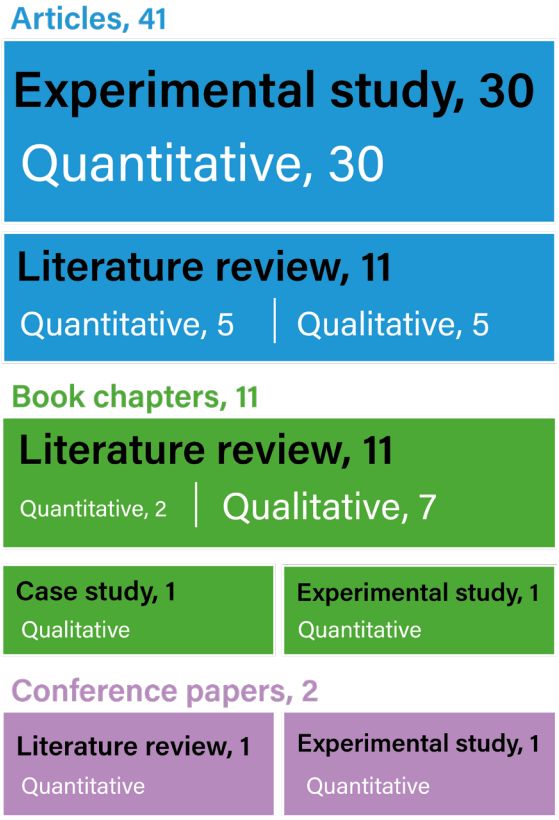


Figure 1. Document type, main research methodology, and quantitative vs. qualitative methods.

Nudging strategies
Figure number 3 illustrates the consolidated 23 specific within four main categories: 'Decision information', 'Decision structure', 'Decision assistance' and 'Miscellaneous'.

The figure clearly indicates that 'social comparison' (especially 'descriptive norms'), 'labelling', 'defaults', and 'pre-commitment' appear to be well researched and tested, whereas other nudges like 'active choice', 'self-nudge', 'single-event nudge', and 'personalised nudge' are mentioned only once and would require additional research to test and validate their effectiveness properly. All nudges alongside a description and an example are summarised in Table 1.

The output of the comparison of the nudges can be seen in Figure number 4.



Figure 2. Distribution of sectors on design level and type of sustainability.

Nudging with ‘defaults’ is the most researched in literature. 'salience' and 'graphics' are the easiest to implement, while feedback-based nudges are very difficult to implement. 'sescriptive norm comparison' and 'option-related effort' are assumed to be highly effective, and nudges such as ‘active choice and ‘single-event’ less so. Overall, ‘static descriptive norm comparison’, ‘defaults’, and ‘salience’ are assumed to be strong on all parameters, while ‘self-nudge’ and ‘personalised nudge’ are weak.

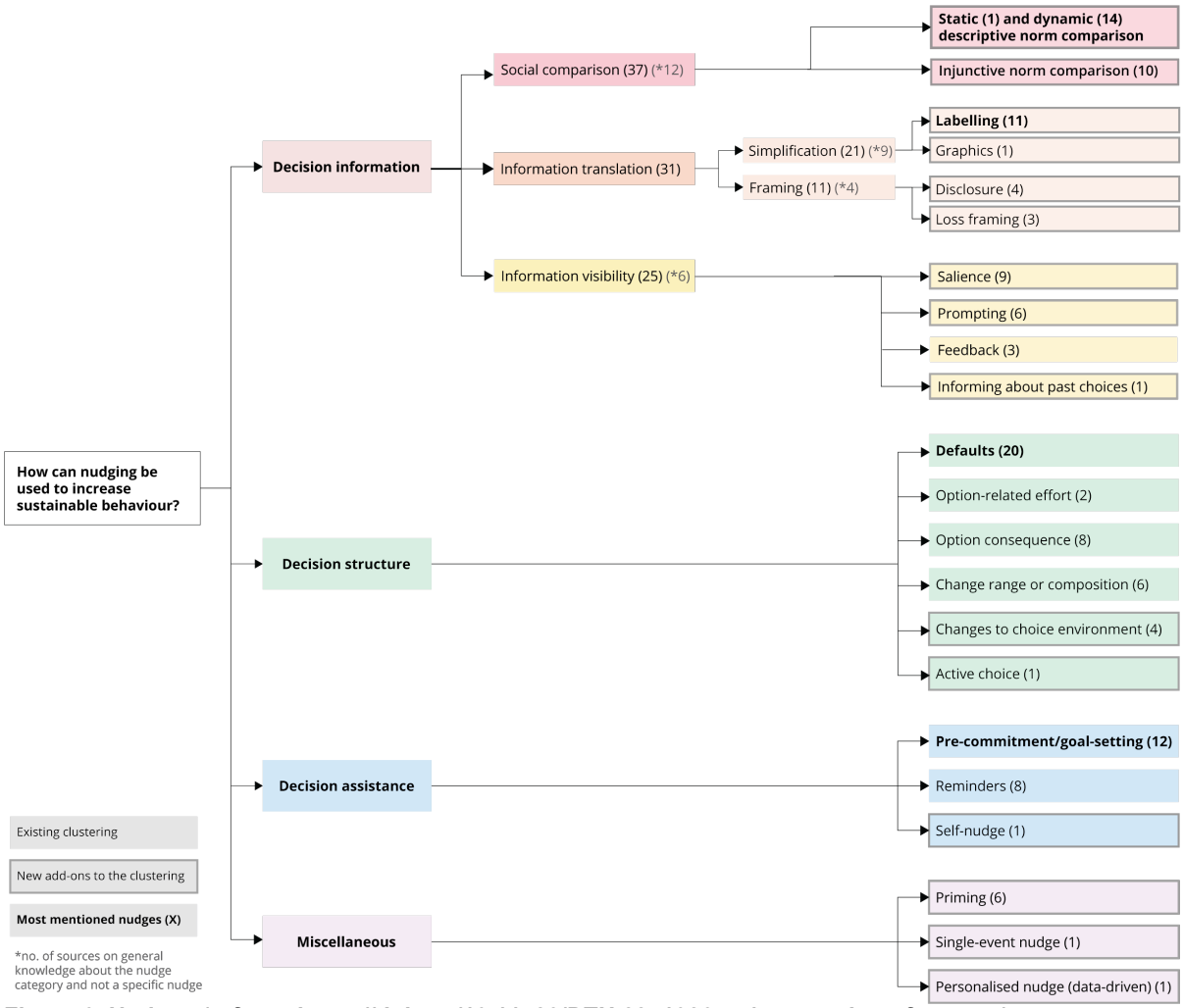


Figure 3. Nudges (refer to https://doi.org/10.11583/DTU.28513265.v1 to see the references)

Nudge strategy	Description of nudge strategy	Example
Decision information		
Social comparison Comparison with social norms, which are rules and standards that are understood by members of a group, can guide/constrain behaviour without the force of law due to humans wish to "do what others are doing".		
Static descriptive norm comparison	Information of "what is done"	Displaying "60% of the customers today chose green food options"
Dynamic descriptive norm comparison	Information about an increasingly changing norm over time	Displaying "More and more people are choosing green food options"
Injunctive norm comparison	Information of "what should be done" nudges the user based on ones morale	Displaying “Take responsibility; we should all contribute to saving the environment together”

Information translation: Simplification Simplifying information by "making it easy" and removing barriers increases the acceptance of procedures by users.		
Labelling	A simple and easy-to-understand way of showing environmental information	Marking the food products with the fairtrade label
Graphics	Graphics, symbols, or a notice of warning simply convey information to users	Using icons to show good/bad products, simplifying environmental information
Information translation: Framing By presenting the same information in different ways/frames, people tend to decide differently.		
Disclosure	Framing information based on disclosure and transparency to convey "the truth"	Disclosing the actual environmental footprint of food on the packaging
Loss framing	People prefer to avoid losses - therefore, framing info as losses can motivate users to certain choices	Comments to your online shopping basket: “This product increases your footprint by 10%”
Information visibility Nudges that make users notice something important by putting visual emphasis on it, which in turn can nudge the user to taking certain choices.		
Salience	Making information stand out with contrast, colours, sizing, and nature pictures	Highlighting sustainable options by increasing their size in an online the store
Prompting	Subtle and noncoercive guidance messages pushed to the user	When adding products in your basket, prompt: “Switch to a more sustainable option?”
Feedback	Receiving feedback can support and nudge users to reflect on their actions	Every month, the user receives information about their energy consumption this month
Information about past choices	Making past choices visible to the user can increase accountability	At check-out, show: “Previous basket CO2 footprint 10.1 kg – now 17.6 kg!”
Decision structure		
Defaults	Setting the preferred choice as a pre-selected default can influence the end choice if the user takes the path of least resistance	Setting most sustainable option in a product-configurator as the default
Option-related effort	Making small changes in the effort required to select an option	Placing sustainable options on the same online shopping tab, reducing effort of locating them
Change range or composition	Changing the placement of an option and the alternatives presented can alter relative attractiveness	Setting the most sustainable options in a product-configurator as the first ones
Option consequence	Changes in external financial or social consequences can nudge users to take certain choices	Rewarding customers with green badges or financial incentives for choosing green food options

Changes to choice environment	Physical changes to choice environment (e.g., simplifying information, removing frictions) can influence decisions	Placing sustainable products in the supermarket on the shelf at eyesight
Active choice	When consumers have to make an explicit choice (i.e., no default is impolemented), users can reflect more and take conscious choices	Having no default option in a product-configurator before the user actively chooses
Decision assistance		
Pre-commitment (goal-setting)	Facilitate goal-setting as people are more likely to behave in line with their goals if they committed beforehand.	Allowing users to commit to keeping their CO2 footprint below a threshold
Reminders	Timely and repeated reminders work as a nudge to make individuals conscious of what they are supposed to accomplish	Reminder at 7.30 each work day: “turn off light before leaving”
Self-nudge	Self-nudging aims to explain why users might fail to reach their goals and provide info and mechanisms of how to overcome these barriers - mixing feedback and framing	Providing free reusable coffee cups reducing single-use cups and reminders to keep using them
Miscellaneous		
Priming	Preparing people for their choice by simulating feelings and thoughts through introducing specific topics, moods, or the consequences of their decision before it takes place	Posters on the way to a canteen about consequences of eating meat
Single-event nudge	One-time activity that changes the specific behaviour for good	An annual bike-to-work event, where participants are nudged to continue biking afterwards
Personalised nudge (data-driven)	Personalised intervention mechanisms based on previously collected data that informs and nudges the user to take certain choices	Providing citizens with a personalised map of the most sustainable route home

Table 1. Nudges (refer to https://doi.org/10.11583/DTU.28513265.v1 to see the references).

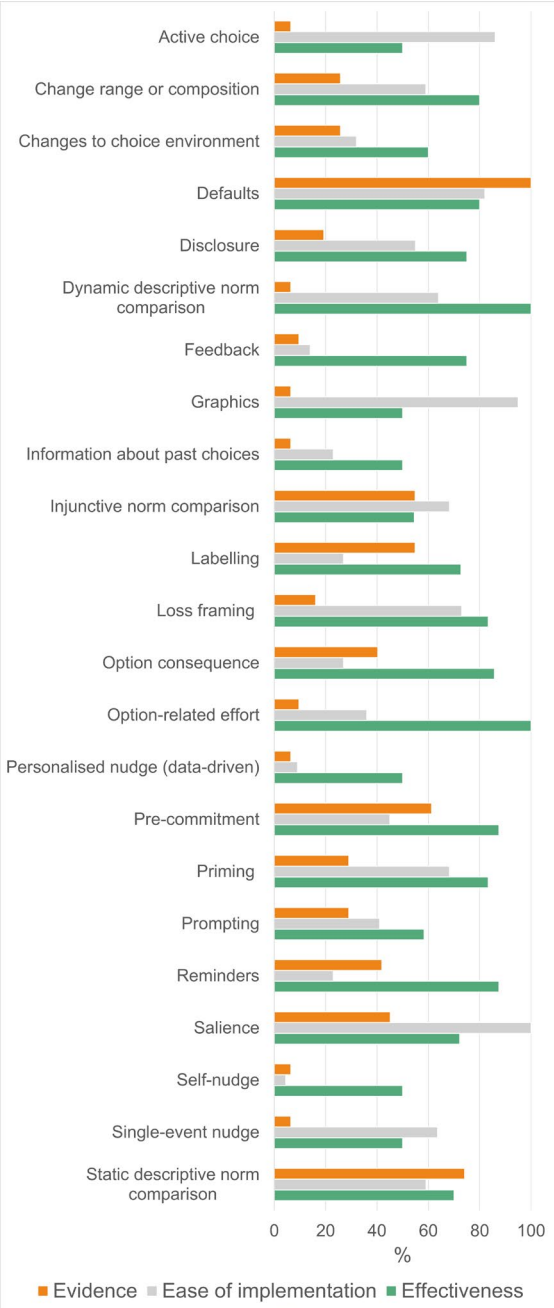


Figure 4. Evidence, ease of implementation, and effectiveness of nudges.

Nudging strategies and their relation to rebound effects

The relation is divided between nudges that are assumed to be most effective in preventing RE and nudges that could potentially lead to more RE (Figure 5). This relation creates the basis for the tool. The RE categories 'Moral licensing' and 'Motivational crowding' seem to be most sensitive to nudging and their risk of leading to more RE. Further, it is evident that the nudge category 'Decision information' is assumed to be most effective in preventing RE. However, they are also the ones that could lead to more RE (especially the descriptive norm comparisons).

Prescriptive Study

The tool was developed to guide designers in the selection of appropriate nudges for tackling specific RE in the early phases of design. The tool consists of five key steps structured around eight Excel tabs (Figure 6). The tool can be accessed on the following link: https://doi.org/10.11583/DTU.28513289.v1

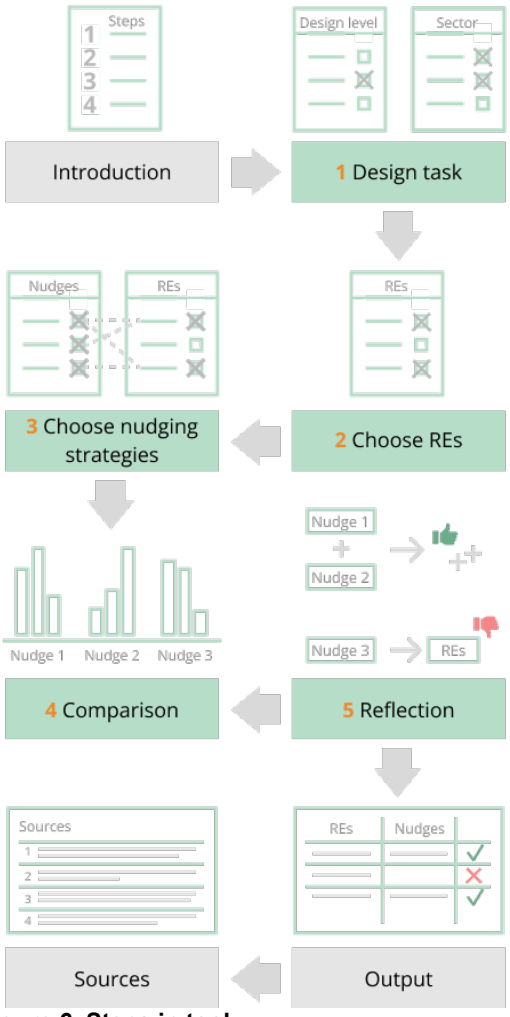


Figure 6. Steps in tool.

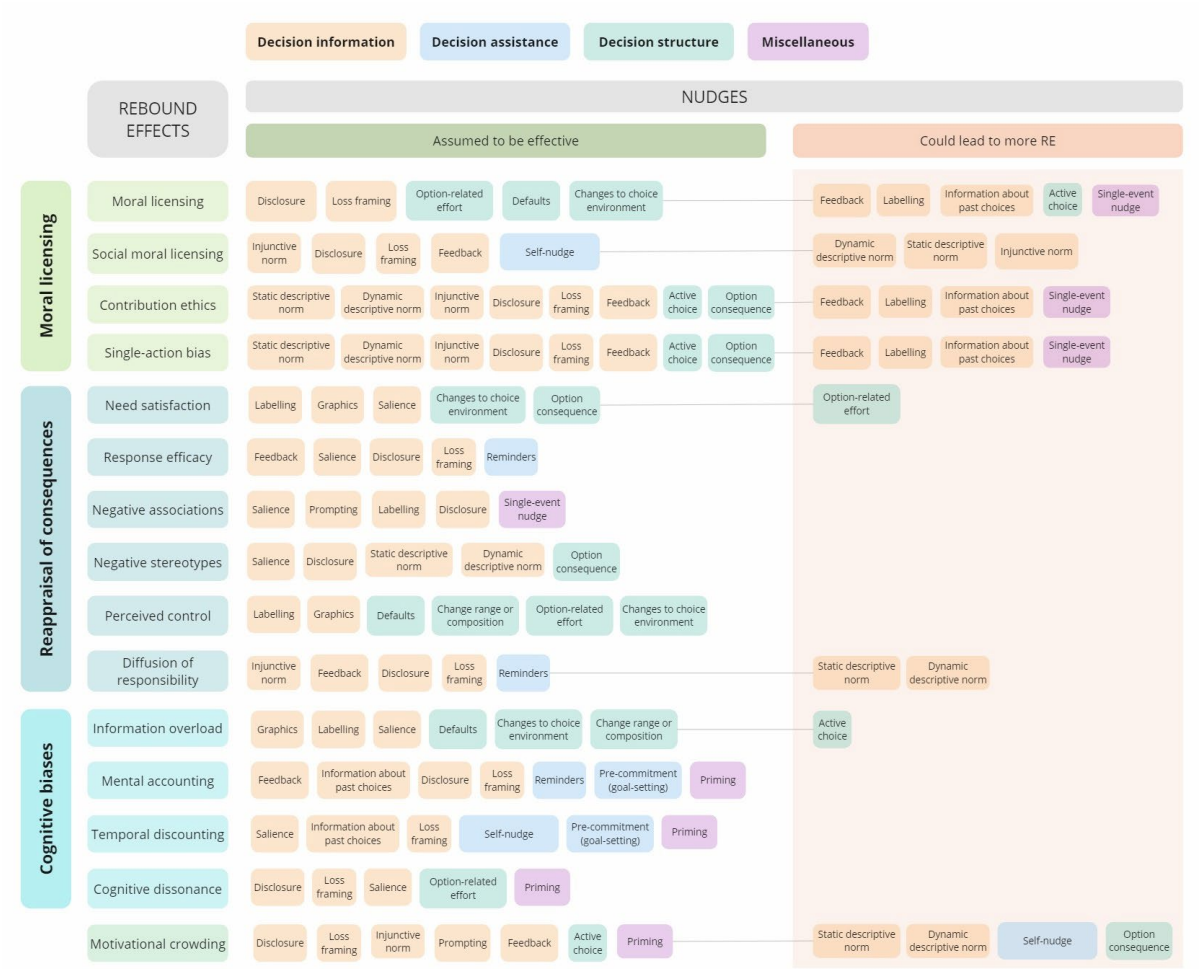


Figure 5. Relation between nudges and RE.

Descriptive Study II

The initial evaluation of the tool demonstrated a high usefulness and good potential for its use (Figure 7); "*It was nice to see that the nudges can be applied to more than one RE. This might also facilitate the design process*". To address the usability constraints faced by Excel, shifting to another platform or making the tool more automated might improve this in the future. Furthermore, it is important to note that the term 'rebound effects' remains difficult for non-experts to understand, as said by one of the design engineers "*there was a lot of terminology, which an unexperienced designer in this field might find confusing*".

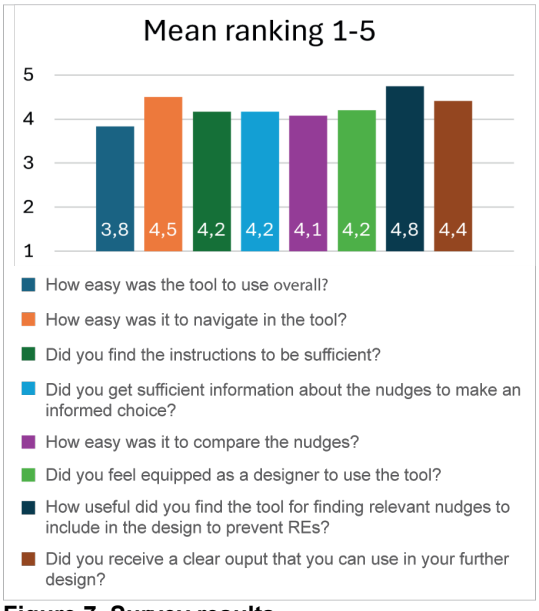


Figure 7. Survey results

Discussion and future research

The results suggest that nudges within the category 'Decision information' have the biggest potential for preventing RE. However, they are also the ones that could lead to more RE. Designers should be aware of this potential dual effect when choosing nudges.

Furthermore, the lack of knowledge on how to use nudging in the design processes for products, PSS, and socio-technical systems is identified as an important gap. Research on rebound effects should further examine the link between 'design process' and nudging. This would also strengthen the usefulness of the presented tool as it could link nudging to specific design processes, especially looking at the early phases of design.

Reflecting on the underlying information of the effectiveness and ease of implementation of the nudges, it is important to note that deviations are expected depending on how the nudge is implemented, in what context, towards what target and by whom. This raises the question whether the effectiveness of nudging is greater than using monetary incentives or mandates. Future research could investigate comparing these different approaches to behaviour change.

Additionally, there remains great controversy on whether nudging is ethical in terms of changing behaviour (Siipi & Koi, 2022). Suggested by Schubert (2017), this risk could be addressed with basic transparency - which holds an opportunity to become a key component to implementing nudging in future research.

Finally, the categorisation of RE as well as their relation to nudges could be elaborated upon in future research, potentially expanding to rebound mechanisms within the field of economics. To evaluate the relations presented in this paper, an important next step is to test these connections and provide more insight into RE and nudging, as well as nudges leading to RE.

Conclusions

This study provides an overview of 23 nudges that could be used to counteract the behavioural rebound mechanisms to prevent RE. This relation is synthesised in a tool for designers to use in the early phases of design, thereby answering the research question: How to support designers to select nudging strategies to prevent RE in the early phases of design?'.

The identified nudges cover 'Decision information', 'Decision structure' and 'Decision assistance', and 'Miscellaneous'. Based on feedback sessions with various experts and designers using the tool, there is a clear indication that nudging can be an effective and easy implementable strategy to tackle RE.

Another key output is the design tool which shows great potential in aiding designers to prevent RE by suggesting nudges in the early phases of design. This tool adds value by being one of the first RE prevention tools with directly applicable strategies for products, product-service systems and socio-technical systems. In summary, this study aims to inspire as well as support researchers and designers reaching the full potential of sustainable design by preventing RE

Acknowledgments

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References

Blessing, L. T. M. & Chakrabarti, A. (2009), DRM, a Design Research Methodology. Springer London. https://doi.org/10.1007/978-1-84882-587-1

Brockway, P.E., Sorrell, S., Semieniuk, G., Heun, M. K. & Court, V. (2021). Energy efficiency and economy-wide rebound effects: A review of the evidence and its implications. In Renewable and Sustainable Energy Reviews (Vol. 141). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.110781

DaSilva, B., Dhar, J., Rafiq, S., & Young, D. (2023). Nudging consumers toward sustainability. In Sustainable Business Model Innovation.

https://doi.org/10.1515/9783111295268-015

Guzzo, D., Walrave, B., Videira, N., Oliveira, I. C., & *Pigosso, D. C. A. (2024).* Towards a systemic view on rebound effects: Modelling the feedback loops of rebound mechanisms. *Ecological Economics,* 217. https://doi.org/10.1016/j.ecolecon.2023.108050

McAloone, T. C., & Bey, N. (2009). Environmental improvement through product development: A guide. Danish Environmental Protection Agency. http://www.kp.mek.dtu.dk/English/Research/areas/ecodesign/guide.aspx

Münscher, R., Vetter, M., & Scheuerle, T. (2016). A Review and Taxonomy of Choice Architecture Techniques. Journal of Behavioral Decision Making, 29(5), 511–524. https://doi.org/10.1002/bdm.1897

Osbaldiston, R., & Schott, J. P. (2012). Environmental sustainability and behavioral science: Meta-analysis of proenvironmental behavior experiments. Environment and Behavior, 44(2), 257–299. https://doi.org/10.1177/0013916511402673

Otto, S., Kaiser, F. G., & Arnold, O. (2014). The critical challenge of climate change for psychology: Preventing rebound and promoting more individual irrationality. European Psychologist, 19(2), 96–106. https://doi.org/10.1027/1016-9040/a000182

Pigosso, D. C. A & Van der Loo, I. (2024).Explaining the rebound effects of sustainabledesign: a behavioural perspective, InternationalDesign Conference – Design 2024. https://doi.org/10.1017/pds.2024.152

Schubert, C. (2017). Green nudges: Do they work? Are they ethical? Ecological Economics, 132, 329–342. https://doi.org/10.1016/j.ecolecon.2016.11.009

Siipi, H., & Koi, P. (2022). The Ethics of Climate Nudges: Central Issues for Applying Choice Architecture Interventions to Climate Policy. European Journal of Risk Regulation, 13(2), 218–235. https://doi.org/10.1017/err.2021.49

Thaler, R. H. & Sunstein C. R. (2009). Nudge: Siipi, Improving Decisions About Health, Wealth, and Happiness. Penguin Books. ISBN-13. 978-0143115267.

Research paper
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No Product is an Island: The Case of Incontinence Pads in a Nursing Home

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Keywords: Relationality; Incontinence pads; Care; Durability; Practices

Abstract: This paper critically examines product durability through an ethnographic study of incontinence pad usage in a Danish municipal nursing home. By focusing on incontinence pads—which are referred to as "diapers" in this setting—we demonstrate that their durability cannot be understood in isolation from their surrounding environment. Instead, diapers attract auxiliary products, which, when integrated into the care practices of the nursing home, take part in enacting the diapers' durability in distinct ways. We conceptualize these enactments as either supporting or challenging the durability of the diapers. Combining this ethnographic work with design theorist Arturo Escobar's interweaving of ontological relationality and design theory, we argue that durability should not be viewed as an inherent property of an object or as determined solely by its human users. Instead, we propose understanding durability as a relational effect that emerges from situated sociomaterial practices. This analytical move challenges modernist assumptions that separate subjects from objects and offers a more nuanced framework for analyzing product durability. Future research on product durability would benefit from adopting this relational approach, as it opens—we hope to show—new ways of thinking and designing with sociomaterial practices and for product durability.

Introduction

Globally, the geriatric population is growing. As a result, the market for single-use disposable incontinence products is also growing. This paper focuses on one of these products—adult incontinence pads. Such incontinence pads are considered medical devices, so they must be European Conformity marked (CE-marked) in the European Union (EU). Producers of incontinence pads must ensure and prove their product's durability. For instance, incontinence pads are evaluated in laboratory settings to verify that they maintain functionality over extended use and that their material strength endures with prolonged or heavy loads. In a laboratory setting, then, incontinence pads support the most dominant definition of product durability, that is, "product characteristics, such as sturdiness, quality of materials and technical solutions," which consequently embodies "a more technical perspective on product longevity" (Jensen et al., 2021, p. 2; see also Cooper, 2010).

For the moment, we bracket this laboratory setting because it does not support our aim of developing a critical perspective on product durability. Instead, we focus on a municipal Danish nursing home. However, this choice should not be understood as us choosing social over technical determinism. We do not intend to simply shift "the focus of [the] investigation of durability from the object (with or without its qualities of enchantment and attachment) to the behaviors, habits, and material expression of the person using it" (Fletcher, 2012, p. 230).

At a nursing home, people and things as well as affective forces and sensory experiences work together to enact care. Agency is distributed, meaning that "agency is not an a priori given feature of an actor but is the outcome of interactions between the heterogeneous actors in the network" (Oudshoorn et al., 2005, p. 86; see also Latour, 2005). Our setting, a Danish nursing home, thus allowed us to explore the durability of incontinence pads as an outcome of how people and things, sensory experiences, emotions, and affective forces connect and disconnect in situated day-to-day practices. It also allowed us to follow design theorist Arturo Escobar's request to "put one foot in a relational

world (or worlds)" (Escobar, 2018, p. 165). We asked "how does the durability of incontinence pads come into being at a nursing home?" We also asked, "how might an answer to that question aid us in developing a critical view of product durability?"

Methodology: Exploring care and durability at a nursing home

One of this paper's authors, Ankerstjerne, currently conducts design ethnographic fieldwork (Müller, 2021) at a municipal nursing home in a mid-sized Danish city. She follows and contributes to the work of the nursing home's caregivers during the day, evening, and night shifts. The fieldworker is interested in how care practices unfold at this nursing home by focusing on the use of incontinence pads (Nicolini, 2009). The reason for this focus is that incontinence pads have significant climate-related and environmental impacts. And, as mentioned, with a globally aging population, the production and use of incontinence pads are expected to grow significantly. Therefore, the questions naturally arise whether it would be possible to use different, less resource-intensive pads, whether it would be possible to use fewer pads, and how these solutions could be implemented without compromising but rather developing existing care practices in caring ways. In terms of incontinence pads, specifically, how might matters of care be harmonized with climate-related and environmental matters?

Our fieldworker conducted her empirical investigations in the context of work on care undertaken in the field of science and technology studies (STS). One point we took from this body of work and seek to bring into dialogue with discussions of product lifetimes and the environment is that technologies and products participate in enacting care. That is, care is not given from one human to another, nor is it purely human. As this body of work suggests, care is enacted in situated sociomaterial practices (see, for instance, Pols, 2023; Puig de la Bellacasa, 2017; Mol, 2002, 2008; Mol et al., 2010). In this vein, Annemarie Mol and colleagues, all key contributors to the field, wrote, "Technologies . . . do not work or fail in and of themselves. Rather, they depend on care work. On people willing to adapt their tools to a specific situation while adapting the situation to the tools, on and on, endlessly tinkering" (Mol et al., 2010, p. 14–15). For our fieldworker, this meant methodologically eliciting and listening to the stories of the residents, caregivers, and nursing home managers about how "living with" an incontinent body "is done in practice" (Mol, 2002, p. 15). It was about listening to—and sensing in all other possible ways—these stories "in a realist mode" (Mol, 2002, p. 15). Instead of "acting on" (Pickering, 2022) a specific health condition, in this case, incontinence—which has been the focus of health and medical sciences since the modern breakthrough and has led to a vast and often unsustainable range of care products, medications, documentation, artifacts, and technologies—understanding care practices in a realist mode allows us to develop ways of "acting with" (Pickering, 2022) existing care practices in our collaborative attempts at "sustainabilizing" them through "care-ful research" (Law & Lin, 2020).

Diapers as attractors of challengers and supporters

As of the time of this writing, our fieldworker had observed and contributed to care work at the nursing home for 160 hours. Building on our understanding of care as enacted through "webby" (Law & Lin 2020, p. 1) and materially, discursively, and socially heterogeneous relations, our fieldworker explored how the "diapers"—the word used for incontinence pads at the nursing home—became connected to and disconnected from a range of other entities in the course of the unfolding of care practices. In the following sections, we offer accounts of how this happens. We show how diapers in the nursing home setting attract the use of other products and equipment and how these other items both challenge and support the diapers' durability.

Diapers as attractors

During an evening shift, our fieldworker observed and assisted a caregiver in preparing a resident, whom we will call "Mrs. X," for bed. For Mrs. X, as for many of her fellow residents, wearing a diaper goes along with using a commode chair and with using a wheelchair to get around. In preparing Mrs. X for bed, the caregiver first utilized a lift to move Mrs. X from her wheelchair to the commode chair. When on the commode chair, the caregiver placed a blanket over Mrs. X's lower body to keep Mrs. X warm and to protect her modesty. The caregiver also drew the window curtains. Our fieldworker observed that the caregiver always did this when conducting intimate care tasks.

The caregiver asked our fieldworker if she could stay with Mrs. X while she was placed on the commode chair so that the caregiver could attend to other matters. “Yes,” our fieldworker answered. Before leaving Mrs. X’s apartment, the caregiver turned on the television. “Mrs. X likes to watch the news while on the toilet,” the caregiver explained. Mrs. X started touching and fiddling with the blanket covering her as the caregiver left the room. Our fieldworker rearranged the blanket three or four times. Our fieldworker then decided to hand Mrs. X the straps that are part of the mechanical lift to give Mrs. X something for her hands to play with, after which Mrs. X left the blanket in place.

The caregiver returned 20 minutes later. She used the lift to release Mrs. X from the commode chair and enable her to clean Mrs. X with disposable wipes and a washcloth. Next, the caregiver placed an incontinence pad on the bed. Then, assisted by the caregiver, Mrs. X put on her nightgown, and the caregiver transferred her into bed using the mechanical lift. The caregiver applied a body lotion to Mrs. X’s legs.

The caregiver removed the plastic bag from the commode chair and emptied its limited contents into the toilet. That plastic bag—and the remaining waste—was put into another plastic bag in a wastebasket. The caregiver took this plastic bag with her as she left Mrs. X’s apartment and put it in a garbage can in the nursing home's common area.

At the nursing home, and, more specifically, in Mrs. X’s apartment, the durability of the incontinence pads she uses cannot meaningfully exclusively be attributed to the incontinence pads. Many other products are attracted and enrolled to support the functioning and durability of the incontinence pads used in Mrs. X’s day-to-day care: a lift, a wheelchair, a commode chair, blankets, curtains, a television, lift straps, disposable wipes, washcloths, and latex gloves. This combination of supportive items suggests that when developing a critical perspective on product durability, we should be skeptical of approaches that urge us to isolate the product under exploration.

Attracting challengers

All caregivers at the nursing home carry a mobile phone. The caregivers receive calls from residents and colleagues who need everything from urgent help to assistance with simple tasks. During day and night shifts, the caregivers’ phones do not ring that often. During day shifts, more caregivers are on call. And, during the night shifts, the nursing home calms down. However, during evening shifts, when fewer caregivers are on duty, the caregivers’ phones do ring quite often.

Several caregivers talked to our fieldworker about their phones and their ringing. The caregiver who looked after Mrs. X explained that “it’s damn annoying” if her phone rings during intimate care, such as the changing of a diaper, as she must take off her latex gloves to answer the phone. In this setting, phones and latex gloves do not collaborate. Phones dominate latex gloves and affect the sensitive and intimate practice of changing a diaper.

A second caregiver told our fieldworker that the nursing home will be getting new phones for the caregivers. On these new phones, the caregivers can choose their ringtone. The ringtone of the current phones is very stress inducing. “It almost sounds like a machine at McDonald's,” the caregiver explained. Some residents react negatively to the ringtone by accidentally kicking at the caregiver during a diaper change. This reaction is especially common for residents with dementia or other cognitive difficulties. The caregiver described a workaround she had developed. To keep residents’ hands busy and minds occupied during diaper changes, she gives sensory items to them to—hopefully—prevent the residents from kicking her—inadvertently or not. A third caregiver described another workaround. She leaves her phone in the hallway during intimate care tasks to avoid making the residents anxious. Anxiety disturbs their sleep and can impact their well-being during the night and into the next day.

For the diapers to perform up to their expected durability as tested and evaluated in a laboratory setting, they must be placed correctly. A ringing phone and a leg that kicks out as a response make this correct placement difficult. Furthermore, the resident wearing the diaper needs to leave it in place. Anxious and cognitively impaired residents might fiddle with a diaper or even tear the diaper apart.

Diapers and diapering practices are associated with other products as well as challenges from other locations—such as a need in another part of the nursing home being made present in a resident’s room through a phone call. These products and practices are also associated with time-related challenges, such as concerns about how a lack of sleep will impact the residents’ well-being the next day. Therefore, at a nursing home, product durability

is a precarious achievement. An achievement that hinges upon the coordination of multiple things and temporalities. Approaches for engaging critically with product durability should enable us to understand this coordination of things and temporalities.

Attracting supporters

One night, our fieldworker learned that at this specific nursing home, the caregivers wear pajamas at night. "Why?" she asked one of the healthcare assistants on duty. The healthcare assistant told her that the staff wearing pajamas visually lets the residents know it's nighttime and, therefore, time to sleep.

The healthcare assistant described a specific resident, Mrs. Y, who often wandered the halls at night. Along with many other residents, Mrs. Y has dementia. She had typically been quite difficult for the healthcare assistant to manage and collaborate with. For instance, Mrs. Y refused to allow the healthcare assistant to guide her back into her apartment by using touch. It is difficult to enact care when touch is excluded.

One night, Mrs. Y—as usual—was walking the hallways. However, when Mrs. Y saw the pajama-wearing healthcare assistant, she said: "Did I wake you up? I'm so sorry! I'll go back to bed now." Moreover, with the pajamas enrolled in the nightly care practices, Mrs. Y allowed the healthcare assistant to touch and guide her.

Our point again is that, at a nursing home, product durability is a precious achievement. Further, product durability can be achieved through creative and "artful integrations" (Suchman 2002, p. 99) of supporting products, such as integrating pajamas into the caregivers' work at night. Yet another way of developing a critical view of product durability would be to look for such artful integrations, understand how they support product durability, and understand how they may be harnessed to advance less resource-intensive ways of caring and living.

Product durability in relational worlds

Recently, several scholars within the social sciences, humanities, and design research fields have begun to conceptualize the sustainable transitioning of our societies as an ontological issue (see, for instance, Escobar et al., 2024; Tonkinwise, 2023; Mol, 2021). Escobar, Osterweil, and Sharma, for instance, suggested that finding answers to today's societal challenges—sustainable transitioning being one of them—is not only about epistemology, that is, "how we know" (Escobar et al., 2024, p. 35), but also "what we think about reality, about the contemporary modes of being human, about the relation between being, knowing, and doing" (p. 36), that is, ontological issues. Escobar, Osterweil, and Sharma further suggested that at the root of current climate and environmental crises lies the ontological assumption of "the radical separateness of objects and subjects, of selves from the environment" (p. 36). The authors urged, instead, that we start thinking relationally to understand "the radical interdependence of all things" much better (p. 36).

Linking the points from Escobar and colleagues to the dominant understanding of product durability, we see that this understanding of product durability is a term of separateness. That is, it forcefully delegates the question of durability to the product itself, thereby rendering its answer a technical one, or to the people using the product, thereby rendering its answer a social one. One way of developing a critical perspective of product durability would, thus, be to attempt to loosen its tight connections to modernity's ontological commitment to objects and subjects as separate.

In an attempt to put some empirical flesh on this otherwise rather esoteric argument about radical interdependence, we visited a nursing home to focus on the use of diapers in such a setting. Diapers are never isolated in a nursing home. Aging legs inadvertently kick, phones ring and ring and ring, and pajamas can calm down a restless resident. Durability in care is for people and things akin to withstand or absorb, deal with, move on from, or move with such challenges. That is, at a nursing home, durability in care as a day-to-day sociomaterial practice is the concern, not product durability.

What do these realities imply for our understanding of the notion of product durability? The nursing home and the care practices that unfolded there urged us to leave behind any ideas of standalone products and to ask a different question: what if we understood product durability as performed through product ecologies? Further, in care practices, the temporal durability of a diaper is somewhat unruly. This is not because the diaper is poorly designed but because other products—the pajamas or phones, for instance—perform

other temporalities and intervene in the diaper's temporality.

We hope to have demonstrated that future work on the notion of product durability can fruitfully begin to tackle the thorny question of how the material and the temporal relate and what kinds of effects their interrelations have.

Conclusions

In this paper, we sought to develop a critical perspective on product durability by visiting a nursing home to focus on understanding the use of incontinence pads in this setting. Second, we related our findings to the work on relationality by Escobar and colleagues (2024). We showed that the durability of incontinence pads is a precarious achievement in the nursing home setting. This is due to the incontinence pads never being separate and isolated but rather, in day-to-day care practices, incontinence pads attract and are associated with many other products and items that can act as challengers and supporters of the incontinence pads' durability.

These insights, however, align poorly with the dominant definition of product durability as either being inherent to the product or in people's use of said product. This misalignment led us to suggest a shift from product durability to durabilities and transformations in sociomaterial practices as a new research strand within the field. Such a shift also implies developing a better understanding of how the material and the temporal relate in caregiving contexts.

Acknowledgments

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References

Cooper, T. (Ed.). (2010). *Longer lasting products: Alternatives to the throwaway society*. Gower Publishing, Ltd.

Escobar, A. (2018). *Designs for the pluriverse: Radical interdependence, autonomy, and the making of worlds*. Duke University Press.

Escobar, A., Osterweil, M., & Sharma, K. (2024). *Relationality: An emergent politics of life beyond the human*. Bloomsbury Visual Arts. DOI: 10.5040/9781350226005

Fletcher, K. (2012). Durability, fashion, sustainability: The processes and practices of use. *Fashion Practice*, *4*(2), 221–238. DOI: 10.2752/175693812X13403765252389

Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021). Barriers to product longevity: A review of business, product development and user perspectives. *Journal of Cleaner Production*, *313*, 127951. https://doi.org/10.1016/j.jclepro.2021.127951.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford University Press.

Law, J., & Lin, W. Y. (2020). Care-ful research: Sensibilities from STS. *Heterogeneities*, 1–16.

Mol, A. (2002). *The body multiple: Ontology in medical practice*. Duke University Press. https://doi.org/10.1215/9780822384151

Mol, A. (2008). *The logic of care: Health and the problem of patient choice.* Routledge. https://doi.org/10.4324/9780203927076

Mol, A. (2021). *Eating in theory*. Duke University Press. https://doi.org/10.1215/9781478012924

Mol, A., Moser, I., & Pols, J. (Eds.). (2010). *Care in practice: On tinkering in clinics, homes and farms*. transcript Verlag.

Müller, F. (2021). *Design ethnography: Epistemology and methodology.* Springer Nature.

Nicolini, D. (2009). Zooming in and out: Studying practices by switching theoretical lenses and trailing connections. *Organization Studies*, *30*(12), 1391–1418. https://doi.org/10.1177/0170840609349875

Oudshoorn, N. E., Brouns, M. L. M., & van Oost, E. C. (2005). Diversity and distributed agency in the design and use of medical video-communication technologies. In H. Harbers (Ed.), *Inside the politics of technology. Agency and normativity in the co-production of technology and society* (pp. 85–105). Amsterdam University Press.

Pickering, A. (2022). Acting with the world: Doing without science. *e-cadernos CES,* (38), 155–165.

Pols, J. (2023). *Reinventing the good life: An empirical contribution to the philosophy of care*. UCL Press. https://doi.org/10.14324/111.9781800086029

Puig de la Bellacasa, M. (2017). *Matters of care: Speculative ethics in more than human worlds.* University of Minnesota Press.

Suchman, L. (2002). Located accountabilities in technology production. *Scandinavian Journal of Information Systems: 14*(2), 91–105.

Tonkinwise, C. (2023). Some theories of change behind and within transition designing. In D. Drabble, A. de Götzen, N. Morelli, & L.

Simeone (Eds.), *Strategic thinking, design and the theory of change* (pp. 270–293). Edward Elgar Publishing. https://doi.org/10.4337/9781803927718.00027

Research paper
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The Wicked Problems of Durability: Rebound Effects and Textile Illiteracy in Circular Policy

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Keywords: Durability; Rebound effects; Product Environmental Footprint; Textile literacy.

Abstract:
This paper takes its starting point from the EU Strategy for Sustainable and Circular Textiles which proposes that:

"Increased durability will enable consumers to use clothing for longer and at the same time support circular business models such as reuse, renting and repair, take-back services and second-hand retail, in a way that creates cost-saving opportunities to citizens" (European Commission, 2022).

While this statement positions durability as a cornerstone of circularity, and assumes that increasing product lifespan will naturally align with economic, environmental, and social benefits. This paper challenges that assumption by investigating the rebound effects and 'wicked problems' associated with durability as a driver for circular business models. By applying Rittel and Webber's (Rittel & Webber, 1973) framework, the analysis addresses multiple levels of root problems that complicate this narrative. Empirical data from two ongoing studies will be presented to illustrate how gaps in textile literacy—both in industry and among consumers—undermine the technocratic assessments underpinning EU strategies. These studies highlight how the erosion of textile knowledge over recent decades has left terms like "durability" and "circularity" poorly understood and misapplied. The concluding argument of this paper is that this lack of historical and practical textile knowledge within EU policy-making constitutes a rebound effect in itself. Without a deeper, more nuanced understanding of what durability and circularity entail and how they can be practiced, the strategy risks failing to achieve its intended positive impacts.

Introduction

Circular Economy Rebound Effects (CERs), as first articulated by Zink and Geyer (2017) critique the over-optimistic assumptions underpinning many circular economy strategies. They argue that "proponents of the circular economy have tended to look at the world purely as an engineering system and have overlooked the economic part of the circular economy" (Zink & Geyer, 2017).

Building on this argument, Siderius and Poldner (2021) contend that technological innovations aimed at fostering circularity cannot succeed without addressing broader behavioral and economic mechanisms. Similarly, Braun et al.(2021), show how product-level assessments can unintentionally exacerbate rebound effects by failing to incorporate system-wide analyses. In a Danish context, Dalgaard Nielsen & Skjold(2023) reveal how resale, if situated within a linear growth paradigm and fashion narrative, it will only drive additional production and consumption of both primary and secondary textile products. Finally, literature on design for longevity suggests that durability – or technical longevity of materials – will not alone support long-lasting use phases, as functional and emotional parameters must be taken into consideration as well (Hasling & Ræbild, 2017) Furthermore, focusing only on the materials and product design level will not leverage deep circularity, as these are nested in larger cultural, social, and economic systems (Engholm, 2023).

These critiques collectively challenge the EU's strategy for Sustainable and Circular Textiles (European Commission, 2022), which fundamentally bases its conception of circular economy on the concept of durability. Not

including a more holistic approach that incorporates cultural and economic dimensions, issues of durability become wicked and unresolving of root problems.

The wicked problem of policy

The concept of 'wicked problems,' introduced by Rittel and Webber (1973) offers a powerful lens for understanding the complexities of policy planning. Originally developed in a period of social and political upheaval, their framework critiques the tendency of policymakers to treat societal challenges as if they were scientific problems with clear definitions and singular solutions that too often generate new problems. A key feature of wicked problems is that every wicked problem can be viewed as a symptom of another, deeper issue why policy solutions often fail, because they address surface-level symptoms rather than the underlying root cause.

This perspective sheds light on the challenges in EU efforts of developing policies for sustainable and circular textiles. Central hereto is the concept of durability, here treated as an isolated metric rather than being interdependent with larger systemic issues. (Solis et al., 2025). For instance, overproduction and overconsumption are rarely addressed (Laurentiis et al., 2024). By failing to account for the interconnected nature of concepts like durability, EU policies risk perpetuating rebound effects.

Thus, this paper aligns with Rittel and Webber's critique: that wicked problems require nuanced, multi-dimensional approaches rather than linear, one-size-fits-all solutions. With this, we wish to showcase how a technocratic focus on measuring and assessing technical durability of textiles cannot stand alone, insofar as textile knowledge about what durability is and how it is practiced is currently not taken into account. The paper will argue how this to a large extent is a result of the efforts of cutting costs and making textile products more affordable through outsourcing of production throughout the last decades, which has made the fast fashion business model possible (Perry & Wood, 2019).

The problem of textile illiteracy

Understanding what textiles are made of, their properties, and the time, effort and cost it requires to develop them – is not compatible with the downward spiral of prices on textile goods that has escalated with the rise of fast fashion. This implies that the EU efforts of stimulating long-lasting, high-quality textiles that are affordable are paradoxical and unrealistic (Richardy & Skjold, 2023).

Still, the focus on assessing durability as a key part of the EU Strategy for Sustainable and Circular Textiles, lies in providing a standardized method for assessing environmental impacts, nested in the framework of the Product Environmental Footprint scheme (PEF). Increasingly, critics argue that it relies on oversimplified, technocratic approaches that fail to incorporate behavioral and cultural dimensions. Wiedemann et al.(2020) note that the PEF's heavy focus on lifecycle metrics neglects crucial aspects such as the functional and emotional durability of textiles—attributes that require a nuanced understanding of fiber properties and garment use patterns. This reflects a broader issue: the absence of textile literacy in policymaking limits the ability of tools like the PEF to drive meaningful sustainability outcomes.

One major factor contributing to the erosion of textile literacy is the massive outsourcing of textile production to low-income countries, catalyzed by the removal of the Multi-Fiber Arrangement (MFA) in the 2000s. The MFA had, in the period of 1974-2004, imposed strict quotas on textile imports to protect European manufacturing (Alam et al., 2018). Its removal allowed for an influx of inexpensive imports, leading to the near disappearance of domestic garment production in many European countries. This outsourcing not only weakened local industries but also severed the transmission of essential textile knowledge within the workforce. As Busch (2008) notes, the resulting "cheapification" of clothing further eroded consumers' ability to evaluate textiles critically.

This decline in knowledge extends beyond the industry to citizens at large, who often lack the skills to identify or care for textiles. For example, many consumers are unaware of the natural or synthetic origins of their garments or how to

assess their quality (Richardy, 2025 (forthcoming)). Concepts such as durability are thus poorly understood or misapplied in practice.

The erosion of textile literacy is also evident in education systems. As the fast fashion industry emerged in the 1990s, design schools shifted focus. Practical textile skills and techniques were deprioritized in favor of fostering artistic expression and cultivating fashion celebrity narratives (Zink & Geyer, 2017)(McRobbie 1998; Skjold 2008; Zink & Geyer, 2017). Consequently, today's design graduates often lack the material knowledge necessary to identify what durability means. This educational gap mirrors the broader societal trend, where the historical understanding of textiles has been supplanted by a consumption-driven mindset.

These intertwined root problems—outsourcing, cheapening, and educational shifts—have left EU policy efforts vulnerable to rebound effects. Without incorporating historical and practical textile knowledge, the EU's focus on durability, and tools like the PEF risks becoming superficial exercises, detached from the material realities of textiles. As Zink & Geyer (2017) point out, the deeper issue is not durability itself but overproduction and overconsumption—a challenge that cannot be solved without addressing the broader loss of textile literacy.

Rebuilding textile literacy is therefore essential. This paper will explore two initiatives aimed at addressing this gap: the development of fiber identification skills among Danish schoolchildren and a workshop series on historical repair techniques. Both initiatives illustrate how reconnecting with material and historical knowledge can empower individuals and inform more effective policy approaches.

Learning by Hand

The next two sections highlight ongoing studies affiliated with the Klothing research Centre at the Royal Danish Academy, Copenhagen, which address issues of textile literacy. First, the development of teaching materials for 30,000 pupils in public and high schools will be explored, emphasizing their goal of fostering fundamental fiber identification skills. Second, the creation of teaching materials designed to communicate textile knowledge—specifically related to repair—to museum visitors and a broader audience will be discussed.

The mass experiment

The empirical data of this case is anchored in the 2024 "mass experiment" on plastics in nature, in the home, and in textiles. The annually returning initiative is hosted by ASTRA, a Danish citizen-science organization for promoting teaching in the natural sciences for school children.

The study involved approximately 30,000 Danish schoolchildren aged 6-18. In the textile part of the initiative conducted by Richardy, the pupils engaged over two weeks in 1) conducting wardrobe audits, 2) sorting textile waste to be discarded from the home, and 3) identifying textile fibers. Here, we focus on the third element—fiber identification and introduce preliminary insights from the study.

Each class received an educational box containing materials such as a cotton ball, textile samples, fiber identification posters, and sensory blind test bags directly informed by Bang's comprehensive research on tactile and sensory learning (Bang, 2013). Furthermore, they were provided with supplementing identification tools like the textile identification key (Figure 1) and instructions for fiber identification through fire testing.

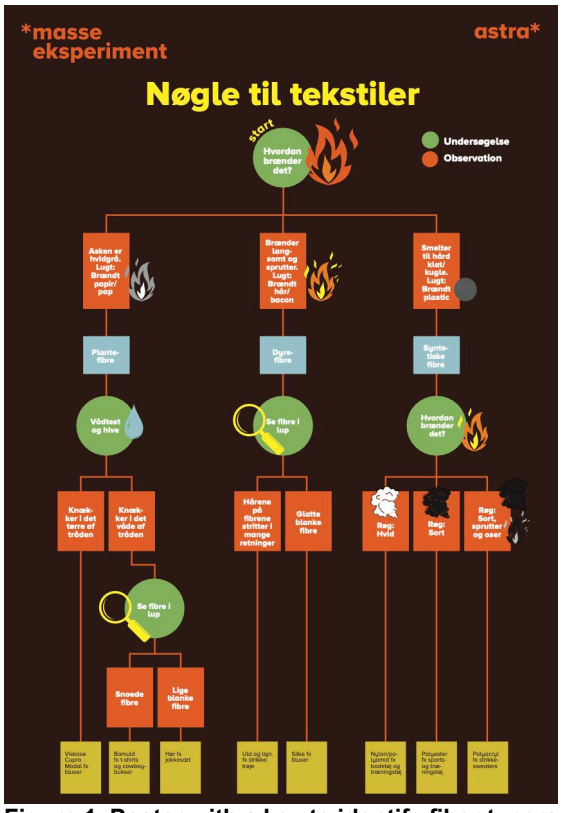


Figure 1. Poster with a key to identify fiber typers developed for the additional teaching material for the mass experiment 2024 © ASTRA.

This way, they performed burn, wet, and microscopic tests to analyze materials and participated in sensory exercises to explore textile properties by touch. These hands-on activities bridged theoretical knowledge and practical application, enhancing textile literacy and fostering environmental awareness.

This teaching kit was developed together with the experienced team of ASTRA and tested in week 17 2024 in a 7th grade class in a public school on Zealand. In situ observations were conducted for making the final improvements of the kit, and for exploring how the pupils interacted with the various elements (figure 2).



Figure 2. Test of educational material and survey in a 7th grade class on Zealand. © Richardy.

The insights from this pilot confirmed the need for a fundamental approach to textile education. For example, none of the pupils were aware of the origins of their garments—whether derived from plants, animals, or oil. Additionally, the blind test bags revealed that the pupils were unable to identify fibers based solely on touch.

In November 2024, a similar pilot test was conducted with students in the fashion and textile MA program at the Royal Danish Academy. During this test, students engaged in a panel training focused on the tactile properties of textiles made from different materials and weaves. The training aimed to develop a shared vocabulary for describing textiles and assigning functional properties to them. Through a series of sensory exercises, the students explored how factors like fiber type, weave density, and surface texture influence perceptions of quality, comfort, and durability. This collaborative process not only enhanced the students' ability to evaluate textiles systematically but also underscored the importance of tactile literacy as a foundational skill for addressing sustainability challenges.

These preliminary insights underscore the state of textile education in design schools in Denmark. Over the past two decades, the teaching of textile skills and techniques has been significantly reduced, with an increasing focus on artistic expression rather than material expertise. This shift, driven by the academization of design schools since the early 2000s, has rendered practical textile education increasingly inadequate (Skjold, 2008).

Hands in History

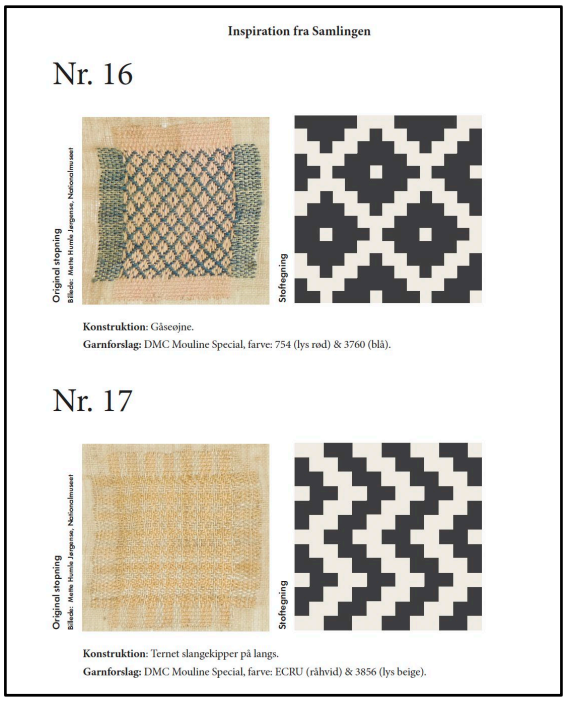
The outreach workshop series *Hands in History*, developed by the National Museum of Denmark (NMD), pay tribute to historic craftsmanship and are offered to museum visitors, In collaboration with Skødt, a workshop on repair techniques and darning was conducted twice—once in the Spring and once in the Autumn of 2024—and attracted 31 and 18 participants respectively.

These two-day workshops focused on historical darning techniques and the history of handicraft education in the Danish primary and secondary schools. One of the workshop's primary objectives was to highlight how techniques from the cultural history of textiles could contribute to

rebuilding citizens' competencies and knowledge in the maintenance and repair of clothing and textiles, thus promoting longevity and extended use of textile materials today.

The two-day workshops included lectures, a guided tour in one of the NMD's exhibitions, hands-on darning activities, and a presentation by a museum curator of darning samplers not currently on display. Participants were introduced to the historic technique of pattern darning, commonly seen in darning samples from the 18th and 19th centuries. Darning samplers are pieces of cloth on which young girls practiced advanced darning techniques for the invisible repair of clothing and textiles. These samplers are thus representative of the historically significant role that textile repair skills have played.

Participants of the workshops were provided with a material and tool kit containing various embroidery needles, two pieces of linen to accommodate different levels of complexity, and a booklet including a step-by-step guide to pattern darning and 25 patterns traced from a 1794 darning sampler, offering inspiration for the participants' own darning endeavors (figure 3). Yarn was also made available for the participants' use.


Inspiration fra Samlingen

Nr. 16

Original stopning

Stoffegning

Konstruktion: Gåseøjne.
Garnforslag: DMC Mouline Special, farve: 754 (lys rød) & 3760 (blå).

Nr. 17

Original stopning

Stoffegning

Konstruktion: Ternet slangekipper på langs.
Garnforslag: DMC Mouline Special, farve: ECRU (råhvid) & 3856 (lys beige).

Figure 3. Excerpt from booklet on pattern darning. © Skødt.

On the first day of the workshop, participants were introduced to the technique of pattern darning and began developing their skills using the provided materials (figure 4). The second day focused on the participants' own garments or other textile items requiring repair. Pattern darning was tested on modern pieces of clothing, and participants also experimented with other historical darning techniques, e.g., for knitted materials.

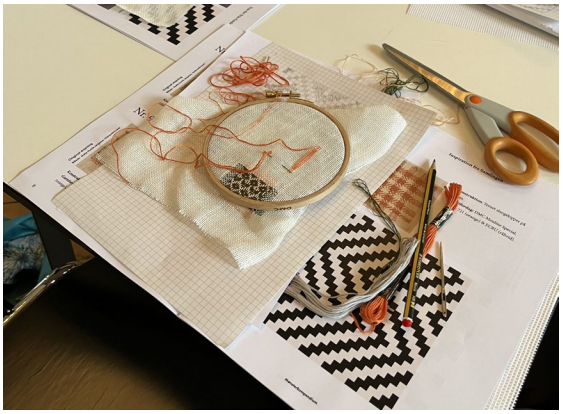


Figure 4. Ongoing pattern darning by workshop participant. © Skødt.

During the workshops, in situ observations were conducted for capturing reactions and responses regarding differences between historical repairs in the context of the teaching material, and the repairs of participants' own objects. Compared to the historical darning samplers, the darning of the participants' work showed less complexity, for example, due to using linens with a lower thread count. The complexity of darning which relate to the linen's thread count was tested prior to the workshop by Skødt and adapted to suit the timeframe of the workshop. Nevertheless, the participants expressed that they found the darning exercise difficult, but doable under guidance.

Consequently, the workshop showed, that the competencies level of the experienced textile craftspeople partaking the workshops was considerably lower than that of the past generations of women who sewed the darning samplers.

Discussion

Critically, the educational interventions of this paper are not merely stopgap measures, but foundational steps toward rebuilding a knowledge base that enables systemic change.

While handcraft education alone will not reverse the effects of outsourcing, it serves as a crucial strategy for reintroducing an understanding of fiber properties, durability, and repairability—skills necessary for evaluating and supporting sustainable textile systems. In contrast, onshoring production without addressing this knowledge gap would risk reproducing the same cycle of uninformed consumption and production under new economic conditions.

While onshoring may seem like a solution to the decline in textile literacy, lost knowledge does not automatically return with production. This decline stems not only from outsourcing but also from cultural and educational shifts that deprioritized material expertise—often termed the "industrial commons"—which does not regenerate on its own (Berger, 2013; Pisano & Shih, 2009). Instead, rebuilding textile literacy requires targeted education, historical knowledge recovery, onshoring of a textile infrastructure, and hands-on engagement (Alam et al., 2018).

Thus, investigating textile practices before fast fashion reveals a stark contrast to the limited and technocratic perception of durability as fiber strength alone: historically, skills in identifying fiber durability, functional and emotional properties, and market value were deeply integrated into societal norms, fostering what could be seen as a genuinely circular economy for textiles. One vivid example is the study of Ûlvang (2013), displaying how garments held significant economic and emotional value in estate valuations. To uphold this economic system of circularity, citizens were expected to understand, maintain, and extend the life of their textiles.

In contrast, modern CER literature critiques "circular" products for their limited appeal and value. Zink & Geyer (2017) emphasize how recycled or repurposed textiles often fail to substitute what they term ‘linear’ products due to lower economic, functional, and emotional worth. The Braun et al. study exemplifies this issue, comparing ‘circular’ and ‘linear’ work jackets without acknowledging detailed evaluations of how textile properties—such as weave density, fiber length, fiber quality, or sensory and aesthetic experience—affect durability. By overlooking these factors, lifecycle assessments risk reinforcing rebound effects rather than addressing systemic issues. Similarly, Larsen (2025) highlights how recycled fibers have historically been considered inferior and of lower quality, whilst they are currently being celebrated. This lack of textile knowledge amongst consumers, policymakers, and industry professionals allows superficial solutions to gain acceptance, without interrogating what truly constitutes concepts of durability.

Altogether, policies such as the EU Strategy for Sustainable and Circular Textiles, often align with what Bauwens et al.(Bauwens et al., 2020) describe as "weak circular economy", where linear economic drivers are patched with technocratic solutions rather than systemic change, which is evident when looking at the proxy of durability as ‘wicked’. In contrast, "bottom-up efficiency" approaches emphasize small-scale, community-driven production, leveraging local knowledge and skills for supporting local needs. The 2024 Circular Gap Report echoes these ideas, advocating for the development of “skills, capacities, and expertise” to support circularity that would require onshoring of a circular infrastructure (Matthew Fraser et al., 2024) – an ambition equally adopted by the Danish partnership for circular economy of plastics and textiles, TRACE (TRACE, 2025).

Aligning with the educational and historical initiatives discussed in this paper, these insights highlight the critical need for re-establishing textile literacy across society.

Conclusions

This paper is not a call to abandon scientific methods or metrics like lifecycle assessments. Instead, it emphasizes that natural science-based measurements must work in tandem with textile literacy to form a holistic understanding of concepts such as durability. Only by integrating these perspectives can we avoid rebound effects and prevent the worsening of current issues.

Examining the wicked problems of durability reveals a complex set of interconnected root issues that are symptomatic of one another and together constitute a ‘higher-level problem.’ The current siloed focus on validating and underpinning assessments of ‘durability’ through natural sciences and engineer-led thinking within EU policy makes circular economy rebound effects almost inevitable.

Instead, this paper proposes a deeper investigation into the parameters that define durability, grounded in a textile knowledge perspective, arguing that achieving deeper circularity will require a population re-educated in textile literacy and a strategy for onshoring a textile infrastructure within the EU. Without this effort, implemented alongside the development of science-based textile assessments, the current trajectory of EU policy will likely exacerbate rebound effects and worsen existing problems. Hence, the studies referenced in this paper collectively explore implications of the proxy of durability by integrating both material and cultural dimensions of textile literacy, thus contributing to a wider, deepened understanding of the concept of durability – one currently lacking in policy today.

References

Alam, M., Selvanathan, E., Selvanathan, S., & Hossain, M. (2018). The apparel industry in the post-Multifiber Arrangement environment: A review. *Review of Development Economics*, *23*. https://doi.org/10.1111/rode.12556

Bang, A. L. (2013). The Repertory Grid as a Tool for Dialog about Emotional Value of Textiles. *Journal of Textile Design Research and Practice*, *1*(1), 9–25. https://doi.org/10.2752/175183513X13772670831038

Bauwens, T., Hekkert, M. P., & Kirchherr, J. (2020). Circular futures: What Will They Look Like? *Ecological Economics*, *175*. https://doi.org/10.1016/j.ecolecon.2020.106703

Berger, S., & Economy, M. T. F. on P. in the I. (2013). *Making in America: From Innovation to Market*. The MIT Press. https://doi.org/10.7551/mitpress/9791.001.0001

Braun, G., Som, C., Schmutz, M., & Hischier, R. (2021). Environmental Consequences of Closing the Textile Loop—Life Cycle Assessment of a Circular Polyester Jacket. *Applied Sciences*, *11*(7). https://doi.org/10.3390/app11072964

Busch, O. von. (2008). *Fashion-able. Hacktivism and engaged fashion design*. https://api.semanticscholar.org/CorpusID:106682618

Dahlagaard Nielsen, M., & Skjold, E. (2023). *Can resale Extend the Use Phase of Garments? ExploringLongevity on the Fashion Resale MArket*. PLATE Product Lifetimes And The Environment.

Engholm, I. (2023). *Design for the New World: From Human Design to Planet Design* (NED-New edition). Intellect; JSTOR. https://doi.org/10.2307/jj.2458924

European Commission. (2022). *EU Strategy for Sustainable and Circular Textiles*. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022DC0141&from=EN

Hasling, K., & Ræbild, U. (2017). *Sustainability Cards: Design for longevity*. https://doi.org/10.3233/978-1-61499-820-4-166

Larsen, A. T. (2025). *From Fiber to Form. Exploring Design Qualities of Mechanically Recycled Textiles*. The PhD school of the Royal Danish Academy.

Laurentiis, V. D., Caldeira, C., Sala, S., & Tonini, D. (2024). Life cycle thinking for the assessment of waste and circular economy policy: Status and perspectives from the EU example. *Waste Management*, *179*, 205–215. https://doi.org/10.1016/j.wasman.2024.02.037

Matthew Fraser, Álvaro Conde, & Laxmi Haigh. (2024). *Circularity Gap Report 2024*. Circle Economy; Policy Commons. https://policycommons.net/artifacts/11317813/cgr-global-2024/

Perry, P., & Wood, S. (2019). *Exploring the International Fashion Supply Chain and Corporate Social Responsibility: Cost, Responsiveness and Ethical Implications*.

Pisano, G., & Shih, W. (2009). Restoring American Competitiveness. *Harvard Business Review*, *87*.

Richardy, J. (2025). *(forthcoming) From Reductionism to Reality: The Behavioral Gap in Textile LCAs*.

Richardy, J., & Skjold, E. (2023). *From Soil to Garment: Missing Links in the Assessment Criteria of Textiles [submitted]*. PLATE Product Lifetimes And The Environment.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169. https://doi.org/10.1007/BF01405730

Siderius, T., & Poldner, K. (2021). Reconsidering the Circular Economy Rebound effect: Propositions from a case study of the Dutch Circular Textile Valley. *Journal of Cleaner Production*, *293*, 125996. https://doi.org/10.1016/j.jclepro.2021.125996

Skjold, E. (2008). *Fashion Research at Design Schools*.

Solis, M., Milios, L., Tonini, D., Hansen, S. F., Scheutz, C., & Huygens, D. (2025). An empirical exploration of the unintended effects of circular economy policies in the European Union: The case of textiles. *Sustainable Production and Consumption*,

54, 452–465. https://doi.org/10.1016/j.spc.2025.01.021

TRACE. (2025). *Textiles*. Trace. https://trace.dk/textiles/

Ulväng, M. (2013). *Klädekonomi och klädkultur: Böndernas kläder i Härjedalen under 1800-talet*. Uppssala Universitet.

Wiedemann, S. G., Biggs, L., Nebel, B., Bauch, K., Laitala, K., Klepp, I. G., Swan, P. G., & Watson, K. (2020). Environmental impacts associated with the production, use, and end-of-life of a woollen garment. *The International Journal of Life Cycle Assessment*, *25*(8), 1486–1499. https://doi.org/10.1007/s11367-020-01766-0

Zink, T., & Geyer, R. (2017). Circular Economy Rebound. *Journal of Industrial Ecology*, *21*(3), 593–602. https://doi.org/10.1111/jiec.12545

Research paper
6th PLATE 2025 Conference
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"Oh no, it's broken!" – How product functionality limits lifespan

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Keywords:
Product lifetime; Functionality; Energy-related Products; Purchase Decisions; Circular Economy.

Abstract: Today a large variety of products with various features and designs are available for consumers. In addition to the main functions of a product, there are more and more additional functions, especially for electrical and electronic appliances. This means that looking for the right product may require extensive research by consumers and does not always lead to a sense of making an informed purchase decision. The wide variety of designs and functions can overwhelm consumers. This creates uncertainty and might lead to overrate products functionality and thus significantly shorten the service lifetime of appliances. Furthermore, the environmental impact of such functions is usually unclear, and can vary depending on the actual usage scenario. In this study, a survey was carried out in order to better understand consumers perceptions and experiences related to additional functions of products, with specific focus on domestic hobs, household refrigerating appliances and televisions. The results confirm the large number of additional functions and their overwhelming effect for consumers. Consumers purchase devices with more features than desired, or replaced them prematurely because an extra feature fails while the main function is still available. The findings of the study can be used to better inform consumers and support them to make environmentally sustainable purchasing decisions.

Introduction

The aim of the European Green Deal is to achieve a climate neutral European Union by 2050 (COM/2019/640 final, 2019). As one related policy initiative, the Circular Economy Action Plan targets product design, circular economy, and sustainable consumption (CEAP, 2020). Scientific research is key in this regard, providing well-founded information for effective legislation and information for consumers to encourage well-considered purchase decisions. A successful implementation of the Green Deal and the CEAP requires measures in all branches of industry and areas of individual life. This also includes the use of electric and electronic devices in private households.

"Oh no, it's broken!" – sounds like a trivial thing to say but it often is not. While there were significantly less product types on the market a few decades ago, the circumstance to purchase a new device for the right application nowadays might require extensive research and frequently lead to an unsatisfactory result for the consumer. Inefficient information might also result in purchase decision in favor to appliances with shorter lifetime. A glance at the electronics stores reveals more devices with additional functions than without. For example, televisions are today no longer just a playback device, they became a multifunctional entertainment tool with pre-installed apps for gaming, streaming, video calls, etc. Many additional functions cannot be clearly assigned to a positive or negative environmental impact as the effects depend to a large extent on utilization. In addition, contradictory effects are possible. Finally, the question whether additional functions increase or decrease products' lifetimes remains.

Like the main function, additional functions have an influence on many product properties. This concerns reparability, which is to be improved with the right to repair and is communicated, for example, via a repair score (Schischke et al., 2022). It also concerns the bill of materials and the total material footprint of the product (Liedtke et al., 2014), as well as the standardization of durable products (Schlegel et al.). In the future, it should also be considered whether some information on additional functions should be included in the consumer-oriented version of the Digital Product Passport

(SVRV, 2024) in order to support the realization of the ESPR (ESPR, 2024/PE/106/2023/REV/1).

Against this background, the aim of the article is to describe the results of a representative survey aiming to better understand consumers perceptions and experiences concerning additional functions of products. A focus is set on the relevance of additional functions for purchasing decisions and product lifetimes, and related information requirements. The survey referred to these three product groups: domestic hobs, household refrigerating appliances and televisions.

What are Additional Functions?

The large variety of different designs and functions coupled with ranges in price can be overwhelming when it comes to purchase decisions. In addition to the primary functions of an appliance category, numerous additional functions are available. The additional functions can complement the primary function, enhance it, or also have no direct connection to it. The environmental impacts of such functions are usually unclear, and can vary depending on the actual usage scenario.

In order to define additional functions more specifically we refer to our earlier article on additional product functions (Tochtrop et al., 2024) and the definition given there: *"Additional functions are the functions of a product that are not related to the intended function or that supplement or reinforce the primary function. In other words, they are functions that are not required to ensure the primary function*".
Figure 1 illustrates this definition.

This definition is based on the "International Electrotechnical Vocabulary" relating to different energy requirements of active-, stand-by- and off-mode. The vocabulary contains the following three definitions of functions that clearly relate to additional functions in our understanding:

- primary function = "function providing the intended purpose" (IEC, 2014a)
- secondary function = "function that enables, supplements or enhances a primary function" (IEC, 2014b)
- tertiary function = "function other than a primary or a secondary function" (IEC, 2014c)

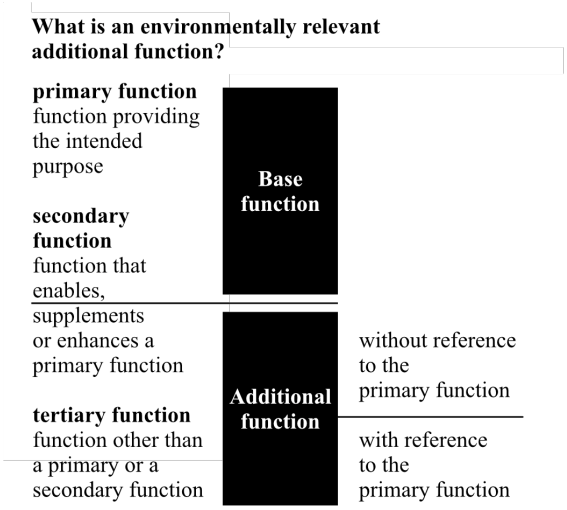


Figure 1: Additional functions in relation to primary, secondary and tertiary functions (Source: (Tochtrop et al. 2024).

Methodology

The overall methodology for this study has been initially described by Tochtrop et al. (2024) with further sources and background information. Here, we explain the key elements of the approach.

The methodology comprises the following five steps:

1. Identifying additional functions
2. Initial assessment by experts in an evaluation matrix
3. Focus group dialogue
4. Survey on user perspectives
5. Information concepts for consumers

The steps are described below, with specific focus on step 4 as the survey on user perspectives is the focus on this paper. Details on the steps 1 to 3 and 5 are described by Tochtrop et al. (2024). These steps are illustrated by reference to the three product groups analyzed: refrigerating appliances, TVs, and domestic hobs
In order to *identify additional functions*, preliminary market research was carried out in conjunction with the clear definition of the product group. The offers on the market were examined for each group of devices and analyzed with regard to these questions: which designs are primarily offered? Which functions can be clustered despite different brand names? The additional features we used to investigate further are listed below.

Refrigerating appliances

- Chill compartment
- Auto-defrost
- WLAN/ smart refrigerator/ control via app
- Camera inside (in combination with WLAN)
- Fast freeze
- Door alarm
- Automatic door opening function
- Door display with calendar and communication tools
- Ice cube maker and water dispenser

TVs

- Extra-large device
- Onboard Audio system
- Camera
- Smart TV onboard
- Smart TV via additional TV streaming stick
- Game hub
- Art mode
- Frame lighting
- ECO mode
- Eye comfort mode
- Special design

Domestic hobs

- Childproof lock
- Frameless design
- Removable control knob, magnetic
- Illuminated markings for cookware recognition
- Fast heating: Automatic boil or boost function
- Frying/cooking sensor for constant temperature
- Cookware recognition with resulting functionality
- Pause function
- Timer function (alarm clock)
- Keep warm function
- Automatic switch-off function
- Integrated fume extraction system

Survey on user perspectives

A total of 3055 participants took part in the survey. The group of participants, even after the following division into subgroups, corresponds to a representative composition of the German population. The questionnaire was structured as follows:

A) Standard demographic questions.
B) Questions on the basic perception of additional functions.
C) The participants are asked questions specifically about one of the three product groups refrigerating appliances, domestic hobs and TVs.
D) Preferences regarding the availability of information on additional functions.

By splitting the approximately 3,000 participants into three groups for the analysis of individual product groups, the questions are structured identically, allowing us to carry out comparative analyses. The questions related to these aspects:

- Which general quality aspects are important to consumers in a theoretical purchase decision?
- A list of additional functions of the appliance group was provided, for which the consumers were asked to decide how important these are for them.
- They should evaluate the same list regarding the suspected environmental impacts.

Due to the immense variety of household appliances and the associated potential additional functions, we decided to use free text fields in the survey. If the answer to the question “Have you ever bought an electrical appliance that had more functions than you actually wanted?” was yes, the next step was for the participants to indicate which appliances these were and which unplanned functions were associated with them. Finally, the participants were asked to rate the additional functions they had mentioned – whether they were a benefit, remained unused, had a negative effect, or had both negative and positive effects.

The following Tables A to D summarize the questions and possible answer fields.

Questions	Answer options
gender	female; male; diverse
year of birth	numerical
level of education	6 levels from 'no school-leaving qualification' to PhD / habilitation
Household income	4 levels from zero to above 4500€
Number of house-hold members	from 0 to 20, differentiation by total number and children under the age of 16

Table A: Standard demographic questions

Questions	Answer options
Please rate the following product groups according to their environmental impact:	
refrigerating appliances	selection boxes with scale 1-5; from positive over neutral to negative influence
domestic hobs	
TVs	
Give your opinion on the following statements: When buying an electrical appliance, it is important to me that...	
... I get a solid device with the basic functions.	selection boxes with scale 1-5; from 'fully agree' over 'yes and no' to 'completely disagree'
... I am technically up to date.	
... I buy a durable product.	
... it looks high quality.	
Have you ever bought an electrical appliance that had more functions than you actually wanted?	
Which device was that? Please give several examples.	5 text fields, only the first compulsory
Name or briefly describe the additional functions.	1 text field for each previously entered answer
Please tell us how you rate these additional functions in retrospect.	selection boxes: as a benefit, unclear, don't care / don't use, as a disadvantage, other (open text field)
Do you remember an electrical appliance that you replaced because an additional function broke down while the main function was still working?	
Which device was that? Please give several examples.	5 text fields, only the first compulsory

Table B: Questions on the basic perception of additional functions

Questions	Answer options
Assuming that your [refrigerator / hob / TV] is broken and you are going to buy a new one within the next few days. Give your assess-ment of the following statements: When buy-ing a [refrigerator / hob / TV], it is important to me that...	
... I get a solid device with the basic functions.	selection boxes with scale 1-5; from 'fully agree' over 'yes and no' to 'completely disagree'
... I am technically up to date.	
... I buy a durable product.	
... it looks high quality.	
Assume your [refrigerator / hob / TV] is broken and you are about to buy a new appli-ance. Which of the following additional functions are important for your purchase decision?	
List with 9-12 additional functions depending on the product group.	selection boxes with scale 1-5; from 'very important' over 'neutral' to 'not important at all'
Assume your [refrigerator / hob / TV] is broken and you are about to buy a new appli-ance. Give an estimation of how the following additional functions affect the sustainability of the appliance.	
Same list as above with 9-12 additional func-tions depending on the product group.	selection boxes with scale 1-5; from positive over neutral to negative influence

Table C: Questions specifically about one of the three product groups

Questions	Answer options
Give your opinion on the following state-ments:	
I would like to be better informed about the environmental impact of additional functions in devices.	selection boxes with scale 1-5; from 'fully agree' over 'yes and no' to 'completely disagree'
I would like to be warned about functions with a high negative environmental impact.	
The information provided by the manufacturer is enough for me to make a good purchase decision.	
How helpful would the following information on additional functions be for you when making a purchase decision?	
Information on additional functions on the EU product information	selection boxes with

sheet (which is linked next to the price at online retailers, for example).	scale 1-5; from 'very helpful' over 'yes and no' to 'not helpful at all' plus the option 'unknown'
An online self-test with environmental information on additional functions.	
An information campaign that draws attention to the topic of environmental relevance of additional functions.	
Mandatory information required from manufacturers on the monetary follow-up costs of additional functions that cannot be switched off and on the availability of devices with basic functionality.	

Table D: Questions on preferences regarding the availability of information on additional functions

Survey Results

As first question on the individual user perspective the respondents were asked to rate the product groups according to their environmental impact. Figure 2 summarizes the results. All product groups were assessed without a clear rating; refrigerators and televisions tended to be more frequently associated with negative environmental impacts than hobs. In Figure 2 the first broader bars in each of the four sections show the mean values for every group. This is followed by a breakdown by demographic group referring to age, education and income. Similar trends are seen across all groups and products. Younger people associate more negative environmental impacts with products than older people. Awareness of environmental issues is positively linked to education and income. However, it is noted that those with the lowest incomes (up to €1500) are more likely to expect negative environmental impacts than those with lower middle incomes (€1501-2250).

A similar analysis is shown in Figure 3 for the question of which aspects are important for the purchase decision. The higher the income, age and level of education, the more attention is paid to quality. Figure 3 shows the combined responses for all three product groups. However, the percentage deviations in the responses between the product groups were rather small, and there were no significant outliers.

For all questions, correlations were examined between demographic groups and their survey responses. Men and women could be analyzed individually. However, there were too few records for the *diverse* entry.

More than half of respondents (56,7 %) were in the affirmative when asked if they had ever bought an electrical appliance that had more functions than they wanted. Conversely, these people have not found the optimal product for their needs. In the following text fields, the participants could indicate which devices these were. A total of 1732 people entered between

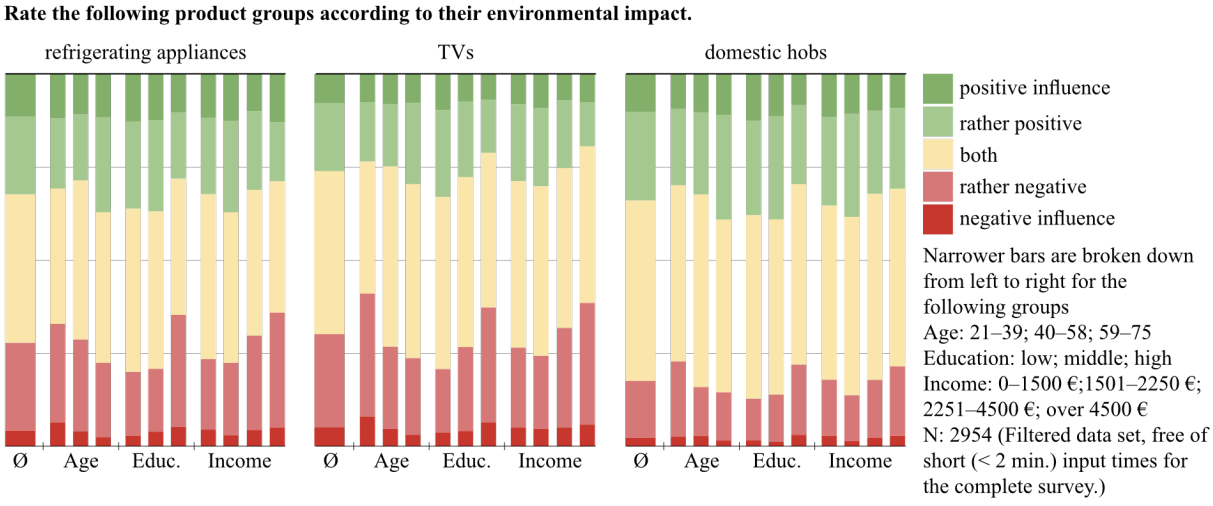


Figure 2: Rated environmental impact of refrigerating appliances, TVs and domestic hobs.

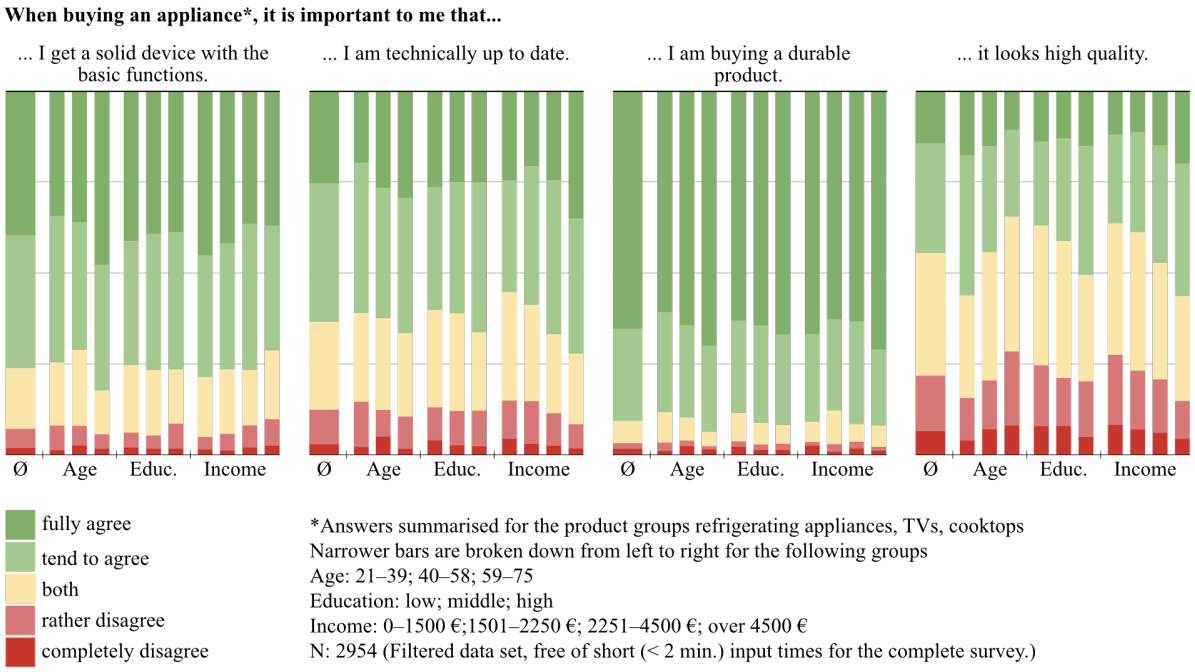


Figure 3: Analysis of quality criteria for new purchases

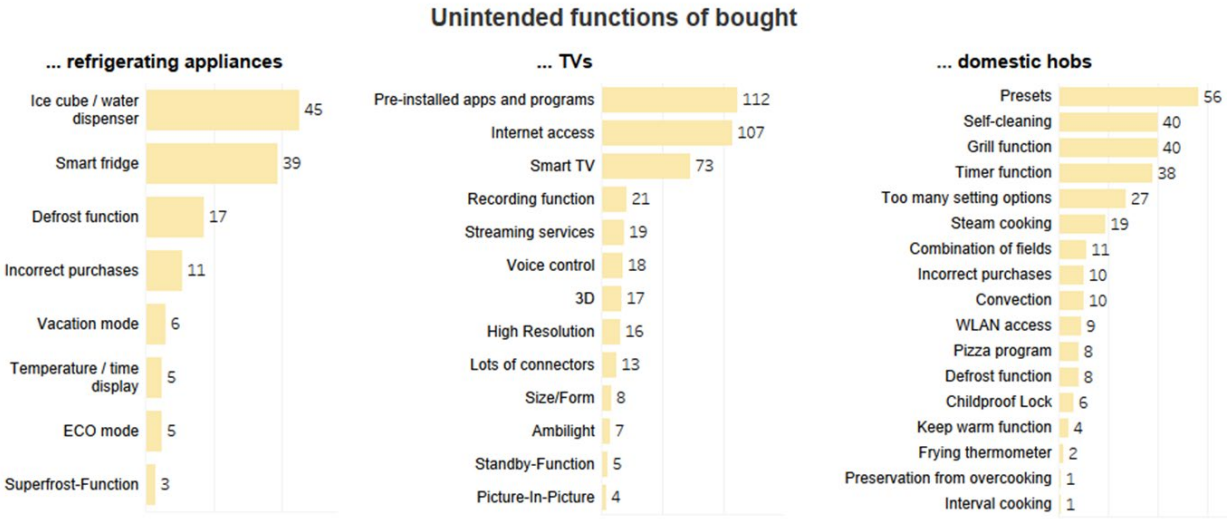


Figure 4: Listed unintended functions of bought products

one and five devices in the text boxes, which we then analyzed. Obviously incorrect and incomprehensible entries were not considered. The remaining data was sorted and counted according to recognizable product groups. Figure 6 shows the results in absolute numbers of mentions. Televisions are by far the most frequently mentioned product group with unintended extra functions. Behind the large number 151 under 'Others' is a total of 45 different products, reflecting the enormous variety available on the market today.

For the devices mentioned, the participants were then invited to list the functions that they did not specifically want when they made their purchase decision. In analyzing this data set, the entries were also harmonized into groups of equivalent features. It can be seen in Figure 4 that digitalization functions were mentioned frequently. In general, over-engineered equipment was often cited as a problem. The "Incorrect purchases" category includes entries where devices appear to have been purchased in the wrong product category. These included

for example buying induction when a ceramic hob was preferred, or buying a fridge-freezer instead of a refrigerator. Figure 5 lists the devices that people have already replaced because of a broken extra function. A total of 129 respondents identified 314 devices that they had replaced. This accounts for approximately 7.5% of the respondents who had purchased unwanted product features.

Based on the results of the detailed methodology and this survey *information concepts for consumers* were developed for consumers, which lead to well-founded purchasing decisions through precise facts. For details see Tochtrop et al.

Discussion

Additional features and functions can be both useful and harmful – and this interpretation varies from user to user. Rebound effects may occur, when equipment that has been purchased for its environmental benefit is perceived too soon to be outdated. But some aspects are clear: Additional features and functions make the market complex, and the survey shows that respondents criticize the over-engineering of devices. The ubiquitous digitalization of everyday objects was identified as a problem for consumers and has also clearly led to more negative impacts on the environment as the United Nations summarize: “Digitalization’s promise of dematerialization has not yet materialized” (United Nations, 2024). All these aspects can lead to a significant reduction in service lifetime. It has become increasingly difficult in terms of transparency to buy a long-lasting device.

Finally, there is wasted potential in minimizing environmental impact in the case of environmentally sustainable (and also economic) purchases decision. The results have shown that people sometimes "accidentally" buy obvious extra features, such as an ice cube dispenser in the refrigerator or a permanently installed frame light on the TV. But even with less resource-intensive extras, there are many uncertainties left. In addition, the variety of brand names for similar functions in a product segment makes it difficult to choose the right product for certain households. Clearer language, maybe a standardized terminology, would help consumers to make informed decisions. One example is the multitude of terms in the refrigerator segment for the

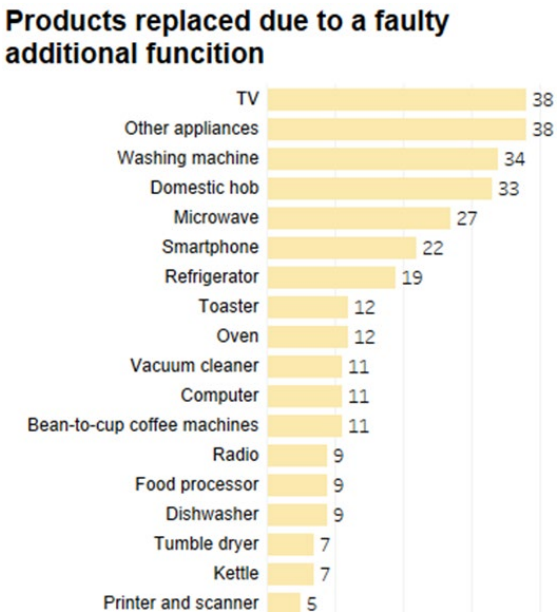


Figure 5: New purchases caused by broken extra functions

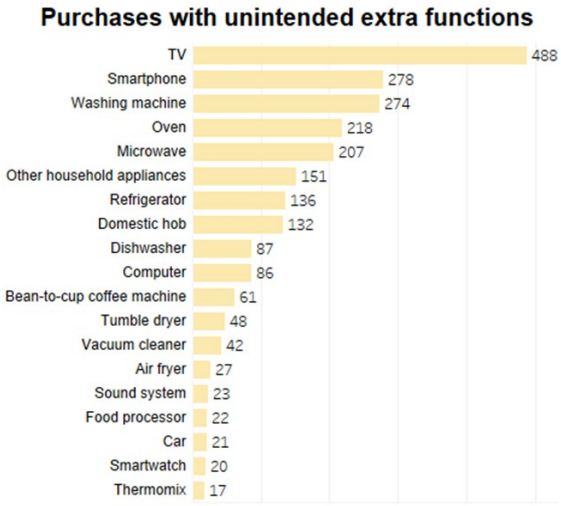


Figure 6: Purchases with unintended extra functions

vegetable drawer: hyperFresh (Plus), VitaFresh (Plus), DailyFresh, Cool Select+, Optimal Fresh+, (Ultra) Fresh Zone+, ExtraChill, UltraFresh, CrispZone, EverFresh+ and FRESHBalancer. The names become even more difficult to assign when trying to work out whether it is a ‘chill compartment’ or a ‘storage compartment for fresh food’ (Commission Delegated Regulation (EU) 2019/2016 of 11 March 2019).

Conclusions

The survey confirms that it is difficult to choose the most appropriate product for specific needs, given by the current diversity of products on the market. At the same time, product designers are challenged by the wide variety of consumer demands. Consumers value the same device very differently depending on their personal needs and life situations.

It remains a major challenge for manufacturers and products' designers to produce products that meet people's needs while minimizing their impact on the environment. The survey shows that it is difficult for consumers to distinguish between a function that adds real value to the user's daily life or one that adds technology to the device that is rarely used. From an environmental perspective, there were only a small number of functions that could be clearly recommend or rejected. In our view, comprehensible impact assessments such as product sustainability reports that are always structured in the same way would be helpful as a possibility to inform consumers. The results could be used to indicate additional functions that could limit the durability of the appliance. An example of this are integrated multimedia displays in refrigerators. Other additional functions, such as the timer function in cookers or the no-frost function in freezers, make longer and more energy-efficient use more likely.

Key stakeholders are called upon to make the overall economy more sustainable than the status quo through smart regulation, appropriate incentives, and thoughtful consumption. A more differentiated consumer communication and sometimes even less functions might contribute to it and the Digital Product Passport can be a building block towards this goal.

Acknowledgments

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References

The European Green Deal, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, 2019. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640

CEAP: A new Circular Economy Action Plan For a cleaner and more competitive Europe, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS; COM/2020/98 final, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN

Commission Delegated Regulation (EU) 2019/2016 of 11 March 2019 supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of refrigerating appliances and repealing Commission Delegated Regulation (EU) No 1060/2010 (Text with EEA relevance.), 2019. http://data.europa.eu/eli/reg_del/2019/2016/oj

Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC (Text with EEA relevance), 2024. https://eur-lex.europa.eu/eli/reg/2024/1781/oj

IEC (Nov. 2014a). *International Electrotechnical Commission; IEC 60050 - International Electrotechnical Vocabulary - Details for IEV number 904-03-02: 'primary function'*. https://www.electropedia.org/iev/iev.nsf/display?openform&ievref=904-03-02

IEC (Nov. 2014b). International Electrotechnical Commission; IEC 60050 - International Electrotechnical Vocabulary - Details for IEV number 904-03-03: 'secondary function'. https://www.electropedia.org/iev/iev.nsf/display?openform&ievref=904-03-03

IEC (Nov. 2014c). International Electrotechnical Commission; IEC 60050 - International Electrotechnical Vocabulary - Details for IEV number 904-03-04: 'tertiary function'. https://www.electropedia.org/iev/iev.nsf/display?openform&ievref=904-03-04

Liedtke, C., Bienge, K., Wiesen, K., Teubler, J., Greiff, K., Lettenmeier, M., & Rohn, H.

(2014). Resource Use in the Production and Consumption System—The MIPS Approach. Resources, 3(3), 544–574. https://doi.org/10.3390/resources3030544

Schischke, K., Berwald, A., Dimitrova, G., Rückschloss, J., Nissen, N. F., & Schneider-Ramelow, M. (2022). Durability, reparability and recyclability: Applying material efficiency standards EN 4555x to mobile phones and tablet computers. Procedia CIRP, 105, 619–624. https://doi.org/10.1016/j.procir.2022.02.103

Schlegel, M.-C [Moritz-C.], McAlister, C., & Rama, M. Pioneering Durability in Electronics - The Role of Standardisation in Policymaking and Vice Versa. In 2024 Electronics Goes Green 2024+ (pp. 1–7). https://doi.org/10.23919/EGG62010.2024.10631230

SVRV. (2024). Shaping the circular economy with the Digital Product Passport for consumers - recommendations from the SVRV to the the BMUV and consumer research on the basis of the work report.: Publications of the Expert Council for Consumer Affairs. German Advisory Council for Consumers. https://www.svr-verbraucherfragen.de/kreislaufwirtschaft-mit-dem-digitalen-produktpass-fuer-verbraucherinnen-gestalten/

Tochtrop, C., Geibler, J. von, Rückschloss, J., & Schlegel, M.-C [Moritz-Caspar]. Product Features: Upgraded Functionality or Sustainability Problem? An Environmental Assessment Approach for Additional Product Functions and Its Application in the Case of Fridge-Freezers. In 2024 Electronics Goes Green 2024+ (pp. 1–12). https://doi.org/10.23919/EGG62010.2024.10631252

United Nations. Digital economy report 2024: shaping an environmentally sustainable and inclusive digital future. United Nations conference on trade and development (UNCTAD).

Research paper
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Behavioural rebound effects and secondary benefits of sustainability-oriented design: two sides of the same coin?

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Keywords: Secondary Benefits; Rebound Effects; Behavioural Mechanisms; Design for Sustainability.

Abstract: Despite the growing body of research on the role of rebound effects (RE) in offsetting potential environmental gains, understanding of secondary benefits (SB) remains limited. SB are induced behavioural or systemic changes triggered by sustainability-oriented design that strengthen, rather than offset, potential environmental gains. To address this gap, this study aims to uncover the underlying behavioural mechanisms with the aid of a systematic literature review. A total of 59 relevant articles has been selected, resulting in the identification of 17 behavioural SB mechanisms. The mechanisms are clustered into five categories: identity, consistency, efficacy, goals, and motivation. For each mechanism, a definition, explanatory quote, moderator list, and source overview is provided. Although each mechanism is unique, similarities in mediators and moderators suggest an interconnected rather than isolated nature. An evaluation of the research trends indicates an increased number of examined interventions. Nevertheless, limitations regarding the diversity of interventions, the intention-behaviour gap, and self-report bias remain. After interpreting the results, potential connections between SB and RE mechanisms are addressed. This study concludes with three recommendations for research to develop a comprehensive understanding of SB mechanisms. Ultimately, this understanding could contribute to achieving the full environmental potential of sustainability-oriented design and preventing RE.

Introduction

Currently, the full environmental potential of sustainability-oriented design remains unrealized due to the occurrence of rebound effects (RE). In this paper, sustainability-oriented design is defined as the process to design interventions (i.e., products, services, or systems) with lower resource consumption, implemented by actors such as designers and engineers. RE are induced behavioural and systemic changes triggered by these interventions, offsetting ca. 47% of the potential sustainability gains, in some cases even resulting in a net-negative impact (i.e., a backfire) (Andrew & Pigosso, 2024). Despite growing recognition of the importance of RE, understanding of the underlying causal structures leading to RE (i.e., mechanisms) is still limited (Guzzo et al., 2024), with a prominent focus on the economic rather than behavioural (e.g., social, psychological) mechanisms (Exadaktylos & van den Bergh, 2021; Santarius & Soland, 2016; Sorrell et al., 2020). Behavioural research tends to focus on the “moral licensing” mechanism, explaining how the adoption of a sustainability-oriented intervention (e.g., refurbished laptop) can result in moral credits or credentials, creating the perception of entitlement to perform subsequent environmental questionable behaviour (e.g., not turning the laptop off), ultimately increasing resource consumption (Merritt et al., 2010; Tiefenbeck et al., 2013).

Contrary to RE, a topic remaining relatively unexplored is the occurrence of secondary benefits (SB), which are induced behavioural or systemic changes that reinforce, rather than offset, potential sustainability gains (Figure 1).

In this study, an environmental impact is defined as negative when it contributes to exceeding the safe operating space of the planetary boundaries (Rockström et al. 2009).

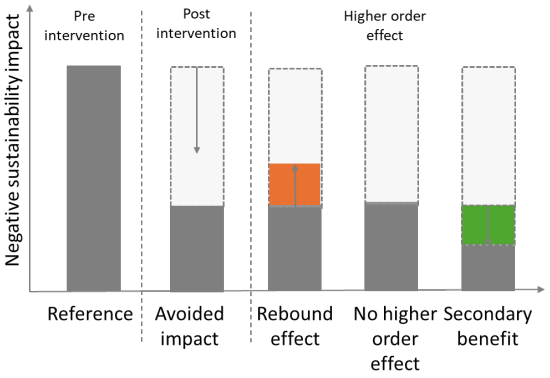


Figure 1. Illustration of a RE and SB

A behavioural SB mechanism occurs when a sustainability-oriented intervention (i.e., independent or predictor variable) triggers at least one change in social or psychological motivation (i.e., mediator) and corresponding behavioural change (i.e., mediator), eventually resulting in a higher order decrease in resource consumption (i.e., dependent or outcome variable) (Figure 2). Whereas the mediators (e.g., strengthened environmental identity) in a mechanism account for the relation between the independent and dependent variable, the moderators (e.g., environmental norms) affect the direction and/or strength of a relation between an independent and dependent variable (Baron & Kenny, 1986).

Although existing RE research generally fails to address SB (Vivanco et al., 2022), relevant insights can be found in spillover literature. A spillover effect occurs when engaging in one pro-environmental behaviour (PEB) prevents (i.e., negative spillover) or promotes (i.e., positive spillover) engagement in subsequent PEB (Truelove et al., 2014). For instance, a positive spillover effect arises when an initial PEB (e.g., recycling) strengthens the environmental identity of an actor resulting in subsequent behaviours in line with this identity (e.g., avoiding single use plastics) (Nilsson et al., 2017). Nevertheless, spillover mechanisms are insufficient to explain RE and SB due to structural differences (e.g., Nash et al., 2017).

Improved understanding of the occurrence of SB and the underlying mechanisms is needed to recognize under which circumstances sustainability-oriented interventions could lead to even more environmental gains than initially achieved. Consequently, this understanding might provide insights into how SB mechanisms can counteract RE mechanisms, ultimately contributing to a design process where the potential environmental gains from interventions are fully realized. Therefore, this study aims to define the potential behavioural mechanisms underlying the SB of sustainability-oriented interventions through a systematic literature review.

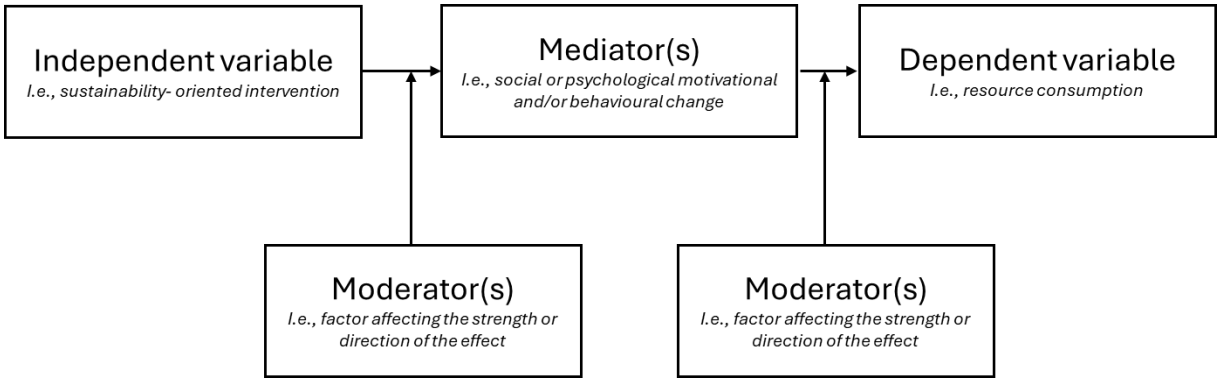


Figure 2. Illustration of a behavioural SB/RE mechanism.

Methodology

A systematic literature review, following the guidelines of Biolchini et al. (2005), is employed to obtain a comprehensive overview of the behavioural mechanisms leading to SB. The search string includes "secondary benefits" and related synonyms in the "title", and "behaviour" and "sustainability" and related synonyms in the "title, abstract, or keywords". Through Scopus, a scientific database known for its extensive journal coverage related to the topic (Falagas et al., 2008), 417 unique articles have been identified. Articles are excluded when not meeting one or more inclusion criteria: elaborating on a (i) behavioural mechanism; (ii) SB; and (iii) the environmental sustainability context. After filtering, 59 articles are selected for the final analysis.

Next, the behavioural SB mechanisms are extracted from the articles. For clarification purposes, the mechanisms are clustered into 5 inductively defined categories. Information on the mediators and moderators of the mechanisms along with the polarity of the relationships (i.e., + if reinforcing, - if offsetting) and an explanatory quote, is used for the development of a comprehensive mechanism overview. Information on the independent variable (e.g., type of intervention) and dependent variable (e.g., measured outcome) is used to develop a reflection of related research trends. Lastly, the results are interpreted, discussed, and translated into three recommendations for researchers to increase understanding of the implications of sustainability-oriented interventions.

Results

This section presents an overview of the identified behavioural mechanisms underlying SB followed by an evaluation of related research trends.

Behavioural mechanisms leading to SB

The 17 identified behavioural mechanisms explain distinct reasons for changes in PEB. The mechanisms are clustered into five not mutually exclusive categories: identity, consistency, efficacy, goals, and motivation (Figure 3). All mechanisms have been examined in an environmental sustainability context, of which most elaborate on conservation (i.e., 26%), carbon footprint (i.e., 29%) and/or circularity (i.e., 15%). It is important to notice, that no significant effect size was found for a few mechanisms (i.e., environmental social identity, goal contagion, and collective efficacy).

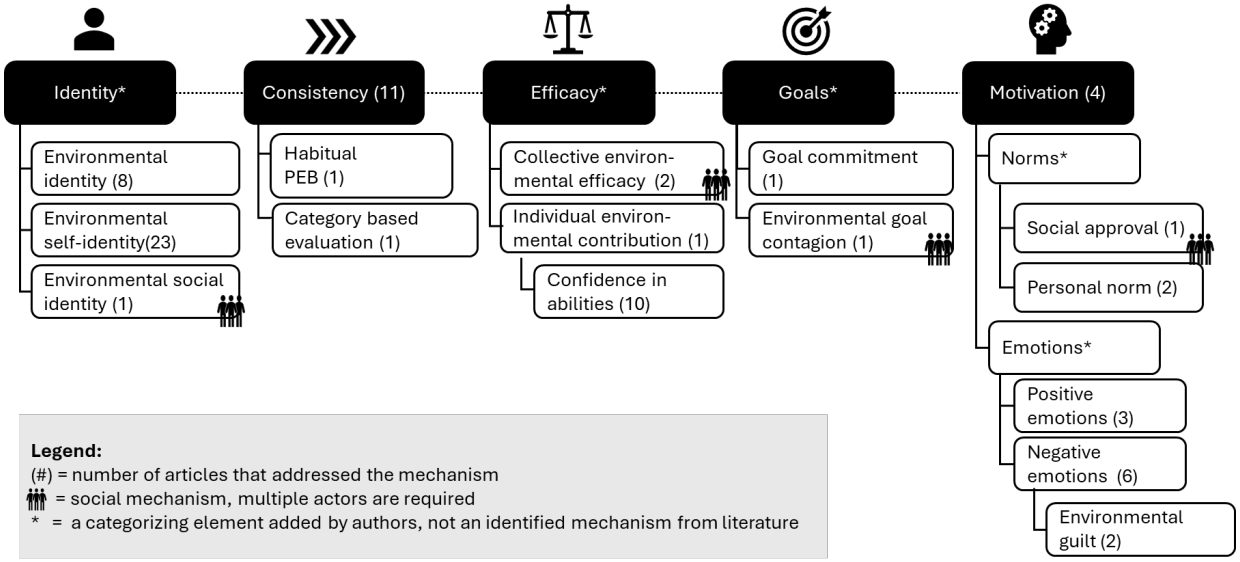


Figure 3. Categorised behavioural mechanisms leading to SB.

Identity

Identity mechanisms (Figure 4) influence how individuals perceive themselves in relation to the environment (i.e., environmental identity), their self-concept (i.e., environmental self-identity), or social group (i.e., environmental social identity):

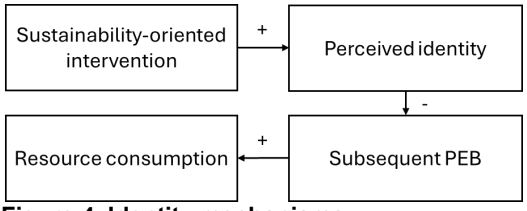


Figure 4. Identity mechanisms.

(1) Environmental self-identity: Identity perception in terms of caring for the environment.
Explanatory quote: "Driving a car with remanufactured components makes me identify myself as an environmentally friendly person and increase other PEB"
Moderators: Initial PEB is more difficult than subsequent PEB and initial and subsequent PEB are similar. Actor has high moral/environmental identity, educational attainment, family income levels, and environmental awareness, strong consistent personality, personal ecological norms, and salient environmental goals.
Sources (23): Capstick et al., 2019; Fanghella et al., 2019; Geiger et al., 2021; Geng et al., 2019; Haggar et al., 2023; Henn et al., 2020; Lacasse, 2016; Lauren et al., 2019; Lope & Weave, 2021; Maki et al., 2019; Nash et al., 2019; Nilsson et al., 2017; Puntiroli et al., 2022; Steinhorst & Matthies, 2016; Thøgersen & Crompton, 2009; Truelove et al., 2014; Truelove & Nugent, 2020; Van Der Werff & Steg, 2018; Wolstenholme et al., 2020; Yang, Cheng, et al., 2021; Yang, Wei, et al., 2021; Zhang et al., 2024; Zhou et al., 2017

(2) Environmental identity: Identity perception in terms of closeness to the natural environment.
Explanatory quote: "Walking instead of driving makes me feel closer to the environment and increase other PEB".
Moderators: Initial PEB is more difficult than subsequent PEB, actor has a high level of professional knowledge.
Sources (8): Frezza et al., 2019; Mateer et al., 2023; Poortinga et al., 2013; Sparkman et al., 2021; Verfuerth et al., 2019; Xu et al., 2018a, 2018b; Zhao & Huangfu, 2023

(3) Environmental social-identity: Identification with environmental groups.
Explanatory quote: "I joined the remanufacturing program offered by my car maintenance supplier, now I feel part of the group of environmentalists and increase other PEB"
Moderators:-
Sources (1): Geiger et al., 2021

Consistency

Consistency mechanisms (Figure 5) explain alignment of behaviours over time. Three consistency mechanisms have been identified, including habitual PEB and category-based evaluation as sub-mechanisms of need for consistency:

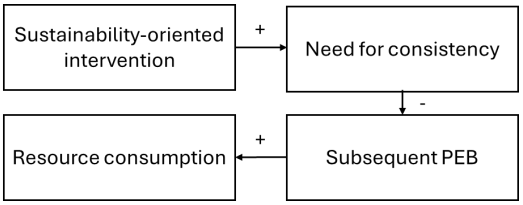


Figure 5. Need for consistency mechanisms.

(4) Need for consistency: Preference for stable patterns of behaviour.
Explanatory quote: "I drive a car with a remanufactured engine, now I also feel the need to get a remanufactured rather than brand new laptop"
Moderators: Initial PEB is more difficult than subsequent PEB and initial and subsequent PEB are similar. Actor has high educational attainment, family income, and environmental awareness, strong consistent personality, environmental self-identity, personal ecological norms, an analytical mindset, and recognises behaviour as normative.
Sources (11): Capstick et al., 2019; Geiger et al., 2021; Nilsson et al., 2017; Penz et al., 2019; Puntiroli et al., 2022; Sintov et al., 2019; Spaccatini et al., 2023; Steinhorst & Matthies, 2016; Suárez-Varela & Dinar, 2020; Thøgersen & Crompton, 2009; Zhou et al., 2017

(5) Habitual PEB: The establishment of automatic behaviours.
Explanatory quote: "Whenever a car part breaks, I try to repair it myself, which makes it

likely that I will apply this habit to other products too"
Moderators:-
Sources (1): Peng et al., 2024

(6) Category-based evaluation: The need to align behaviours of the same category.
Explanatory quote: "I drive a car with remanufactured parts, now I also feel the need to drive more energy-efficient to further reduce the negative environmental impacts of my mobility behaviours"
Moderators:-
Sources (1): Thøgersen ,1999

Efficacy

Efficacy mechanisms (Figure 6) deal with the perceived ability to effectively contribute to the outcome. Three efficacy mechanisms have been identified on the individual level (i.e., confidence in abilities, individual environmental contribution) and social level (i.e. collective environmental efficacy):

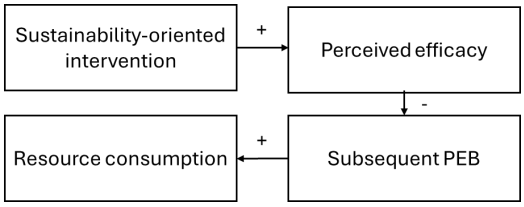


Figure 6. Efficacy mechanisms.

(7) Confidence in own abilities: Perceived confidence in one's own knowledge and skills.
Explanatory quote: "I got a car with remanufactured parts, which gives me knowledge and skills that make it easier to adopt other remanufactured products"
Moderators: Initial and subsequent PEB are similar. Actor has a strong consistent personality and environmental self-identity.
Sources (10): Elf et al., 2019; Haggar et al., 2023; Kaida & Kaida, 2015; Lauren et al., 2016, 2019; Lope & Weave, 2021; Nilsson et al., 2017; Steinhorst et al., 2015; Wang et al., 2024; Ye et al., 2022

(8) Individual environmental contribution: Perception of added value to the environment.
Explanatory quote: "I drive a car with remanufactured instead of brand-new parts, this convinces me that I can make a difference and makes me increase other PEB"
Moderators:-
Sources (1): Arias & Trujillo, 2020

(9) Collective environmental efficacy: Perception of collective willingness and competency to make positive environmental impact.
Explanatory quote: "Learning about the remanufacturing initiatives in my neighborhood convinces me that we can make a difference together and stimulates me to increase PEB"
Moderators:-
Sources (2): Haggar et al., 2023; Lauren et al., 2019

Goals

The mechanisms in the goals cluster (Figure 7) relate to the pursuit of specific objectives. Environmental goal contagion and goal commitment are the two identified goal mechanisms:

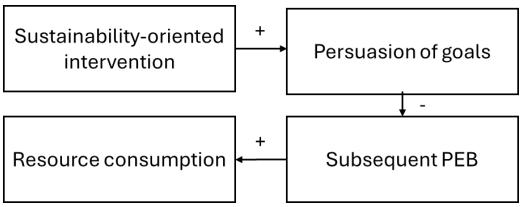


Figure 7. Goal mechanisms.

(10) Environmental goal contagion: Adopting goals from other actors.
Explanatory quote: "Seeing my colleagues using remanufactured products inspires me to choose remanufactured rather than brand-new parts to my car"
Moderators: Messenger is significant to actor and the actor and messenger belong to the same social group.
Sources (1): Jaich et al., 2023a

(11) Environmental goal commitment: Likelihood to pursue objectives.
Explanatory quote: "Driving a car with remanufactured parts motivates me to set a goal to lower my general environmental footprint and increase other PEB"
Moderators: User has low levels of relative deprivation and low levels of segmentation preference.
Sources (1): Zhao et al., 2024

Motivation

Motivation mechanisms (Figure 8) are related to changes in the driving forces of behaviours. Five motivation mechanisms have been identified, of which environmental motivation can be interpreted as the overarching mechanism. Negative emotion and environmental guilt can be interpreted as the emotional mechanisms and personal norms and social approval can be identified as the norm mechanisms:

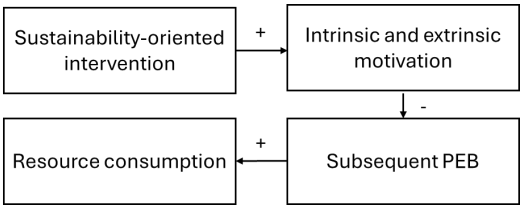


Figure 8. Motivation mechanisms.

(12) Environmental motivation: Includes intrinsic (e.g., autonomy, relatedness, competence) and extrinsic (e.g., rewards) motivators.
Explanatory quote: "I enjoy driving a car with remanufactured parts, which makes me motivated to go for the most sustainable option more often"
Moderators:-
Sources (3): Akers & Yasué, 2019; Toussard & Meyer, 2024; Wang et al., 2021

(13) Negative emotions: Includes anger, worry, guilt.
Explanatory quote: "Learning about the negative environmental impact of short product lifetimes in the mobility industry makes me angry and motivates me to increase PEB in multiple domains"
Moderators: Initial and subsequent PEB are similar, actor has low product involvement.
Sources (6): Carrico et al., 2018; Ha & Kwon, 2016; Sparkman et al., 2021; Truelove & Nugent, 2020; Wang et al., 2021; Xu et al., 2018a

(14) Environmental guilt: Feeling of remorse and regret related to the environment.
Explanatory quote: "Learning about the negative impact of short product lifetimes in the mobility industry makes me feel guilty and motivates me to increase PEB in multiple domains"
Moderators: Initial and subsequent PEB are similar.
Sources (2): Truelove & Nugent, 2020; Yang, Cheng, et al., 2021

(15) Positive emotions: Includes pleasure, pride, approval.
Explanatory quote: "Driving a car with remanufactured instead of brand new parts makes me feel happy about reducing negative environmental impact, and motivates me to involve in other PEB"
Moderators: Actor has a high level of professional knowledge.
Sources (3): Wang et al., 2024; Ye et al., 2022; Zhao & Huangfu, 2023

(16) Personal norm: The moral obligation to do the 'right thing'.
Explanatory quote: "After learning about the negative environmental impact of short product life times in the mobility sector, I realized I am not living up to my moral standards and decided to increase PEB in multiple domains"
Moderators:-
Sources (2): Lacasse, 2019; Steinhorst et al., 2015

(17) Social approval: Injunctive norms.
Explanatory quote: "Seeing many cars with remanufactured parts makes me realize this is the norm and adopt a remanufactured instead of a brand-new parts too"
Moderators: Recognising behaviour as normative.
Sources (1): Jaich et al., 2023b

Research trends

Sustainability-oriented intervention trends are investigated based on nine intervention categories (adopted from Geiger et al. (2021)). While the number of studies uncovering behavioural SB mechanisms and the diversity in interventions is increasing (Figure 9), most interventions are behavioural rather than economic, political, or technological, which could limit our understanding of the occurrence of behavioural SB mechanisms in different contexts.

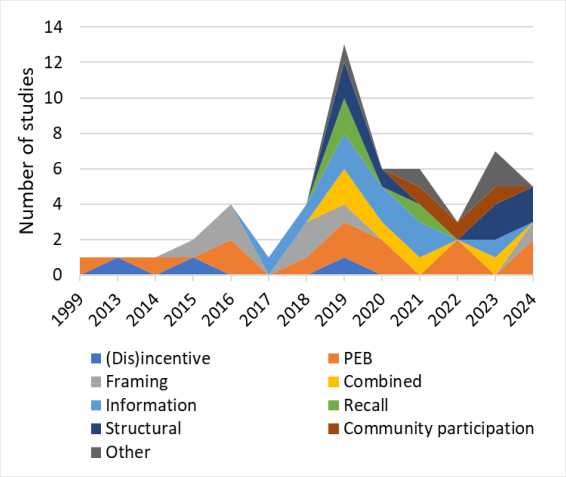


Figure 9. Examined interventions over time.

Additionally, most studies are empirical studies measuring behavioural change as a change in self-reported or intended behaviour rather than actual behaviour (Figure 10), potentially reflecting an intention-behaviour gap (Sheeran & Webb, 2016) and response bias (Van de Mortel, 2008).

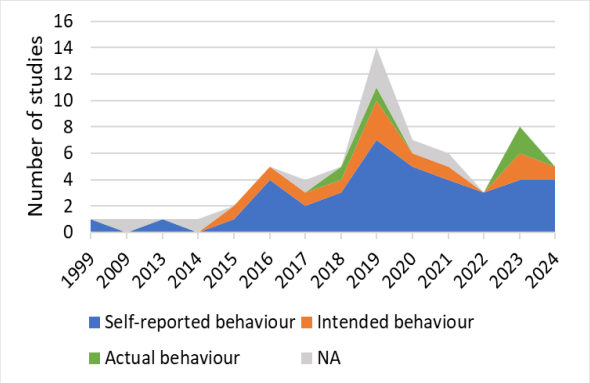


Figure 10. Measured behavioural outcomes over time.

Discussion

To improve the understanding of the relatively unexplored SB, this study identified 17 behavioural SB mechanisms through a systematic literature review, clustered in 5 areas. Even though each mechanism is unique demonstrating that SB can happen because of different reasons, some of the mechanisms have similar mediators. For instance, goal contagion can be seen as a motivational change and the need for consistency is reflected in the goal commitment mechanism. This suggests that the mechanisms do not always occur in isolation and can interact. Additionally, the results demonstrate that different mechanisms can be strengthened by similar moderators. For instance, similarity of the initial and subsequent behaviour is said to strengthen the preference for consistency, confidence in own abilities, negative emotions, environmental guilt, and environmental self-identity mechanism. Taken together, this indicates that in specific cases one intervention can be used to alter multiple SB mechanisms.

A comparison of the behavioural mechanisms leading to RE and SB reveals potential relationships. Moral licensing (RE), for instance, seems to counteract the need for consistency (SB), while negative stereotypes (RE) neutralise social approval (SB), and motivational crowding (RE) seems to counterbalance environmental motivation (SB). The connections between SB and RE mechanisms highlight the importance of in-depth mechanism analysis to develop accurate predictions and interventions capable of maximising environmental gains. Nevertheless, it is important to note that directions cannot be made for all RE and SB mechanisms. For instance, both information overload (RE) and environmental identity (SB) do not have a clear counteracting mechanism. Whereas this could suggest that certain mechanisms solely explain RE or SB, the gaps could also indicate that the counterparts of these mechanisms are still to be explored.

Nevertheless, one should keep in mind that RE and SB are heavily context dependent, and that the related negative and positive environmental sustainability impact can change accordingly.

The results can be translated into three research recommendations:

i. RE studies should further explore SB mechanisms as there exists a variety of SB mechanisms that might counteract or occur in parallel to the RE mechanisms. A better understanding of SB mechanisms, their effect sizes, and stimulation strategies can ultimately increase environmental gains and potentially prevent the occurrence of RE.
ii. SB researchers should tackle the existing limitations in literature (e.g., limited intervention diversity, intention-behaviour gap, response bias) to

improve understanding in different contexts. Additionally, since most results in this study stem from behavioural spillover literature, the assumptions made regarding changes in resource consumption should be addressed in follow-up studies to ensure the validity of the findings.

iii. Lastly, due to the novelty of the field, not all included mechanisms have been examined in a product lifetime context. SB research is encouraged to verify the assumptions made related to this context, and is additionally encouraged to examine different perspectives (e.g., economic, social), types of mechanisms (e.g., direct, indirect), sustainability domains (e.g., biodiversity), and research methods (e.g., qualitative) to build towards a more comprehensive understanding of SB.

Conclusion

The 17 identified behavioural SB mechanisms suggest that sustainability-oriented design can trigger behavioural or systemic changes resulting in strengthened environmental gains. Nevertheless, due to the novelty of the research area, future research is needed to examine the interaction with RE mechanisms, tackle the research gaps, and address different contexts. Ultimately, a comprehensive understanding of SB mechanisms can support designers in developing interventions that reach their full environmental potential.

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References

Andrew, E., & Pigosso, D. C. A. (2024). Multidisciplinary perspectives on rebound effects in sustainability: A systematic review. *Journal of Cleaner Production*, *470*. https://doi.org/10.1016/j.jclepro.2024.143366

Arias, C., & Trujillo, C. A. (2020). Perceived consumer effectiveness as a trigger of behavioral spillover effects: A path towards recycling. *Sustainability (Switzerland)*, *12*(11). https://doi.org/10.3390/su12114348

Baron, R. M., & Kenny, D. A. (1986). *The Moderator-Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations* (Vol. 51, Issue 6). Psychological Association, Inc.

Biolchini, J., Gomes Mian, P., Candida Cruz Natali, A., & Horta Travassos, G. (2005). *Systematic Review in Software Engineering.*

Capstick, S., Whitmarsh, L. E., Nash, N. C., Haggar, P., & Lord, J. (2019). Compensatory and catalysing behavioural beliefs: Development and psychometric properties of an instrument for measuring spillover-related perceptions in seven countries. *Frontiers in Psychology*, *10*(APR). https://doi.org/10.3389/fpsyg.2019.00963

Carrico, A. R., Raimi, K. T., Truelove, H. B., & Eby, B. (2018). Putting Your Money Where Your Mouth Is: An Experimental Test of Pro-Environmental Spillover From Reducing Meat Consumption to Monetary Donations. *Environment and Behavior*, *50*(7), 723–748. https://doi.org/10.1177/0013916517713067

Elf, P., Gatersleben, B., & Christie, I. (2019). Facilitating positive spillover effects: New insights from a mixed-methods approach exploring factors enabling people to live more sustainable lifestyle. *Frontiers in Psychology*, *9*(JAN). https://doi.org/10.3389/fpsyg.2018.02699

Exadaktylos, F., & van den Bergh, J. (2021). Energy-related behaviour and rebound when rationality, self-interest and willpower are limited. *Nature Energy*, *6*(12), 1104–1113. https://doi.org/10.1038/s41560-021-00889-4

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses. *FASEB Journal*, *22*(2), 338–342. https://doi.org/10.1096/fj.07-9492LSF

Fanghella, V., d'Adda, G., & Tavoni, M. (2019). On the use of nudges to affect spillovers in environmental behaviors. *Frontiers in Psychology*, *10*(JAN). https://doi.org/10.3389/fpsyg.2019.00061

Font Vivanco, D., Freire-González, J., Galvin, R., Santarius, T., Walnum, H. J., Makov, T., & Sala, S. (2022). Rebound effect and sustainability science: A review. *Journal of Industrial Ecology*, *26*(4), 1543–1563. https://doi.org/10.1111/jiec.13295

Frezza, M., Whitmarsh, L., Schäfer, M., & Schrader, U. (2019). Spillover effects of sustainable consumption: combining identity process theory and theories of practice. *Sustainability: Science, Practice, and Policy*, *15*(1), 15–30. https://doi.org/10.1080/15487733.2019.1567215

Geiger, S. J., Brick, C., Nalborczyk, L., Bosshard, A., & Jostmann, N. B. (2021). More green than gray? Toward a sustainable overview of environmental spillover effects: A Bayesian meta-analysis. *Journal of Environmental Psychology*, *78*. https://doi.org/10.1016/j.jenvp.2021.101694

Geng, L., Chen, Y., Ye, L., Zhou, K., & Chen, Y. (2019). How to predict future pro-environmental intention? The spillover effect of electricity-saving behavior under environmental and monetary framing. *Journal of Cleaner Production*, *233*, 1029–1037. https://doi.org/10.1016/j.jclepro.2019.06.088

Guzzo, D., Walrave, B., Videira, N., Oliveira, I. C., & Pigosso, D. C. A. (2024). Towards a systemic view on rebound effects: Modelling the feedback loops of rebound mechanisms. *Ecological Economics*, *217*. https://doi.org/10.1016/j.ecolecon.2023.108050

Ha, S., & Kwon, S. Y. (2016). Spillover from past recycling to green apparel shopping behavior: the role of environmental concern and anticipated guilt. *Fashion and Textiles*, *3*(1). https://doi.org/10.1186/s40691-016-0068-7

Haggar, P., Whitmarsh, L., & Nash, N. (2023). A Drop in the Ocean? Fostering Water-Saving Behavior and Spillover Through Information Provision and Feedback. *Environment and Behavior*, *55*(6–7), 520–548. https://doi.org/10.1177/00139165231201371

Henn, L., Otto, S., & Kaiser, F. G. (2020). Positive spillover: The result of attitude change. *Journal of Environmental Psychology*, *69*. https://doi.org/10.1016/j.jenvp.2020.101429

Jaich, H., Jastram, S. M., & Blind, K. (2023a). Organizational practices as drivers of societal change: contextual spillover effects of environmental management on employees' public sphere pro-environmental behavior. *Sustainability Accounting, Management and Policy Journal*, *14*(1), 130–153. https://doi.org/10.1108/SAMPJ-11-2021-0478

Jaich, H., Jastram, S. M., & Blind, K. (2023b). Spillover of Social Norms at Work On Employees' Self-Reported Private Sphere Pro-Environmental Behaviour: A Mixed Method Investigation. *Schmalenbach Journal of Business Research*, *75*(4), 519–547. https://doi.org/10.1007/s41471-023-00167-x

Kaida, N., & Kaida, K. (2015). Spillover effect of congestion charging on pro-environmental behavior. *Environment, Development and Sustainability*, *17*(3), 409–421. https://doi.org/10.1007/s10668-014-9550-9

Lacasse, K. (2016). Don't be satisfied, identify! Strengthening positive spillover by connecting pro-environmental behaviors to an "environmentalist" label. *Journal of Environmental Psychology*, *48*, 149–158. https://doi.org/10.1016/j.jenvp.2016.09.006

Lauren, N., Fielding, K. S., Smith, L., & Louis, W. R. (2016). You did, so you can and you will: Self-efficacy as a mediator of spillover from easy to more difficult pro-environmental behaviour. *Journal of Environmental Psychology*, *48*, 191–199. https://doi.org/10.1016/j.jenvp.2016.10.004

Lauren, N., Smith, L. D. G., Louis, W. R., & Dean, A. J. (2019). Promoting Spillover: How Past Behaviors Increase Environmental Intentions by Cueing Self-Perceptions. *Environment and Behavior*, *51*(3), 235–258. https://doi.org/10.1177/0013916517740408

Lope, C. W., & Weave, R. C. (2021). Understanding impacts of environmental stewardship programs through community geography: Pro-environment behaviors cultivated and reinforced. *Electronic Green Journal*, *1*(45), 1–28. https://doi.org/10.5070/G314548511

Maki, A., Carrico, A. R., Raimi, K. T., Truelove, H. B., Araujo, B., & Yeung, K. L. (2019). Meta-analysis of pro-environmental behaviour spillover. *Nature Sustainability*, *2*(4), 307–315. https://doi.org/10.1038/s41893-019-0263-9

Mateer, T. J., Melton, T. N., Miller, Z. D., Lawhon, B., Agans, J. P., Lawson, D. F., Brasier, K. J., & Taff, B. D. (2023). The Potential Pro-Environmental Behavior Spillover Effects of Specialization in Environmentally Responsible Outdoor Recreation. *Land*, *12*(11). https://doi.org/10.3390/land12111970

Merritt, A. C., Effron, D. A., & Monin, B. (2010). Moral Self-Licensing: When Being Good Frees Us to Be Bad. *Social and Personality Psychology Compass*, *4*(5), 344–357. https://doi.org/10.1111/j.1751-9004.2010.00263.x

Nash, N., Whitmarsh, L., Capstick, S., Hargreaves, T., Poortinga, W., Thomas, G., Sautkina, E., & Xenias, D. (2017). Climate-relevant behavioral spillover and the potential contribution of social practice theory. Wiley

Interdisciplinary Reviews: Climate Change, 8(6). https://doi.org/10.1002/wcc.481

Nash, N., Whitmarsh, L., Capstick, S., Thøgersen, J., Gouveia, V., Araújo, R. C. R., Harder, M. K., Wang, X., & Liu, Y. (2019). Reflecting on behavioral spillover in context: How do behavioral motivations and awareness catalyze other environmentally responsible actions in Brazil, China, and Denmark? *Frontiers in Psychology*, *10*(JUN). https://doi.org/10.3389/fpsyg.2019.00788

Nilsson, A., Bergquist, M., & Schultz, W. P. (2017). Spillover effects in environmental behaviors, across time and context: a review and research agenda. *Environmental Education Research*, *23*(4), 573–589. https://doi.org/10.1080/13504622.2016.1250148

Peng, X., Fang, P., Lee, S., Song, W., Wang, L., & Zhou, D. (2024). Overcoming double positive spillovers: automatic habits and dual environmental cognitions driving pro-environmental behaviors among hotel customers. *Journal of Sustainable Tourism*. https://doi.org/10.1080/09669582.2024.2325011

Penz, E., Hartl, B., & Hofmann, E. (2019). Explaining consumer choice of low carbon footprint goods using the behavioral spillover effect in German-speaking countries. *Journal of Cleaner Production*, *214*, 429–439. https://doi.org/10.1016/j.jclepro.2018.12.270

Poortinga, W., Whitmarsh, L., & Suffolk, C. (2013). The introduction of a single-use carrier bag charge in Wales: Attitude change and behavioural spillover effects. *Journal of Environmental Psychology*, *36*, 240–247. https://doi.org/10.1016/j.jenvp.2013.09.001

Puntiroli, M., Moussaoui, L. S., & Bezençon, V. (2022). Are consumers consistent in their sustainable behaviours? A longitudinal study on consistency and spillover. *Journal of Business Research*, *144*, 322–335. https://doi.org/10.1016/j.jbusres.2022.01.075

Rockström, J., Steffen, W., Noone, K. *et al.* A safe operating space for humanity. *Nature* 461, 472–475 (2009). https://doi.org/10.1038/461472a

Santarius, T., & Soland, M. (2016). Towards a psychological theory and comprehensive rebound typology. In *Rethinking Climate and Energy Policies: New Perspectives on the Rebound Phenomenon*. https://doi.org/10.1007/978-3-319-38807-6_7

Santarius, T., Walnum, H. J., & Aall, C. (2018). From unidisciplinary to multidisciplinary rebound research: Lessons learned for comprehensive climate and energy policies. In *Frontiers in Energy Research* (Vol. 6, Issue NOV). Frontiers Media S.A. https://doi.org/10.3389/fenrg.2018.00104

Sheeran, P., & Webb, T. L. (2016). The Intention–Behavior Gap. *Social and Personality Psychology Compass*, *10*(9), 503–518. https://doi.org/10.1111/spc3.12265

Sintov, N., Geislar, S., & White, L. V. (2019). Cognitive Accessibility as a New Factor in Proenvironmental Spillover: Results From a Field Study of Household Food Waste Management. *Environment and Behavior*, *51*(1), 50–80. https://doi.org/10.1177/0013916517735638

Sorrell, S., Gatersleben, B., & Druckman, A. (2020). The limits of energy sufficiency: A review of the evidence for rebound effects and negative spillovers from behavioural change. *Energy Research and Social Science*, *64*. https://doi.org/10.1016/j.erss.2020.101439

Spaccatini, F., Riva, P., Richetin, J., Porcelli, E., Pancani, L., Capellini, R., & Sacchi, S. (2023). From past to present (for a better future): The moderating role of cognitive mindset on spillover effects in environmental behaviors. *Current Psychology*, *42*(18), 15858–15873. https://doi.org/10.1007/s12144-022-02917-2

Sparkman, G., Attari, S. Z., & Weber, E. U. (2021). Moderating spillover: Focusing on personal sustainable behavior rarely hinders and can boost climate policy support. *Energy Research and Social Science*, *78*. https://doi.org/10.1016/j.erss.2021.102150

Steinhorst, J., Klöckner, C. A., & Matthies, E. (2015). Saving electricity - For the money or the environment? Risks of limiting pro-environmental spillover when using monetary framing. In *Journal of Environmental Psychology* (Vol. 43, pp. 125–135). Academic Press. https://doi.org/10.1016/j.jenvp.2015.05.012

Steinhorst, J., & Matthies, E. (2016). Monetary or environmental appeals for saving electricity? -Potentials for spillover on low carbon policy acceptability. *Energy Policy*, *93*, 335–344. https://doi.org/10.1016/j.enpol.2016.03.020

Suárez-Varela, M., & Dinar, A. (2020). The role of curtailment versus efficiency on spillovers among pro-environmental behaviors: Evidence from two towns in Granada, Spain. *Sustainability (Switzerland)*, *12*(3). https://doi.org/10.3390/su12030769

Thøgersen, J., & Crompton, T. (2009). Simple and painless? The limitations of spillover in environmental campaigning. *Journal of Consumer Policy*, *32*(2), 141–163. https://doi.org/10.1007/s10603-009-9101-1

Thøgersen, J. (1999). Spillover processes in the development of a sustainable consumption

pattern. In *Journal of Economic Psychology* (Vol. 20).

Tiefenbeck, V., Staake, T., Roth, K., & Sachs, O. (2013). For better or for worse? Empirical evidence of moral licensing in a behavioral energy conservation campaign. *Energy Policy*, *57*, 160–171. https://doi.org/10.1016/j.enpol.2013.01.021

Truelove, H. B., Carrico, A. R., Weber, E. U., Raimi, K. T., & Vandenbergh, M. P. (2014). Positive and negative spillover of pro-environmental behavior: An integrative review and theoretical framework. *Global Environmental Change*, *29*, 127–138. https://doi.org/10.1016/j.gloenvcha.2014.09.004

Truelove, H. B., & Nugent, M. R. (2020). Straw wars: Pro-environmental spillover following a guilt appeal. *Journal of Environmental Psychology*, *72*. https://doi.org/10.1016/j.jenvp.2020.101521

Van de Mortel, T. F. (2008). Faking it: Social desirability response bias in selfreport research. *Australian Journal of Advanced Nursing*, *25*(4), 40–48.

Van der Loo, I.G.H, & Pigosso D.C.A. (2024). Explaining the rebound effects of sustainable design: a behavioural perspective. *Proceedings of the Design Society*, *4*, 1497-1506. doi:10.1017/pds.2024.152

Van Der Werff, E., & Steg, L. (2018). Spillover benefits: Emphasizing different benefits of environmental behavior and its effects on spillover. *Frontiers in Psychology*, *9*(DEC). https://doi.org/10.3389/fpsyg.2018.02347

Verfuerth, C., Jones, C. R., Gregory-Smith, D., & Oates, C. (2019). Understanding contextual spillover: Using identity process theory as a lens for analyzing behavioral responses to a workplace dietary choice intervention. *Frontiers in Psychology*, *10*(MAR). https://doi.org/10.3389/fpsyg.2019.00345

Wang, J., Yang, X., Bailey, A., & Wang, J. (2021). Positive spillover of consumers' sustainable behaviors: The mediating role of self-determination need satisfaction. *Journal of Cleaner Production*, *317*. https://doi.org/10.1016/j.jclepro.2021.128436

Wang, Y., Wang, S., Zhang, R., Ma, H., Hu, A., Wu, J., Yu, B., & Fan, S. (2024). Exploring the potential impact of household photovoltaic systems on low-carbon production behavior in rural areas: unveiling the pro-environmental spillover effect. *Frontiers in Energy Research*, *12*. https://doi.org/10.3389/fenrg.2024.1297575

Wolstenholme, E., Poortinga, W., & Whitmarsh, L. (2020). Two Birds, One Stone: The Effectiveness of Health and Environmental Messages to Reduce Meat Consumption and Encourage Pro-environmental Behavioral Spillover. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.577111

Xu, L., Zhang, X., & Ling, M. (2018a). Pro-environmental spillover under environmental appeals and monetary incentives: Evidence from an intervention study on household waste separation. *Journal of Environmental Psychology*, *60*, 27–33. https://doi.org/10.1016/j.jenvp.2018.10.003

Xu, L., Zhang, X., & Ling, M. (2018b). Spillover effects of household waste separation policy on electricity consumption: Evidence from Hangzhou, China. *Resources, Conservation and Recycling*, *129*, 219–231. https://doi.org/10.1016/j.resconrec.2017.10.028

Yang, S., Cheng, P., Wang, S., & Li, J. (2021). Towards sustainable cities: The spillover effects of waste-sorting policies on sustainable consumption. *International Journal of Environmental Research and Public Health*, *18*(20). https://doi.org/10.3390/ijerph182010975

Yang, S., Wei, J., & Cheng, P. (2021). Spillover of different regulatory policies for waste sorting: Potential influence on energy-saving policy acceptability. *Waste Management*, *125*, 112–121. https://doi.org/10.1016/j.wasman.2021.02.008

Ye, J., Yao, Y., & Li, L. (2022). The more involved, the more willing to participate: An analysis of the internal mechanism of positive spillover effects of pro-environmental behaviors. *Journal of Cleaner Production*, *375*. https://doi.org/10.1016/j.jclepro.2022.133959

Zhang, S., Ren, S., & Tang, G. (2024). From Passive to Active: The Positive Spillover of Required Employee Green Behavior on Green Advocacy. *Journal of Business Ethics*, *192*(1), 57–76. https://doi.org/10.1007/s10551-023-05494-x

Zhao, B., & Huangfu, X. (2023). The More Training, the More Willingness? A Positive Spillover Effect Analysis of Voluntary Behavior in Environmental Protection. *Sustainability (Switzerland)*, *15*(13). https://doi.org/10.3390/su151310069

Zhou, J., Liu, Q., Mao, R., & Yu, X. (2017). Habit spillovers or induced awareness: Willingness to pay for eco-labels of rice in China. *Food Policy*, *71*, 62–73. https://doi.org/10.1016/j.foodpol.2017.07.006

Extended Abstract
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The rebound mechanisms identification tool: finding rebound effects in circular economy business models

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Keywords: rebound effect, circular economy, business models, design tools

Introduction

The pervasive occurrence of rebound effects (RE) jeopardises the potential sustainability benefits of circular economy (CE) (Castro *et al.*, 2022; Metic and Pigosso, 2022; Zink and Geyer, 2017). RE are driven by economic and behavioural mechanisms that offset the potential sustainability gains of interventions (Guzzo *et al.*, 2024; Lange *et al.*, 2021).

Despite the evidence that rebound mechanisms are a critical path to addressing RE (Colmenares *et al.*, 2020; Guzzo *et al.*, 2024; Lange *et al.*, 2021; Metic and Pigosso, 2022), several challenges hinder the identification of rebound mechanisms in the early phases of circular economy business models (CEBM) innovation.

Designers struggle to anticipate potential RE emerging from CEBM interventions, as higher-level effects are hard to identify (Guzzo *et al.*, 2023). While tools for identifying RE in CE are emerging (Ackermann and Tunn, 2024; Das *et al.*, 2023; Metic *et al.*, 2024; Schultz *et al.*, 2024; Zerbino, 2022), they still fail to build the causal thread between the CE action and the rebound mechanisms, which would better explain RE and enable addressing them.

Building upon efforts into 'cracking the RE code' that conceptually associated the dynamics between CEBM patterns and rebound mechanisms (Guzzo and Pigosso, 2024a), this work aims to develop a rebound mechanisms identification tool to assist designers in systematically identifying potential rebound mechanisms emerging from CEBM. In this paper, we describe the steps for using the tool and demonstrate its use in one case (i.e., Bundles, a washing machine as a service solution). Directions for further development are also discussed.

Method

This research employed three steps for the conceptualisation and demonstration of the rebound mechanisms identification tool:

Step 1: The tool was developed by operationalising the knowledge about CEBM patterns, the actors potentially performing those patterns, and the stimulation of consumption factors to anticipate the activation of potential rebound mechanisms based on previous work (Guzzo and Pigosso, 2024a). It was implemented in Excel as a step-by-step process to assist designers in systematically revealing the interplay between CEBM patterns and rebound mechanisms.

Step 2: Document analysis (Yin, 2009) of a CEBM case was employed to demonstrate the use of the tool. The analysis of the CEBM patterns followed a strict content analysis of available descriptions for the case (Bundles, n.d.; Ellen Macarthur Foundation, 2021; Grassi and Zimmer, 2021), and comprised critical analyses of the stimulation of consumption factors activating rebound mechanisms.

Step 3: To test the usefulness of the tool, the results were compared with a previous case study aiming at RE identification of the Bundles case using a similar but more time-consuming method, carried out manually (Guzzo and Pigosso, 2024b).

Results

The rebound mechanisms identification tool

The application of the rebound mechanisms identification tool (Guzzo and Pigosso, 2025), which is implemented in Excel and intended for use in a workshop setting to analyse an existing CEBM or a CEBM concept, involves three main steps:

1. Analyse the BM
   a. Identify the relevant CEBM patterns based on a set of 24 BM patterns representing alternative configuration options (Pieroni et al., 2021).
   b. Determine the relevant actors considering business-to-business (B2B) and business-to-consumer (B2C) setups for the CEBM.

2. Determine the consumption factors (i.e., factors that lead to consumption and production activities) potentially stimulated by the selected CEBM patterns.

3. Review the scenarios for consumption factors stimulation to determine candidate rebound mechanisms activated within the CEBM, following the 26 underlying economic and behavioural rebound mechanisms (Guzzo *et al.*, 2024).

Case study: Bundles

The analysis of the case resulted in the selection of 10 CEBM patterns (step 1a), with the definition of the key actors (step 1b): Bundles (service provider), household consumers (renters), washing machine, and Miele (machine manufacturer)

Subsequently, out of the analysis of 38 instances of consumption factor stimulation suggested (step 2), 21 instances remained – 7 within the service provider (e.g., new revenues from the product as a service contract), 13 within household consumers (e.g., decreased costs to own a product by replacing products less frequently due to life care services), and one within product manufacturer (i.e., decreased costs from using circular supplies). Most factors are economic/financial (16), while some relate to consumer choices (5).

Finally, step 3 led to identifying economic/financial rebound mechanisms within the company (e.g., output, re-investment, and factor substitution mechanisms—8 instances) and the individuals (e.g., income, re-spending, and substitution mechanisms—7 instances). Three instances of motivational consumption and substitution mechanisms are also related to consumer choices (individuals).

Several of the consumption factors stimulation instances match the existing case study (e.g., reduced investment cost from consumers, decreased costs from more efficient use, and moral hazard from no ownership and no charges for repair), showing a consistent case analysis in a significantly shorter timeframe.

Nevertheless, the tool did not help identify rebound mechanisms linked to released time for household chores—previously identified. It limited the consideration of nuances that could constrain consumption factors, potentially leading to secondary benefits. Finally, the tool only indicates rebound mechanisms whose dynamics have been previously mapped.

Final remarks

By enabling the visualisation of the causal chains from the CEBM to RE via the stimulation of consumption factors and activation of rebound mechanisms, this research demonstrated the potential to enable the anticipation and prevention of potential RE.

The tool accelerated the identification of instances of consumption factor stimulation consistent with the previous case study, leading to the recognition of relevant rebound mechanisms for further consideration. The structured and stepwise approach shows promise to aid in identifying RE in CEBM cases.

Future research should expand the risk analysis of identified rebound mechanisms. Also, there is room to further integrate socio-behavioural mechanisms, secondary benefits, leverage points, and interventions beyond CEBM. The tool and its supporting conceptual frameworks ought to be examined as boundary objects for engaging with designers in structured and less structured applications, thereby facilitating the understanding of its strengths and limitations while ensuring its ability to assist non-specialists in recognising RE in CEBM.

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References

Ackermann, L. and Tunn, V.S.C. (2024), "Careless product use in access-based services: A rebound effect and how to address it", *Journal of Business Research*, Elsevier Inc., Vol. 177 No. August 2022, p. 114643. doi:10.1016/j.jbusres.2024.114643.

Bundles. (n.d.). "Bundles", available at: https://bundles.nl/ (accessed 13 November 2023).

Castro, C.G., Trevisan, A.H., Pigosso, D.A. and Mascarenhas, J. (2022), "The rebound effect of circular economy: Definitions, mechanisms and a research agenda", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 345 No. October 2021, p. 131136. doi:10.1016/j.jclepro.2022.131136.

Colmenares, G., Löschel, A. and Madlener, R. (2020), "The rebound effect representation in climate and energy models", *Environmental Research Letters*, Vol. 15 No. 12, available at:https://doi.org/10.1088/1748-9326/abc214. doi:10.1088/1748-9326/abc214.

Das, A., Konietzko, J., Bocken, N. and Dijk, M. (2023), "The Circular Rebound Tool : A tool to move companies towards more sustainable circular business models", *Resources, Conservation & Recycling Advances*, Elsevier B.V., Vol. 20 No. October, p. 200185. doi:10.1016/j.rcradv.2023.200185.

Ellen Macarthur Foundation. (2021), "A model offering multiple benefits for multiple electronic products: Bundles", available at: https://www.ellenmacarthurfoundation.org/circular-examples/a-model-offering-multiple-benefits-for-multiple-electronic-products (accessed 13 November 2023).

Grassi, C.A. and Zimmer, J. (2021), "Subscription-based, payment per use, sensors for household washing equipment", *Circle Economy*, available at: https://knowledge-hub.circle-economy.com/cirkular/article/3543 (accessed 13 November 2023).

Guzzo, D. and Pigosso, D.C.A. (2024a), "Cracking the code of rebound effects induced by circular economy", *Manuscript Submitted for Publication*.

Guzzo, D. and Pigosso, D.C.A. (2024b), "Identifying rebound effects in product-service systems: actors, mechanisms, triggers and drivers", *Proceedings of the Design Society*, Vol. 4, pp. 1279–1288. doi:10.1017/pds.2024.130.

Guzzo, D. and Pigosso, D.C.A. (2025), "The rebound mechanisms identification tool", Technical University of Denmark, doi:10.11583/DTU.28436777.v1.

Guzzo, D., Walrave, B. and Pigosso, D.C.A. (2023), "Unveiling the dynamic complexity of rebound effects in sustainability transitions: Towards a system's perspective", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 405 No. March, p. 137003. doi:10.1016/j.jclepro.2023.137003.

Guzzo, D., Walrave, B., Videira, N., Oliveira, I.C. and Pigosso, D.C.A. (2024), "Towards a systemic view on rebound effects: Modelling the feedback loops of rebound mechanisms", *Ecological Economics*, Vol. 217, p. 108050. doi:10.1016/j.ecolecon.2023.108050.

Lange, S., Kern, F., Peuckert, J. and Santarius, T. (2021), "The Jevons paradox unravelled: A multi-level typology of rebound effects and mechanisms", *Energy Research and Social Science*, Elsevier Ltd, Vol. 74, p. 101982. doi:10.1016/j.erss.2021.101982.

Metic, J., Guzzo, D., Kopainsky, B., Mcaloone, T.C. and Pigosso, D.C.A. (2024), "A simulation-based approach for investigating the dynamics of rebound effects in the Circular Economy: a case of use-oriented product/service system", *Journal of Environmental Management*, Elsevier Ltd, Vol. 365 No. December 2023, p. 121627. doi:10.1016/j.jenvman.2024.121627.

Metic, J. and Pigosso, D.C.A. (2022), "Research avenues for uncovering the rebound effects of the circular economy: A systematic literature review", *Journal of Cleaner Production*, Vol. 74 No. 1934, p. 133133. doi:10.1016/j.jclepro.2022.133133.

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2021), "Circular economy business model innovation: Sectorial patterns within manufacturing companies", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 286, p. 124921. doi:10.1016/j.jclepro.2020.124921.

Schultz, F.C., Valentinov, V., Reinhardt, R.J. and Pies, I. (2024), "The circular economy rebound effect: Reconceptualizing rebound approaches and mitigation opportunities from an ordonomic perspective", *Journal of Industrial Ecology*, Vol. 28 No. 3, pp. 374–385. doi:10.1111/jiec.13485.

Yin, R.K. (2009), *Case Study Research: Design and Methods*, *Essential Guide to Qualitative Methods in Organizational Research*, Vol. 5, available at:https://doi.org/10.1097/FCH.0b013e31822dda9e. doi:10.1097/FCH.0b013e31822dda9e.

Zerbino, P. (2022), "How to manage the Circular Economy Rebound effect: A proposal for contingency-based guidelines", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 378 No. March, p. 134584. doi:10.1016/j.jclepro.2022.134584.

Zink, T. and Geyer, R. (2017), "Circular Economy Rebound", *Journal of Industrial Ecology*, Vol. 00 No. 0, pp. 1–10. doi:10.1111/jiec.12545.

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The limitations of product longevity: Are longer product lifetimes really better for the environment?

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Keywords: product longevity; clothing; environmental impacts; literature review.

Introduction

Prolonging product lifetimes is an important strategy in the circular economy, as environmental benefits are expected from slower material cycles and reductions in production, transport, and waste (Cooper, 2020). However, our recent literature review on the environmental impact of product lifetime extension (PLE) revealed shortcomings in the underlying assumptions and a mismatch with the empirical research that could validate them (Maldini et al., unpublished). This paper builds on the literature review and ads a discussion on potential increases in environmental impact, using clothing as a case study. The expected environmental benefits of PLE rely on a logic of product substitution (see Fig 1), but instead, a logic of accumulation is most often found in clothing. Replacement behaviour is rare, and therefore longer product lifetimes do not result in the anticipated environmental savings. The implications of these findings are discussed, and recommendations for advancing knowledge on the impact of PLE across product types, users, and sectors are provided.

Method

In the previous study, a literature search focused on all products was conducted in the Scopus and Web of Science databases using two sets of search terms: longevity or durability-related, and sustainability-related. Further, a detailed process of backward citation tracking was applied, leading to a total of 192 publications, of which 37 were classified as empirical. In this follow-up study, we conduct a more detailed analysis of the existing empirical knowledge identified, specifically focusing on studies about clothing (12 publications), to discuss the implications of accumulation in assessing the environmental impact of PLE.

Findings

The identified publications anticipate environmental benefits of PLE across various product groups, except for those with high impact during use. Clothing is the most frequently studied category, followed by electronics, household appliances and vehicles. The most significant environmental benefits of PLE are attributed to savings in production, stemming from reduced demand due to delayed or avoided product replacement (see Fig. 1).

While literature on electronics, household appliances, and vehicles discusses PLE's environmental benefits with caution due to increasing energy efficiency (e.g. Iraldo et al. 2017; Kagawa et al. 2008), publications on clothing tend to discuss environmental savings with more certainty (e.g. Jung & Jin, 2014; Sun et al., 2021).

The 12 studies presenting empirical evidence on the environmental impact of clothing longevity include eight publications reporting results from LCAs (Beton et al., 2014; Farrant, 2008, Perdijk et al., 1995; Roos et al., 2015 as discussed by Roos et al., 2016; Slocinski and Fisher, 2016 as discussed by Laitala et al., 2018; Schmidt et al., 2016; Thomas et al., 2012; WRAP, 2012a,b) and Life Cycle Optimisation Modelling (Downes et al., 2011). Four publications report on consumer behaviour observed in the field (Armstrong & Park, 2020; Maldini et al., 2019; Stevenson & Gmitrowicz, 2012; WRAP, 2017). The LCAs rely on assumptions about product substitution previously discussed, except for Farrant (2008), who conducts field research on consumer behaviour to inform the LCA.

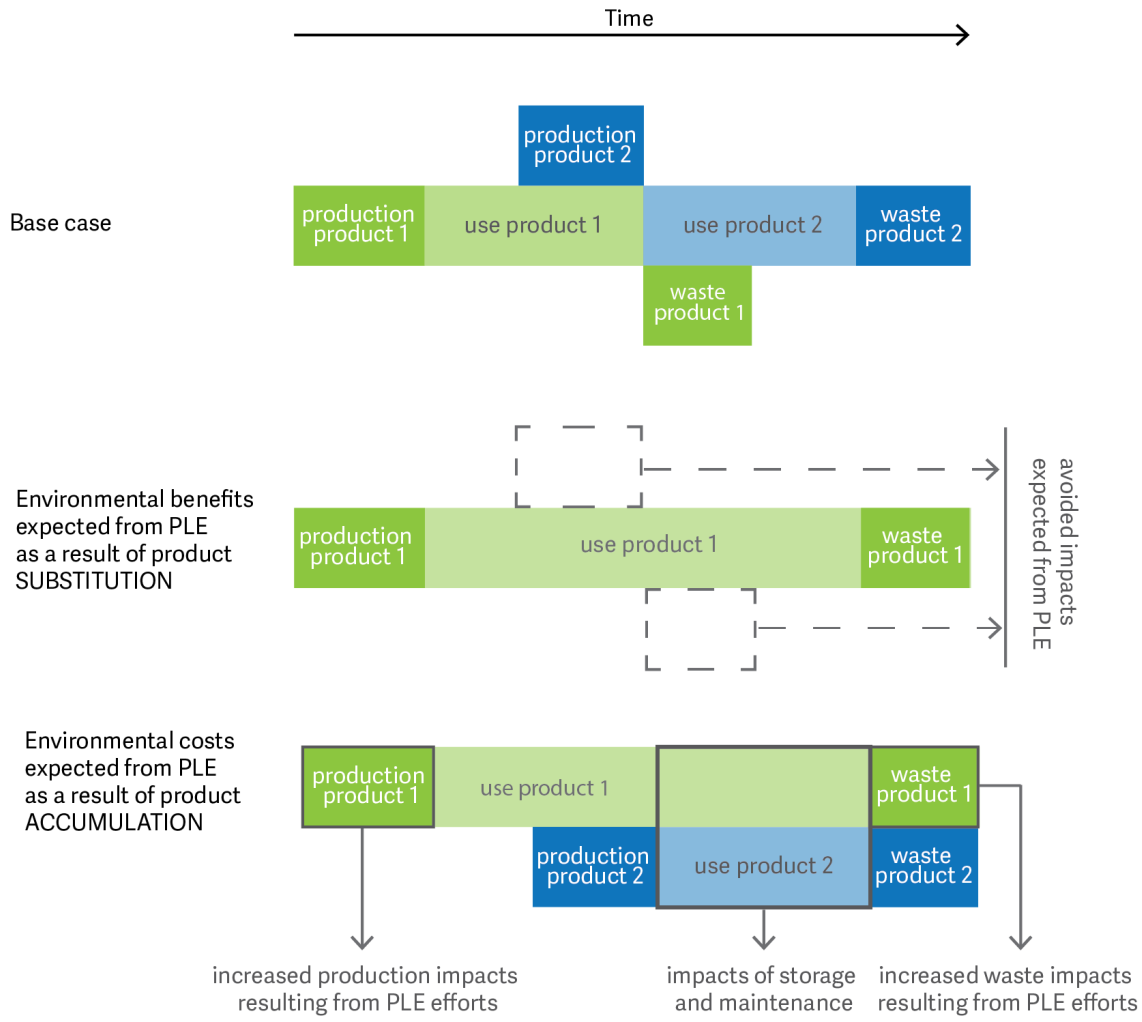


Figure 1. Environmental impacts of products over time and the expected effects of PLE in a scenario of product substitution vs. accumulation.

The other studies that include insights from consumer behaviour question the reductions in demand and production assumed by LCAs. They observe that longer clothing lifetimes reduce demand only if consumers refrain from new purchases, which is not the most common behaviour. These studies highlight the significance of clothing accumulation rather than demand reduction resulting from PLE.

Since quantitative assessments of the environmental impact on clothing lifetime extension rely on behaviours not confirmed in field research, it is questionable whether clothing longevity presents environmental benefits. Moreover, the context of product accumulation (rather than substitution) introduces additional environmental costs associated with PLE.

Discussion: Increased impact

Accumulating clothing and other consumer goods requires storage space (see Wieser et al. 2023). The impact of this additional infrastructure is not considered in any of the quantitative assessments reviewed. A study by Klint and Peters (2021) showed that the building space for washing machines is as impactful as the appliances themselves, indicating the importance of accumulation. Wardrobes grow over time (Haugrønning & Haugsrud, 2024), requiring space and attention. The fact that two thirds of clothes are not worn out when discarded might be related to this accumulation (Syversen et al., 2023).

Another negative effect may come from the growing focus on PLE in environmental policy (Heidenstrøm et al., 2021). Making clothes more "durable" is an important aim of the EU Textile Strategy (EC, 2022), and circular strategies in general (Klepp et al., 2023).

Current requirements for measuring durability favour synthetic materials because polyester, the most widely used fibre in textiles, is stronger and lighter than natural fibres (Fletcher et al., 2023). Evidence shows that consumers prefer natural fibres (Sigaard & Laitala, 2023) and use them for longer time and reuse them more often than synthetic materials, despite their lower physical durability (Laitala & Klepp, 2020). Moreover, fossil-based materials generate additional impacts associated with micro and macro plastic release (Kounina, 2024). Therefore, as Fig 1. shows, aiming at PLE may increase their environmental impact, especially if the savings expected from product substitution do not materialise.

Conclusion and recommendations

The environmental impact of PLE depends heavily on consumer and industry behaviour and their influence on product replacement or accumulation. Knowledge of how these behaviours vary across product groups, industries and users is lacking.

We suggest that research in the PLE field should avoid making claims about environmental impact without evidence. Much of the PLE literature does this, but repetition alone does not make something true. We recommend research on consumer and industry behaviour to understand not only when PLE reduces impact, but also how to make it effective. Examining the dynamics between the inflow, the outflow and the stock of products such as clothing is an important place to start.

The political implication of these findings is that PLE is not a solid foundation for environmental policy, as it is not known when reduction will occur. If the goal of the policy is to reduce environmental impact, it should instead be targeted towards quantities directly. So far, this approach has been effectively hindered (Maldini and Klepp, 2025 in press).

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References

Armstrong, C. M., & Park, H. (2020). Online Clothing Resale: A Practice Theory Approach to Evaluate Sustainable Consumption Gains. Journal of Sustainability Research, 2(2), 1–24. https://doi.org/10.20900/jsr20200017

Beton, A., Dias, D., Farrant, L., Gibon, T., Le Guern, Y., Desaxce, M., Perwueltz, A., Boufateh, I., Wolf, O., Kougoulis, J., Cordella, M., & Dodd, N. (2014). Environmental Improvement Potential of textiles (IMPRO Textiles). In Report EUR 26316 EN (January). https://doi.org/10.2791/52624

Cooper, T. (2020). Slower cycles: An essential characteristic of the circular economy. In S. Eisenriegler (Ed.), *The Circular Economy in the European Union: An Interim Review* (pp. 99–116). Springer. https://doi.org/10.1007/978-3-030-50239-3_9

Downes, J., Thomas, B., Dunkerley, C., & Walker, H. (2011). Longer Product Lifetimes: Summary Report.

EC. (2022). EU strategy for sustainable and circular textiles. Brussels Retrieved from https://ec.europa.eu/environment/publications/textiles-strategy_en

Farrant, L. (2008). Environmental benefits from reusing clothes. Master Thesis. Technical University Denmark.

Fletcher, K., Maldini, I., Klepp, I. G., Laitala, K., Måge, J., & Tobiasson, T. S. (2023). Ecodesign position paper: Textiles and footwear. In: Clothing Research.

Haugrønning, V., & Haugsrud, I. (2024). Comparing Male and Female Wardrobes: Gender Dynamics in the Practice of Dressing. In E. Jacobsen, P. Strandbakken, A. Dulsrud, & S. E. Skuland (Eds.), Consumers and Consumption in Comparison (Vol. 37, pp. 139-165). Emerald Publishing Limited. https://doi.org/10.1108/S0195-631020240000037007

Heidenstrøm, N., Strandbakken, P., Haugrønning, V., & Laitala, K. (2021). Product lifetime in European and Norwegian policies. https://oda.oslomet.no/oda-xmlui/handle/11250/2774663

Iraldo, F., Facheris, C., & Nucci, B. (2017). Is product durability better for environment and for economic efficiency? A comparative assessment applying LCA and LCC to two energy-intensive products. In *Journal of*

Cleaner Production (Vol. 140). https://doi.org/10.1016/j.jclepro.2016.10.017

Jung, S., & Jin, B. (2014). A theoretical investigation of slow fashion: Sustainable future of the apparel industry. *International Journal of Consumer Studies*, 38(5), 510–519. https://doi.org/10.1111/ijcs.12127

Kagawa, S., Kudoh, Y., Nansai, K., & Tasaki, T. (2008). The economic and environmental consequences of automobile lifetime extension and fuel economy improvement: Japan's case. *Economic Systems Research*, 20(1), 3–28. https://doi.org/10.1080/09535310801890615

Klepp, I. G., Løvbak Berg, L., Sigaard, A. S., Tobiasson, T. S., Hvass, K. K., & Gleisberg, L. (2023). THE PLASTIC ELEPHANT: overproduction and synthetic fibres in sustainable textiles strategies (SIFO-Project report 5-2023), https://hdl.handle.net/11250/3086387

Klint, E., & Peters, G. (2021). Sharing is caring - the importance of capital goods when assessing environmental impacts from private and shared laundry systems in Sweden. International Journal of Life Cycle Assessment, 26(6), 1085-1099. https://doi.org/10.1007/s11367-021-01890-5.

Kounina, A., Daystar, J., Chalumeau, S. et al. The global apparel industry is a significant yet overlooked source of plastic leakage. Nat Commun 15, 5022 (2024). https://doi.org/10.1038/s41467-024-49441-4

Laitala, K., Klepp, I., & Henry, B. (2018). Does Use Matter? Comparison of Environmental Impacts of Clothing Based on Fiber Type. *Sustainability*. https://doi.org/10.3390/su10072524

Laitala, K., & Klepp, I. G. (2020). What affects garment lifespans? International clothing practices based on wardrobe survey in China, Germany, Japan, the UK and the USA. Sustainability, 12(21), Article 9151. https://doi.org/10.3390/su12219151o

Maldini and Klepp (2025 in press) The EU Textile Strategy: how to avoid overproduction and overconsumption measures in environmental policy. *Journal of Sustainable Marketing.*

Maldini, I. Klepp, I.G., Laitala, K. The environmental impact of product lifetime extension: a literature review and research agenda. Unpublished

Maldini, I., Stappers, P. J., Gimeno-Martinez, J. C., & Daanen, H. A. M. (2019). Assessing the impact of design strategies on clothing lifetimes, usage and volumes: The case of product personalisation. *Journal of Cleaner Production*, 210, 1414–1424. https://doi.org/10.1016/j.jclepro.2018.11.056

Perdijk, E. W., Slob, A. F. L., & Steenwinkel, I. (1995). LOEP - Levensduur Optimalisatie en de E(nergie, economie en ecologie)-aspecten van Produkten.

Roos, S., Sandin, G., Zamani, B., & Peters, G. (2015). Environmental Assessment of Swedish Fashion Consumption. http://www.mistrafuturefashion.com/en/PublishingImages/Single-use pictures/Environmental assessment of Swedish fashion consumption - LCA.pdf

Roos, S., Zamani, B., Sandin, G., Peters, G. M., & Svanström, M. (2016). A life cycle assessment (LCA)-based approach to guiding an industry sector towards sustainability: the case of the Swedish apparel sector. Journal of Cleaner Production, 133, 691–700. https://doi.org/10.1016/j.jclepro.2016.05.146

Schmidt, A., Watson, D., Roos, S., Askham, C., & Poulsen, P. B. (2016). Gaining benefits from discarded textiles. In Nordic Council of Ministers. http://dx.doi.org/10.6027/TN2016-537

Sigaard, A. S., & Laitala, K. (2023). Natural and sustainable? Consumers' textile fiber preferences. Fibers, 11(2), Article 12. https://doi.org/10.3390/fib11020012

Slocinski, C., & Fisher, B. (2016). Use phase of wool apparel - supplement to the LCA Report.

Stevenson, A., & Gmitrowicz, E. (2012). Study into consumer second-hand shopping behaviour to identify the re-use displacement effect. https://zerowastescotland.org.uk/sites/default/files/Study into consumer second-hand shopping behaviour to identify the re-use displacement affect.pdf

Sun, J. J., Bellezza, S., & Paharia, N. (2021). Buy Less, Buy Luxury: Understanding and Overcoming Product Durability Neglect for Sustainable Consumption. *Journal of Marketing*, 85(3), 28–43. https://doi.org/10.1177/0022242921993172

Syversen, F., Klepp, I. G., Skogesal, O., Rabben, K., Sigaard, A. S., Berg, L. L., & Laitala, K. (2023). *Dypdykk i materialstrømmene for tekstiler fra husholdninger i Norge*. https://mepex.no/wp-content/uploads/2024/02/05.01.24_Mepex_Dypdykk-i-materialstrommene-for-tekstiler-fra-husholdninger-i-Norge-1-1.pdf

Thomas, B., Fishwick, M., Joyce, J., & van Santen, A. (2012). A Carbon Footprint for UK

Clothing and Opportunities for Savings - Final Report.

Wieser, H., Hofmann, F., Jaeger-Erben, M. & Marwede, M. (2023). Durable economies: towards a new research programme. In M. Jaeger-Erben, H. Wieser, F. Hofmann, & M. Marwede (Eds.), *Durable Economies: Organizing the Material Foundations of Society*. Transcript, Bielefeld, pp. 7-48 https://www.transcript-publishing.com/media/pdf/46/e7/1d/oa9783839463963.pdf

WRAP (2012a). Valuing our Clothes: the Evidence Base. Technical Report.

WRAP (2012b). Valuing our clothes. The True Cost of how we Design, Use and Dispose of Clothing in the UK. http://www.wrap.org.uk/content/valuing-our-clothes

WRAP (2017). Valuing Our Clothes: the Cost of UK Fashion. http://www.wrap.org.uk/sites/files/wrap/valuing-our-clothes-the-cost-of-uk-fashion_WRAP.pdf

Extended Abstract
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Recommerce Rebound Effects- The Case of Second-hand Apparel

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Keywords: Rebound; Reuse; second-hand; displacement; LCA; GHG

Introduction

Reuse is widely recognized as one of the main cornerstones of sustainability and a key strategy in the much-needed circular economy transition (Cooper and Gutawski, 2017). By extending product lifespans, reuse allows to meet human needs with fewer material and energy inputs (Makov & Font Vivanco, 2018; Makov et al., 2018, Zink and Gayer, 2017). For example, estimates suggest that the average T-shirt is only worn 7-20 times while its functional durability typically extends far beyond that. Since most of the environmental impacts associated with apparel are related to production stages, reuse of pre-owned garments, is seen as an especially promising sustainability strategy (Niinimäki et al., 2020; Vesterinen & Syrjälä, 2022; Moon 2023).

Though apparel reuse is by no means a new phenomenon, digital second-hand markets, also referred to as reCommerce, and specifically those focusing on fashion and apparel items have experienced significant growth in the past few decades (Makov et al., 2018; Meshulam et al., 2022). Driven by the convenience of online platforms, the growing availability of apparel items, and increased consumer interest in sustainable fashion alternatives, the global second-hand apparel market is expected to reach $350 billion globally by 2028, according to recent industry reports (ThredUp, 2023; Statista, 2023). Yet despite its vast potential, the net environmental benefits of reuse through second-hand markets may fall short of expectations.

Pre-owned (i.e. used) items are often not perfect substitutes for new ones. Research suggest that consumers expect used products to have shorter lifespans compared to identical new items (Sandin and Peters, 2018; Amatuni et al., 2023). As such, purchasing a pre-owned apparel items doesn't always displace the purchase nor lead to the avoided production of a new item at a 1:1 ratio (Sandin and Peters, 2018). In fact, despite fears across different industries that sales of used products cannibalize sales of new ones, research suggests that higher sales volumes in second-hand markets don't necessarily lower sales of new ones substantially (Blass & Geyer, 2006; Thomas, 2012, Zink and Gayer, 2017). Instead, the availability and expansion of second-hand markets often times triggers additional demand- a phenomenon typically studied under the construct of environmental rebound effect Font Vivanco et al., 2022; Makov & Font Vivanco, 2018).

Rebound effects are broadly defined as the share of expected environmental benefits that are offset when behavioral and market responses to improved environmental efficiency, trigger added demand. In a recent survey of US second-hand shoppers, many respondents indicated they agree with the statement "*if I couldn't shop second-hand, I would be buying less apparel*" (ThredUp 2022, pg 22). Such added demand for clothing, can be conceptualized as a direct rebound effect. Relatedly, when consumers use money saved from buying second-hand on other products and services (e.g. food or leisure) such added consumption can be conceptualized as indirect (or re-spending) rebound effects (Meshulam et al., 2022). While, the environmental impacts associated with added demand from direct or indirect rebound may offset some or even all of the expected environmental benefits of buying used apparel, these are seldom taken into account fully by researches, businesses, policy makers, or sustainability advocates. As a result, the potential contribution reCommerce can make to climate change mitigation and keeping within planetary boundaries may be systematically overestimated.

Methods

Here we quantify second-hand apparel rebound effects and assess the share of expected environmental benefits that are offset under

three scenarios- I) No rebound, II) indirect rebound only, and III) full rebound.

Building on data covering over 11 million pre-owned apparel items sold in the US during 2023 via eBay.com, we first quantify expected environmental benefits of second-hand apparel using EXSIOBASE - an environmentally extended input output model which allows us to assess environmental impacts such as GHG emissions based on monetary data (Stradler et al., 2018). Under scenario I (No rebound) we assume all used items bought are perfect substitutes for new ones, and each purchase of a used clothing item leads to the avoided production (and subsequently avoided impacts) of a new one. Under Scenario II (Indirect rebound only), we account for cost savings resulting from cheaper prices in 2nd hand markets and consider re-spending rebound effects- namely, the share expected benefits which are offset when consumers use money saved to buy other (non-apparel) products and services. Following the approach outlined in Meshulam et al. (2022), we model re-spending of marginal savings across consumption categories (COICOP) using Almost ideal demand model (AIDS), and then quantify negated environmental benefits using EXSIOBASE. Finally, we account for both re-spending and imperfect substitution between new and used items under scenario III (full rebound). Combining AIDS with market research reports and surveys among US second-hand apparel shoppers we assess the share of expected GHG emission eroded. Specifically, we assume a 64% displacement rate between used and new apparel items, and that all other cost savings are re-spent on the other consumption categories proportionally.

Results

We find that under the Baseline scenario (Scenario I), expected avoided emissions resulting from reuse of apparel items sold in the US via eBay.com amounted to almost 340 million kg of CO_2e. Of these, 47% were potentially offset by indirect rebound effects (Scenario II), as consumers re-spent the money saved by shopping second-hand to buy other products and services. When also accounting for imperfect substitution (Scenario III) where only 64% of used items replace new ones (Farfetch, 2020; ThredUp, 2022), we find that 55% of the expected avoided GHG were potentially offset on account of both direct and indirect rebound effects (Scenario III).

Conclusions

reCommerce holds much promise to alleviate the environmental impacts associated with apparel consumption through reuse. However, greater material efficiency, cheaper prices, and the ease of buying via second-hand digital platforms may trigger added demand and rebound effects. Here we propose a comprehensive approach to fully account for both income effects and imperfect displacement under the construct of rebound effects. Our results indicate that rebound can potentially erode over half of the expected environmental benefits of apparel reuse. These results highlight the limits of sustainable behavioral changes that also lower the effective price of goods and such savings are typically re-spent and thus have environmental impacts. To the best of our knowledge, this work presents one of the first attempts to quantify rebound effects resulting from apparel reuse via secondary markets. More work is needed to ascertain if and how rebound effects would look under different replacement rates, geographies, and for different items or consumer segments. In sum, our findings illustrate the importance of incorporating rebound estimates in environmental assessment of recommerce.

References

Anthesis Consulting Group. (2022). Methodology to calculate the environmental and financial benefits of recommerce. Retrieved from https://cdn-static.farfetch-contents.com/content/UP/PRODUCTION/LANDING-PAGES/SUSTAINABILITY-CALC/Understanding_the_Environmental_Savings_of_Pre-owned_Farfetch_Report_2020.pdf

Amatuni, L., Yamamoto, T., Baldé, C. P., Clemm, C., & Mogollón, J. M. (2023). Quantifying total lifetimes of consumer products: Stochastic modelling accounting for second-hand use and establishing an open-collaborative database. *Resources, Conservation and Recycling*, 197, Article 107103. https://doi.org/10.1016/j.resconrec.2023.107103

Blass, V. D., & Geyer, R. (2010). The economics of cell phone reuse and recycling. *International Journal of Advanced Manufacturing Technology*, 47, 515–525. https://doi.org/10.1007/s00170-009-2228-z

Cooper, D. R., & Gutowski, T. G. (2017). The environmental impacts of reuse: A review. *Journal of Industrial Ecology*, 21(1), 38–56. https://doi.org/10.1111/jiec.12388

Farfetch. (2020). Understanding the environmental savings of buying pre-owned fashion.

Retrieved from https://cdn-static.farfetch-contents.com

Font Vivanco, D., Freire-González, J., Galvin, R., Santarius, T., Walnum, H. J., Makov, T., & Sala, S. (2022). Rebound effect and sustainability science: A review. *Journal of Industrial Ecology*, 26, 1543–1563. https://doi.org/10.1111/jiec.13295

Hegwood, M., Burgess, M. G., & Costigliolo, E. M. (2023). Rebound effects could offset more than half of avoided food loss and waste. *Nature Food*, 4, 585–590. https://doi.org/10.1038/s43016-023-00792-z

Makov, T., Fishman, T., Chertow, M. R., & Blass, V. (2019). What affects the secondhand value of smartphones: Evidence from eBay. *Journal of Industrial Ecology*, 23, 549–559. https://doi.org/10.1111/jiec.12806

Makov, T., & Font Vivanco, D. (2018). Does the circular economy grow the pie? The case of rebound effects from smartphone reuse. *Frontiers in Energy Research*, 6, Article 39. https://doi.org/10.3389/fenrg.2018.00039

Meshulam, T., Font Vivanco, D., Blass, V., & Makov, T. (2022). Sharing economy rebound: The case of peer-to-peer sharing of food waste. *Journal of Industrial Ecology*, 26(6), 1914–1927. https://doi.org/10.1111/jiec.13319

Moon, D. (2024). Promoting sustainable practices: Exploring secondhand clothing consumption patterns and reductions in greenhouse gas emissions in Japan. *Sustainable Production and Consumption*, 45, 294–305. https://doi.org/10.1016/j.spc.2024.01.007

Moon, D., Kuris, K., & Tahara, K. (2023). Which products are bought second-hand and by whom? Analysis of consumer-preferred acquisition modes by product type. *Resources, Conservation and Recycling*, 190, Article 106860. https://doi.org/10.1016/j.resconrec.2022.106860

Sandin, G., & Peters, G. M. (2018). Environmental impact of textile reuse and recycling—A review. *Journal of Cleaner Production*, 184, 353–365. https://doi.org/10.1016/j.jclepro.2018.02.266

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., … Tukker, A. (2018). EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input-output tables. *Journal of Industrial Ecology*, 22(3), 502–515. https://doi.org/10.1111/jiec.12715

Thomas, V. M. (2003). Demand and dematerialization impacts of second-hand markets. *Journal of Industrial Ecology*, 7(2), 65–78. https://doi.org/10.1162/108819803322564352

ThredUp. (2024). Resale report 2024. Retrieved from https://www.thredup.com/resale

Vesterinen, E., & Syrjälä, H. (2022). Sustainable anti-consumption of clothing: A systematic literature review. *Cleaner and Responsible Consumption*, 5, Article 100061. https://doi.org/10.1016/j.clrc.2022.100061

Zink, T., & Geyer, R. (2017). Circular economy rebound. *Journal of Industrial Ecology*, 21(3), 593–602. https://doi.org/10.1111/jiec.12545

Education, Tools, and Games for Product Lifetimes



Research paper
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Learning by Transforming: Widening Access to Complex Circular Economy Science using Experimental Design

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Keywords: Materialisation; Visualisation; Experimental design-science education; Biobased recycling processes; Textiles circularity.

Abstract: This paper presents a pilot pedagogical project exploring the potential of experimental design methods to engage students with complex scientific concepts, by focusing on translating these concepts specifically for a public audience. Conducted within the UKRI-funded Textiles Circularity Centre (TCC) at the Royal College of Art, the project tasked design students with designing an experience that can communicate the science of biobased textile recycling, an emerging circular economy process that is complex and typically inaccessible for laypeople. Framed as a process of translation rather than mastery, the project integrated interdisciplinary, multisensory, and speculative design and teaching methods to engage with a range of ways of conceptualizing and communicating complex science to a diverse audience. Students worked closely with scientific researchers, engaging with scientific materials and techniques, including enzymatic recycling and bacterial cellulose production. Through iterative development, the students produced *Catalyst*, a multisensory installation that employs tactile interaction, visual displays, and soundscapes to create an interactive material simulation of biobased recycling. The study identifies three key pedagogical outcomes with potential for application in wider contexts: enhanced technical comprehension, emotional engagement, and learner agency. We discuss the relationship of multimodal design methods to whole-systems thinking and learning. We propose that interdisciplinary, multisensory methods for enhancing complexity-oriented learning and public engagement, and raise possibilities to scale the model to other contexts that involve communication of complex information, as it may be able to activate new forms of learning and public engagement.

Introduction

Art and design teaching offers a valuable contribution to interdisciplinary pedagogy by activating sensory experience. Through creative visualisation and physical materialisation, it enables deeper, more meaningful engagement with complex processes, including those related to futures of sustainable practice in research (Ribul and de la Motte 2018). In this paper we review the process and outcomes of a pilot pedagogical project, which was developed to explore how learners engage with new and complex concepts when the imperative is not simply to understand the concepts, but ultimately to communicate them to others through created experiences. This pilot was carried out within the Royal College of Art (RCA)'s UKRI-funded Textiles Circularity Centre (TCC), a project investigating the transition to a circular textile economy for the UK fashion industry. In the pilot, design students were tasked with creating an experiential artwork for a public audience that communicates the workings of biobased textile recycling, as a way of engaging the public with sustainable textile futures. Building on existing research that confirms the potential of advanced visualisation and materialisation methods to enhance learning (Klerkx et al., 2014) the pilot demonstrates the value of experimental design practices for interdisciplinary learning, where the imperative is not just to learn for oneself, but to translate concepts to mixed audiences.

Advances in biotech have enabled a novel category of circular textiles recycling, involving complex bio-based processes that transform

biowaste into new materials (Ribul et al. 2021). Making the public aware of how such processes work, as well as why they are innovative and valuable, has an impact on new product adoption and perception of brands who use such practices (Braga et al., 2024). Understanding parts of the processes themselves is important, as consumers tend to respond more favorably to changes when they can be assimilated within existing competencies (O'Keefe et al. 2016). This presents particular challenges when the processes involved in biobased recycling are highly complex and typically inaccessible in that they are confined to a laboratory setting. These factors are barriers to public understanding and interest, and represent a missed opportunity to prime the public to adopt new modes of decision-making in relation to fashion.

Having access to a wide range of interdisciplinary expertise in creative experimentation at the RCA, our response was to consider how experimental design methods could be tested as a mode of learning new concepts. TCC and the RCA's Materials Science Research Centre (MSRC) commissioned and supported students in creating public-facing designed experiences, where the outcome was designed to engage the public with the bio-based materials recycling processes in a way that would be engaging as well as faithful to the science. Our broader intention was to evaluate the effectiveness of framing the knowledge gap (students had no previous knowledge of these scientific processes) as a design challenge, where the ultimate goal was to make the information legible and interesting to others. We aimed furthermore to explore the applicability of this framing and methodological approach beyond the formal educational environment.

Background

Experiential design, immersion and complexity education

There is a consistent suggestion across research that immersive experiences, engaging both digital and analogue elements, can promote change in perspective and decision-making by triggering motivational processes that engage 'thinking-through' versus 'thinking-of' (Wouters et al. 2013). Immersive experiences, in this context, refer to environments or activities—physical, digital, or hybrid—that fully absorb participants' attention and invite creative improvisation and active engagement with the world or a simulated system. Rather than merely observing, participants are situated within a responsive environment that encourages exploration, experimentation, and reflexivity. This definition spans virtual reality (VR), augmented reality (AR), physical prototyping, and performative engagements where the process of interaction is as critical as the content (Dourish 2001; Murray 1997; Bolter and Grusin 1999; Gibbons 2018).

With respect to socio-environmental issues, immersive experience has real impact for education and communication on issues related to sustainability (Mnih et al., 2015; Verburg et al. 2016; Doganca Kucuk and Saysel 2018). Furthermore, immersive experiences that involve building or making, including 3D visualisation and active interaction with materials and content, enhance learning experiences and lead to deeper and more comprehensive understanding (Lau and Lee 2015; Angel et al. 2015; Jowsey and Aguayo 2017). Examples include Aalto University's New Silk project, where collaborative making across science, design, and art generated new knowledge through experimentation (Niinimäki, Groth, and Kääriäinen 2018). Similarly, the ChemArts programme also at Aalto University fosters interdisciplinary exploration of cellulosic and biomaterials, inspiring designers and advancing research (Kataya and Kääriäinen 2018; Kääriäinen et al. 2020).

Multisensory Experience, Emotion and Scale in Learning Complex Concepts

Conceptual frameworks focused on the visual ('visualisation') tend to dominate engagement strategies and have the widest body of associated research validating their effectiveness in teaching and learning. As a result, 'visualisation' is often used in the literature as a catch-all term where the visual is a key element rather than the only element. Video, animation and generative data visualisations are acknowledged as important education tools in the context of complex science, enabling exciting forms of visual storytelling, and introducing elements of temporality and dynamism which may underline

how components are in relation between each other (Curtis and Lue 2015).

Using multiple sensory modes are found to be valuable in engaging learners with complex concepts, particularly when communicating different levels of systemic interaction simultaneously (Ouhaichi et al., 2024). This was an important starting point for our pilot. A dimension of particular interest for us was the emotional impact of material experience and its relation to learning, where some research suggests that learners connect to concepts more effectively and with greater enjoyment when they engage both physically and emotionally with tangible objects or materials (Harley et al. 2016). This is not fully understood, but there appears to be a positive connection between haptics (touch), emotional experience, and behaviour change associated with new knowledge. This follows consumer research where the human 'need for touch' has been identified in marketing and consumer behaviour, the phrase used to describe a common trait where haptic information is highly valued and influential in decision-making (Peck and Childers 2003; Yazdanparast and Spears 2012).

Sound has a particular impact on learning in complex scenarios, where researchers have found fruitful conceptual links that enable them to use soundscapes to communicate variability of landscapes and biodiversity, for example, and to use acoustic parameters to help users assess complex variables of real complex environments (Maffei et al. 2016). There is a growing body of research concerning the capacity for sonic experience to be used in consumer-facing projects related to soil biodiversity, ocean reef health, and other environmental and systemic concepts that are not simple to communicate in language (Hayes & Stein, 2018). Finally, working in multiple sensorial registers enables the learning process to engage with multiple scales of reference, including spatial and temporal. This is a particular benefit in relation to scientific and systemic problem spaces, where most impacts and interactions are usefully understood as connected across multiple scales (Ribul and de la Motte 2018).

Method

Our approach combined design-led and science-led pedagogical methods. Students were tasked with creating an in-person experience to engage lay audiences with biobased recycling processes. The brief framed this as a process of 'translation,' requiring students to explore both analogue and digital design methods and to engage directly with the scientific processes through guided research and participation in TCC activities over six months. They received a consumables budget, and the final selected work, exhibited in the TCC's public Regenerative Fashion Hub, received a prize. A core principle of the brief was scientific correspondence—ensuring accuracy—balanced with the need to create an emotionally and intellectually engaging audience experience. While the work could abstract or simplify the science for accessibility, it could not misrepresent it.

The project began with a briefing and workshop where the TCC research team and interdisciplinary partners presented their expertise. Students then received tutorials on both design and scientific elements before project proposals were reviewed by TCC members and associates. Once selected, the student team participated in weekly tutorials with TCC researchers and exhibition designer Claudio Quintana, receiving design critiques and feedback from experts at key stages of development (see Figure 1).



Figure 1. One of the tutorials with the selected team investigating the option of inserting a light feature in the drum.

Science Teaching & Research Methods

The structure of the learning process required that students first demystify the science for themselves through interdisciplinary research and with the support of the TCC team, and then to translate the science for laypeople through

design, with the support of tutors in Information Experience Design. Students were embedded within the TCC project for the duration of their work, participating in, for example, an interdisciplinary seminar where Simon McQueen-Mason presented a novel biobased recycling concept in which post-consumer textiles can be deconstructed through the use of an enzymatic digestion to produce sugars that can then be fermented by bacteria leading to a biological repolymerisation (Lanot et al., 2025). The students were then given access to a video illustrating how the overall process can be carried out in a laboratory setting and how the structure of the material can be analysed using a Scanning Electron Microscope. The seminar, videos, scientific materials and meetings provided the means for integrating scientific principles and understanding into the design of the collaboration.

Based on the literature review conducted on design-led and science-led case studies of materials' visualisation of scientific processes, a scalar paradigm and a matrix tool was proposed to the students to approach the development of the project (see Figure 2).

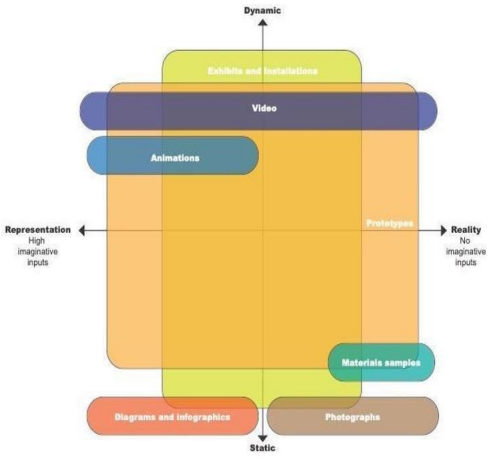


Figure 2. The visualisation and materialisation matrix suggests how different methods could be placed. For example, prototypes can be dynamic or statics and could have a real function or they could be diegetic objects, hence the category 'prototypes' expands in each quadrant of the matrix. On the other hand, photographs are statics and often offer an 'edited' portrayal of the reality hence they occupy the 'static-reality' quadrant.

The scalar paradigm entailed: the macro scale, the human scale and the micro scale. The opportunity for the students to receive feedback, regular reviews and to discuss directly with the research team has played a pivotal role in first developing their understanding of the stages underlying the scientific principles of the complex biobased recycling process of the TCC, namely: cellulose-based waste feedstocks such as post-consumer textiles (cotton or lyocell) and straw to produce a liquid mixture using enzymes which then feeds bacteria to create cellulose strands that self-form into sheets, as a feedstock for circular textile production (Lanot et al, 2025).

Experimental Art & Design Methods

The learning and teaching methods arising from experimental design focused on using speculative and postdigital practices to deepen engagement with the materials and concepts at hand, and to widen possibilities for engaging audiences in novel formats. Speculative practices are enabled by modes of thinking beyond the given parameters, involving "what if" questions and scenarios. In the essay *"Treading Lightly in a World of Many Worlds",* design team Dunne and Raby muse upon how "[o]ur senses edit what is out there, as do those of every creature. Some life forms live in worlds where the human-body shape is meaningless. We appear more like clouds, atmospheres or energy fields" (2023). The idea that everything we encounter is filtered through our particular biology is useful in reframing how we might communicate with others, and indeed what we might communicate. In tutorials and through the design process, we challenged the students to engage in different speculative practices designed to reframe the scientific processes and engage with these from different possible perspectives, including nonhuman materials and micro-scale interactions.

Postdigital methods deliberately blend analog and digital, technological and biological, resisting binary thinking and technological determinism (Kamenarac, 2024). This approach disrupts boundaries between formal and informal learning, shifting 'unreflexive certainties into reflexive uncertainties' and encouraging learners to explore multiple futures (Jandric et al., 2018). Guided by this, students combined digital and analog modes and crossed disciplinary boundaries without conforming to traditional discourse. This aligns

with Jandric and Ford's concept of postdigital ecopedagogies—educational practices that embrace the complexity and interdependence of human, machine, and nonhuman ecosystems (2022). These recent revisions of broader interdisciplinary pedagogic practice are conversant with whole-systems thinking and change, as well as with the ecological sciences, particularly landscape ecology and Earth system science.

With these conceptual guides, the experimentation process was governed by methodologies from experimental design practice, including embedded research processes, informed speculation, iterative audience and materials testing, and collaborative/connected praxis. Early ideation processes led to an agreement that the work should entail three elements: learning through playful interaction; an interplay between human and nano-scales; and the engagement of the layperson as a stakeholder in the recycling process. The final outcome produced from within this framework was a piece titled *Catalyst* (2022) (Figure 3, Figure 4), wherein the audience becomes the catalyst in the transformation of textile waste into materials in biobased recycling. It includes a tactile sculpture (a rotating drum to be operated by visitors), a visual display illustrating the production of bacterial cellulose (Figure 5), and an evolving soundscape linked to these. Together, the three elements form a narrative, wherein publics are invited to play the role of the 'catalyst' in biotech processes creating a more sustainable textile industry.



Figure 3. The Catalyst installation close up.

Discussion

We understand the value of using experimental design methods as teaching tools in a scientific context to arise in three areas: technical comprehension, emotional engagement, and agency.



Figure 4. The Catalyst in the exhibition space.



Figure 5. One of the stills from the video which portrayed the journey from the nano-scale to the materialisation of the bacterial cellulose into a textile-like material.

Technical Comprehension

By engaging with the science itself, including material experimentation with bacterial cellulose, students were able to contextualise the technical dimensions of their creative materialisation against the real technical dimensions of the recycling process. The contributions of the scientific stakeholders in the research phase involved making these technical concepts accessible for students through access to materials, processes and documentation, from low-fi sketches to high-quality digital imagery. Students used shared materials throughout the pilot to develop their own translations in visual and other sensorial formats, in every case recontextualising the processes iteratively to understand them in different contexts.

Emotional Engagement

Emotional engagement was of interest to both the designers and the researchers, as the design process and the intended emotional content of the work itself, ie. the hoped-for emotional impact on audiences who might engage with it, are both important to the brief. This informed the processes and outcomes in several ways. Given sound's established emotional impact (Comstock & Hocks 2016), students used it to foster empathy with micro-scale entities, enhancing audience connection. The designers' decision to include the audience as the 'catalyst' of the piece (and the implicit commentary that transformation depends upon an investment of energy by people) was another decision that reflected a focus on engaging audiences emotionally with the piece, involving them directly in the outcome. Immersive experiences, including visualisations, sound and installation, can effectively induce mood states of awe, which has interesting potential for application to experience design (Chirico et al 2016) and is noted by the students in their own experience in this project.

Agency

Students separated into disciplines are often attuned to division in a way that keeps them "in a single lane"; for example, a belief that scientific research is highly complex, abstract, distant, and owned by a group of specialists; students of science might say the same of the field of experimental art. This project intentionally broke disciplinary silos, positioning students as translators rather than specialists, shifting focus from mastery to communication. This not only levels certain hierarchies, but also refocuses effort from the self—attention on one's own success or failure in mastering new material—to the community—attention on how this might be useful or interesting to others, and have benefits beyond the self. In practical terms, this means that when encountering information, the student is obliged to think about what information will be most relevant and interesting for someone else, what type of narrative will be most suitable for different audiences, and how they might empower others to engage even when mastery or certainty is not likely. The final piece likewise engages learners (in this case, the audience) in activating their own learning process by physically engaging as an active part of the process, rather than attuning to a high level of specialist and possibly alienating scientific detail. A paper associated with the audience reactions by the TCC project team is under review elsewhere (Jewitt et al).

Conclusions

The pilot study presented in this paper has evaluated and identified clear potential for an interdisciplinary model of translation-focused learning, with the simultaneous goal of widening access to complex circular economy science of textile recycling in a public-facing context. Within this study, the students metabolised the complex science behind biobased recycling–supported by constant interactions with the interdisciplinary TCC team–and translated this complex process in a multi-sensory installation to allow laypeople to interactively navigate the process. The project benefitted from embracing the three scales of representation at the cross-section of design and science: macro-, human- and micro-scale and from the adoption of multimedia and multi-sensory input. This supported a cognitive and emotional experience that facilitated understanding of complex processes for the students, as a valuable learning process. The methodologies and insights resulting from this work can be scaled and adapted to other contexts in complexity-oriented education, where language- and text-based modes are less effective. This has special relevance for institutions, courses and subjects that benefit from interdisciplinary and whole-systems approaches; the findings also have potential for application by those interested in emotional and

sensory learning modes applied to complex topics, in a variety of educational contexts including public engagement.

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Data availability statement

The original data presented in the study is openly available in the publicly accessible Royal College of Art repository: https://researchonline.rca.ac.uk/5662/. For the purpose of open access, the authors have applied a Creative Commons Attribution (CC BY) licence.

References

Angel, J., LaValle, A., Iype, D. M., Sheppard, S. & Dulic, A. (2015). Future Delta 2.0an Experiential Learning Context for a Serious Game about Local Climate Change,. SIGGRAPH Asia 2015 Symposium on Education, 1–10. doi:10.1145/2818498.2818512.

Braga, L. D., Tardin, M. G., Perin, M. G., & Boaventura, P. (2024). Sustainability communication in marketing: a literature review. *RAUSP Management Journal*, *59*(3), 293-311.

Chirico, A., Yaden, D. B., Riva, G. & Gaggioli, A. (2016). The Potential of Virtual Reality for the Investigation of Awe. *Frontiers in Psychology* 7: 1766. https://doi.org/10.3389/fpsyg.2016.01766

Comstock, M., & Hocks, M. E. (2016). The Sounds of Climate Change: Sonic Rhetoric in the Anthropocene, the Age of Human Impact. *Rhetoric Review, 2*(35), 165–175. https://doi.org/10.1080/07350198.2016.1142854

Curtis, S. & Lue, R., (2015). Bridging Science, Art, and the History of Visualization: A Dialogue between Scott Curtis and Robert Lue. *Discourse,* 37(3) 193-206. https://doi.org/10.13110/discourse.37.3.0193

Doganca Kucuk, Z. &Saysel. A. K. (2018). Developing Seventh Grade Students' Understanding of Complex Environmental Problems with Systems Tools and Representations: A Quasi-Experimental Study. *Research in Science Education,* 48(2), 491–514. doi:10.1007/s11165-017-9620-8.

Harley, J. M., Poitras, E. G., Jarrell, A., Duffy, M. C., & Lajoie, S. P., (2016). Comparing virtual and location-based augmented reality mobile learning: emotions and learning outcomes. *Educational Technology Research and Development,* 64(3), 359-388. https://doi.org/10.1007/s11423-015-9420-7

Hayes, L., & Stein, J. (2018). Desert and sonic ecosystems: Incorporating environmental factors within site-responsive sonic art. *Applied Sciences*, *8*(1), 111. https://doi.org/10.3390/app8010111

Jandrić, P., & Ford, D. R. (2022). Postdigital ecopedagogies: Genealogies, contradictions, and possible futures. In *Postdigital ecopedagogies: Genealogies, contradictions, and possible futures* (pp. 3-23). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-97262-2_1

Jewitt, C., Golmohammadi, L., Petreca, B., O'Nascimento, R., Berthouze, N., Fotopoulou, A., & Baurley, S. Interrogating wellbeing and alternative circular consumer experiences. (under review).

Jowsey, S., & C. Aguayo, C. (2017). O-Tū-Kapua ("What Clouds See"): A Mixed Reality Experience Bridging Art, Science, Technology in Meaningful Ways. *Teachers and Curriculum,* 17(2). doi:10.15663/tandc.v17i2.166.

Kääriäinen, P., Tervinen, L., Vuorinen, T., & Riutta, N. eds. (2020). The CHEMARTS Cookbook. Aalto University. https://shop.aalto.fi/media/filer_public/3b/bf/3bbf53d7-347a-4ca4-a6b1-2479cfde39c2/aaltoartsbooks_thechemartscookbook.pdf

Kataya, K. & Kääriäinen, P., eds. (2018). Designing Cellulose for the Future: Design-Driven Value Chains in the World of Cellulose (Dwoc 2013-2018). https://cellulosefromfinland.fi/wp-content/uploads/2018/09/DWoC_Loppuraportti_FINAL_s%C3%A4hk%C3%B6inen.pdf

Klerkx, J., Verbert, K., & Duval, E. (2014). Enhancing learning with visualization techniques. *Handbook of research on educational communications and technology*, 791-807. https://doi.org/10.1007/978-1-4614-3185-5_64

Kamenarac, O. (2024). Postdigital Thinking. In *Encyclopedia of Postdigital Science and Education* (pp. 1-8). Cham: Springer Nature

Switzerland. https://doi.org/10.1007/978-3-031-35469-4_69-1

Lanot, A., Tiwari, S., Purnell, P., Omar, A. M., Ribul, M., Upton, D. J., Eastmond, H., Badruddin, I. J., Walker, H. F., Gatenby, A., Baurley, S., Bartolo, P. J.D.S., Rahatekar, S. S., Bruce, N. C., & McQueen-Mason, S. J. (2024). Demonstrating a biobased concept for the production of sustainable bacterial cellulose from mixed textile, agricultural and municipal wastes. *Journal of Cleaner Production*, 486(144418). doi:10.1016/j.jclepro.2024.144418

Lau, K. W., & Lee, P. Y. (2015). The Use of Virtual Reality for Creating Unusual Environmental Stimulation to Motivate Students to Explore Creative Ideas. *Interactive Learning Environments,* 23(1), 3–18. doi:10.1080/10494820.2012.745426.

Maffei, L., Masullo, M., Pascale, A., Ruggiero, G., & Romero, V. P. (2016). Immersive virtual reality in community planning: Acoustic and visual congruence of simulated vs real world. *Sustainable Cities and Society*, 27, 338-345. https://doi.org/10.1016/j.scs.2016.06.022

Mnih, V., Kavukcuoglu, K., Silver, D., Rusu, A. A., Veness, J., Bellemare, M. G., Graves, A. et al. (2015). Human-Level Control through Deep Reinforcement Learning. *Nature,* 518(7540), 529–533. doi:10.1038/nature14236.

Niinimäki, K., Groth, C. & Kääriäinen, P. (2018). NEW SILK: Studying Experimental Touchpoints between Material Science, Synthetic Biology, Design and Art. *Temes de Disseny*, 34, 34–43. doi:10.46467/TdD34.2018.34-43.

O'Keefe, L., McLachlan, C., Gough, C., Mander, S. & Bows-Larkin, A. (2016). Consumer Responses to a Future UK Food System. *British Food Journa*l 118 (2), 412–428. https://doi.org/10.1108/BFJ-01-2015-0047

Ouhaichi, H., Bahtijar, V., & Spikol, D. (2024, July). Exploring design considerations for multimodal learning analytics systems: an interview study. In *Frontiers in Education* (Vol. 9, p. 1356537). Frontiers Media SA.

Peck, J., & Childers, T. L. (2003). To Have and to Hold: The Influence of Haptic Information on Product Judgments. *Journal of Marketing,* 67(2), 35–48. doi:10.1509/jmkg.67.2.35.18612

Ribul, M., Lanot, A., Tommencioni Pisapia, C., Purnell, P., McQueen-Mason, S. J. & Baurley, S. (2021). Mechanical, chemical, biological: Moving towards closed-loop bio-based recycling in a circular economy of sustainable textiles. *Journal of Cleaner Production,* 326(129325). https://doi.org/10.1016/j.jclepro.2021.129325

Ribul, M., & de la Motte, H. (2018). Material Translation: Validation and Visualization as Transdisciplinary Methods for Textile Design and Materials Science in the Circular Bioeconomy. *Journal of Textile Design Research and Practice (RFTD)*, 6(1), 66-88. https://doi.org/10.1080/20511787.2018.1467206

Verburg, P. H., Dearing, J. A. , Dyke, J. G., van der Leeuw, S., Seitzinger, S., Steffen, W. & Syvitski, J.. (2016). Methods and Approaches to Modelling the Anthropocene. *Global Environmental Change,* 39, 328–340. doi:10.1016/j.gloenvcha.2015.08.007.

Wouters, P., Van Nimwegen, C., van Oostendorp, H. & van Der Spek, E. D. (2013). A Meta-Analysis of the Cognitive and Motivational Effects of Serious Games. *Journal of Educational Psychology,* 105(2). 249-265. https://doi.org/10.1037/a0031311

Yazdanparast, A., & Spears, N. (2012). Need for Touch and Information Processing Strategies: An Empirical Examination. *Journal of Consumer Behaviour* 11(5), 415–421. https://doi.org/10.1002/cb.1393

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Communicating Circular Design: A ReSuit case study of embedding knowledge of circularity from design to wholesale to shop assistant

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Keywords: Communication; Circular design; Salespeople; Knowledge transfer

This paper explores how garments, which have had circular design embedded within them, can be communicated in industry from the design department to wholesale, shop managers/assistants and lastly the consumer. The research was situated within the ReSuit project as a case study and was a collaboration between design researchers at Kolding School of Design, anthropologists at Behave Green and industry partner Bestseller. The research was conducted in two parts. Firstly, it investigated, through interviews, how designers communicate circular/sustainable design to wholesale. Secondly, a parallel study used interviews to investigate the communication from shop assistants to customers. The findings show that designers find it complex to communicate sustainability and circularity embedded within designs to wholesale, and the information regarding these topics gets diluted as the overall information burden is seen as too overwhelming. It was also found that shop floor staff were not equipped to guide customers towards sustainable/circular choices and that the customers knowledge, though interested, is lacking. However, it also demonstrates a range of methods that brands could draw on to aid communication, namely overview presentations supplemented with physical visuals, diagrams, first-hand experience or changing the presentation location. Furthermore, aids were suggested, such as mini guides, QR codes and websites. This paper proposes that, to communicate outwardly, brands should first look inward, to educate/upskill their sales teams (Business-to-Business and Business-to-Customer) with fundamental sustainable/circular knowledge. The paper concludes that salespeople have the potential to play a pivotal role in the transition to a circular economy.

Introduction

Circular design is complex which makes communicating about it even more so (Knight et al., 2023). The communication of circular design has focused primarily on educating the public on the principles (EMF, 2021); providing information for industry designers (H&M, 2021); how to communicate within education (Joore et al., 2019); and more recently to industry (Hall et al., 2023). This paper explores how circular design, that has been embedded within garments, can be communicated downstream to wholesale, shop managers/assistants and onto the consumer.

Circular Communication & Sales

Much of the focus of this area is on consumer knowledge and how this affects the attitude-behaviour gap in sustainable fashion consumption (Rausch & Kopplin, 2021). Barriers to this include the consumers' limited knowledge of environmental consequences, lack of environmental concern, perceptions of unfashionable aesthetics, and higher prices.

Relevant to this paper, the research shows that the consumers perceived level of environmental knowledge is essential for their intention behaviour to purchase sustainable products (Chan, 2001; Mostafa, 2006; Kumar et al., 2017). Yet, the communication of sustainability/circularity in fashion is often fragmented and confusing. Furthermore. as Diaz-Bustamante-Ventisca et al (2024, p.1) point out:

> *"the increase in misleading and ambiguous communication narratives featuring sustainable values of companies has led to a certain mistrust and scepticism among consumers".*

To address this issue the European Commission (2023) has adopted a proposal for a Directive on green claims. Once the directive

is put in place a company must substantiate and verify any explicit environmental claims.

While brands have to walk this tight-rope of informing the consumer without miscommunicating, Goworek et al.'s (2012) study suggests that sustainable purchase behaviour can be influenced at the point-of-sale. Here, 'sales' could refer to both B2C (Business-to-Customer) or B2B (Business-to-Business). Supported by Leslie et al. (2015) and Brydges (2018) they suggest that retail spaces could be utilised by brands to communicate, amongst other things, sustainability initiatives.
However, the role of the sales person in relation to sustainability/circular economy has only recently started to be investigated (Sharma, 2020; Gabler et al., 2023).

Salespeople, according to Gabler et al. (2023, p.12):

> *"span the boundary between the firm and the customer. They are responsible for understanding customer wants and needs, adapting to changing customer expectations, and managing customer relationships in both B2B and B2C contexts."*

This is supported by Han et al. (2017) who explain the point-of-sale is an opportunity for brands to connect with their customers and share sustainable fashion information. Unfortunately, as Gelderman et al. (2021) explain, the field of 'green sales' has not had much focus but in their study they found that a salesperson with 'green' expertise directly affects customer satisfaction.

Upskilling sales teams provides them with new skills (Chaudhary et al., 2024) and training sales staff has been proven to improve customer satisfaction (Shah et al., 2020). However, knowledge or expertise is not a new desirable quality for salespeople. According to Jefkins (1990, p.85) a good wholesaler must have the fullest understanding of what they are selling:

> *"It's no good telling the prospective customer he will find out all about the product by reading the instructions supplied with it. A lot of people won't be bothered to read. They expect to be told. The person behind the counter should know the instructions backwards as many do when one is buying, say, a camera, lawn-mower or a typewriter. Or even a can of paint."*

However, if the salesperson is tasked with 'to much' they can become overburdened (Gabler et al., 2023). Thus, a balance needs to be struck in what and how much knowledge is required to be communicated.

Unfortunately, the communication of circular fashion, Han et al. (2017) explains is often limited. While the teams behind the garments may have carried out extensive research, such as how to source reused, recycled, or secondary and sustainable raw materials, this is not carried through to the communication strategy.

Furthermore, as Brydges et al. (2022) explain, for large brands educating/training employees around sustainability dissemination can be challenging and becomes more difficult when the brand sells items wholesale, as their values or priorities for communication in this regard may not align.

This paper uses the ReSuit project (Recycling Technologies and Sustainable Textile Product Design) as a case study (see below) investigating how circular design embedded into garments was communicated to sales teams (B2B). In addition, the paper also explores communication B2C within the brands retail spaces.

ReSuit Case study

This paper explores work of design researchers at Kolding School of Design (KSD) and anthropologists from Behave Green with industry partner Bestseller.

This research was part of Bestseller's 'Circular Design Challenge' activity together with KSD. And began with the development and publication of their 'Circular Design Guidelines' (CDG) version 1 (Bestseller, 2022), created to communicate circular design strategies to Bestsellers own designers (see Figure 1). The challenge asked Bestseller brands to create circular garments using the guidelines. This research investigates how these designs were communicated to the wholesale departments.

In addition, anthropologists at Behave Green conducted a parallel investigation into consumer behaviour and the communication of sustainable initiatives and circular design in a series of Bestseller stores.

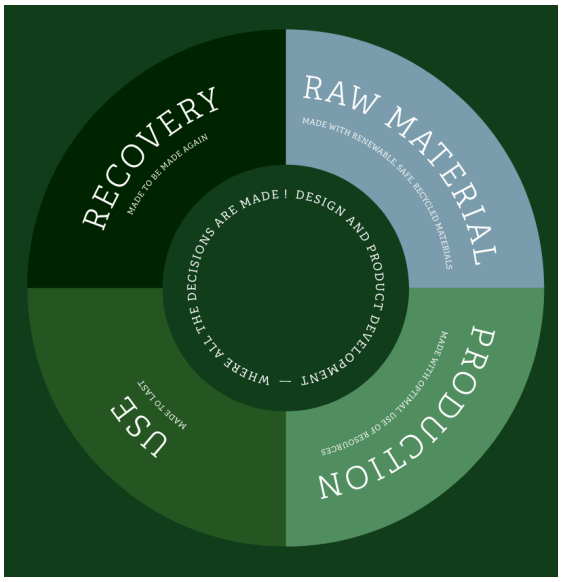


Figure 1. Circular Design Framework from Bestseller's Circular Design Guidelines version 1, (Bestseller, 2022)

Methods

This research was split into two parts. The first used interviews of eight Bestseller brands who participated in the Circular Design Challenge across markets, including men, women, plus size and children. Interviews were semi-structured (Flick, 2009) and conducted online with a diverse range of employees from each brand that actively participated in the challenge (see Table 1). The interview data was analysed using thematic analysis (Flick, 2009) to draw out connections and relationships.

The second part of the research explored the perspectives of customers, staff, and store managers regarding the communication of sustainability at two Bestseller Brands. The research presented here was part of a larger study, with only findings relevant to this paper included. Across the whole study, a range of interviewing methods was used, including 84 mini-interviews with customers in four city-centre store locations. Store managers were informally interviewed for their perspectives, and in-depth customer interviews and user journeys were conducted with a small group (6 women, 2 men, and 7 teenagers) recruited in-store. The interview data was analysed qualitatively (Flick, 2009) focusing on pattern recognition to identify recurring themes, attitudes, and behaviours related to sustainability communication.

Table 1. Summary of the interviewed designers/product developers within the brands.

Brand	Job Title
1	Designer
	CSR and Sustainability Responsible
2	Sustainability Responsible
3	Designer
4	Supply Chain Management and Quality Responsible
	Design Manager
	3D Developer
5	Sustainability Manager
6	Designer
7 & 8	Creative Buyer
	Team Leader
	Sustainability Responsible

Findings

The findings are presented in two parts representing the two halves of the research. First exploring how design communicates to sales and second communication from shop to customer.

Communication from Design to Sales

During the interviews of the Bestseller design teams the researchers explored how they communicated their circular design concepts to wholesale which could be used to disseminate to their customers (B2B and B2C). The findings are discussed across three themes: communication volumes, communication selection, and communication methods.

Communication volumes

Across all the brands interviewed there was a consensus that to fully understand the circular design embedded in the garments (including materials, production, use and recovery as specified in Bestseller's (2022) CDG) would require a significate amount of information to be communicated. It was raised by one

interviewee that the types of information the sales team is required to know:

> *"it's insane what they have to remember…this price was changed to this and now we put this in that colour, now we change the length of this dress. This is in a repeat and this and that"*

The addition of circularity details would require the sales team to remember an additional set of details. This was seen as a burden and therefore, the brand explained their strategy was to provide:

> *"something that's so bulletproof and clear because in one collection you have so many different approaches, stories, new fibres that they have to remember"*

The challenge of editing information to create a concise and clear message was also highlighted.

> *"Trying to eliminate unnecessary knowledge but still have them informed was perhaps the biggest challenge"*

Another brand stressed that to avoid the overload of information that the 'selling points' of the circular design, especially those that they were more familiar with could be the focus.

> *"the recycled cotton…these were just some really easy selling points of the products"*

This method is one of information selectivity which will be explored further in the next section.

Selecting communication

A common challenge was the technical details of information that had to be omitted when communicating with sales.

> *"if it gets too technical it will be lost in translation"*

In addition, the background work of creating a more circular product was also often excluded. For example, one brand worked with their supplier to recycle offcuts to produce a recycled cotton.

> *"we didn't talk too much into how the cut-offs and how they are reusing it…maybe we didn't go that much into that story"*

Whilst this type of storytelling could be picked up by marketing it was omitted for the sales teams. Instead, the information was simplified to 'made from recycled cotton'.

In another example a brand excluded discussing how they had started to wear test their garments.

> *"this whole testing framework… that's impossible to explain to an end consumer at this level. So that was internal work. So no, actually we only put the word on that it's made for longevity. You can wear it for long time. …it has to be these simple words. We can't explain other things like that. I would say that would be a bit hard."*

This demonstrates that there is a lot of work embedded within the circular design that is not communicated to sales and by extension the consumer.

The concept of including only the most relevant and easy to understand messages was echoed across many of the interviews. Achieving simple and effective communication about the circular concepts was key to ensure their buy-in and to promote these garments at wholesale.

> *"if we show from the beginning how they can communicate it and give them something, then probably they are more likely to buy into it instead of saying 'ohh that's too tricky for me to communicate so then I rather leave it'"*

The methods used to communicated are addressed in the next section.

Communication methods

One of the main issues that brands repeatedly explained was how the sales teams would not be able to retain the information and the need for prompts was highlighted.

> *"for our sales team when we deliver the collection to them, they cannot remember all that information if it's not stated on the actual product"*

Across all the interviews the brands discussed a range of different communication methods to support the sales and communication to the customer (see Table 2).

Table 2. Summary of the methods brands used to communicate circular design

Method	Quote
Presentations	"we have a the internal in-house sales meeting where we present the collection and at this time it's usually our designers who present the collection we are going to sell" "the only thing what we have done differently… was a general explanation of circularity what the four phases are…. and doing the presentation to our country sales managers, we actually explained what is it about"
Physical Aids	"we had in the stand…some plastic bottles that we asked the kitchen if they could save the pant to explain the process of the recycled polyester" "The plan was actually also to make the circular design guide in a mini format, like a pocket version so it's easier for them to also explain to the customers what's actually has been fulfilled on each product."
Visual Aids	"we printed out two lay plans - the before and the after… the biggest one…was a 50% difference on waste. So they could have it very visually "
Person	""we made a stand in the in the sales meeting… we had the VFX model with the 3D style on. And the model was there as well… she has never seen herself in those clothes and she was sharing that experience as well with the and sales representatives"
Location	"we took …the beachwear out of the office environment, down to the harbour…I know it's a bit cheesy, but it made them think differently about the project than when we stand in the showroom…they can understand it as a package and a shift their values."
Hangtags	"you can always have it on a hangtag, but then when the hangtag is taken off there's no message" "a hangtag where we had these tick off boxes so you could tick off what we have done. But we are not allowed to do that because then we need to explain 100% what has been done and then we end up with the 100 hang tags and that doesn't make sense"
QR codes	"we made the QR codes to guide them that they could just stand with the customer, scan it and then they will run through the whole story" "I think there were only worried little bit about the communication to our customers. They could see it because they could also scan the QR code. They could see what we are communicating. They were like, OK, this is super cool"
Video	"one of the designers and myself did a video where I talked generally about the concept of the circular design guide and he talked more about the

	products so that they have also a small video to support them in the showrooms"

Across the methods presentations were one of the most common methods which was explained by one brand as part of normal working practices. These were often simple PowerPoints outlining the circular design concept and selling points. This could also be supported with visual aids.

However, we can also see the designers got creative. For example, *one* brand moved their presentation out of the office to communicate the story of circular design. Physical aids were leant on such as mini-guides and illustrative items (such as plastic bottles to help explain recycling processes).

Furthermore, video was a popular method.
This type of content is not only useful for sales but can double up (if created far enough in advance with the help of marketing) to communicate to the customer. However, as pointed out by one interviewee this also needs to be quick, clear and concise.

> *"We normally can only use a max of nineteen seconds. It has to be said in that time, otherwise people lose interest."*

Another popular method to support sales was the use of QR codes leading to webpages with information relating to circularity. However, the amount of work that goes into making this form of communication was also acknowledged. For smaller brands they did not have the resources and even the larger brands found it resource heavy.

> *"And then we were talking about a QR code. But again, right now for us as a small brand we cannot make that much marketing material"*

> *"it's a huge job to make this landing page with a QR code, a huge job. It could maybe seem easy, but it's not. There's a lot of work behind that"*

The latter brand explained that it would not be option to have a QR code leading to a landing page for every style. Therefore, other solutions would need to be found.

Others considered hangtags with information on them to support sales teams, however this method was rejected due to volume of information and longevity of the communication for customer. *This highlights the issue of what is required/allowed to be communicated. Furthermore, mentions of speaking to the respective brands legal department came up in the interviews and the challenge of greenwashing was raised directly by one interviewee.*

> *"Working with today these terms about sustainability, about circularity that is so fragile within green washing"*

This demonstrates the fine line that has to be navigated by the brands to communicate the circular work they are doing.

Communication from Shop to Customer

In the second part of the research both consumers and stop managers from two bestseller brands were interviewed. Relevant for this paper were the customers responses to questions regarding their level of knowledge of circularity/sustainability and the factors that influence a purchase in this regard. To compliment this the store managers were also asked about their knowledge and thereby explore both perspectives on this issue.

First, the researchers asked customers what they associated with 'sustainable clothing.' It was found that most respondents had a hard time answering the question. As the literature suggests (Rausch & Kopplin, 2021), sustainability plays a minimal role when customers shop for new clothes. This was supported as the research found customers had difficulties in making sustainable choices. This was largely due to the overwhelming presence of 'green' marketing. While most participants had learned about environmental issues in school, few connected these to the textile industry. However, some respondents clearly expressed curiosity about sustainability in textiles, raising questions such as:

> *'How are clothes produced?'*

> *'Can clothing be made from reused materials?'*

> *'What happens to clothes when we no longer use them?'*

When answering questions about the purchase situation, customers not only highlighted price and size but also the importance of the guidance and expertise from the sales assistant, but that they had a 'lack of knowledge' about sustainability.

> *"I have tried to ask a sales assistant what it means when clothes are recycled. She couldn't give me an answer. So in general, I think we lack knowledge about this matter. I usually do not expect much from the sales assistants because I know that most of them do not have the knowledge. Instead, I expect to find answers to my questions on the brands' websites."*

Additionally, when interviewing the shop staff, they struggled to define or explain what 'sustainable clothing' was. This is not the fault of the staff themselves, but rather highlights a gap in their training. One of the shop managers emphasised the issue:

> *"We are not getting any training about sustainability - we just get a little bit of information we can use in the sales situation"*

Some of the store managers mentioned that their employees could benefit from more information about sustainable clothing and textile production. By learning more about these matters, they explained, it would be easier for them to guide their customers.

Discussion & Conclusion

Embedding circular design strategies is certainly challenging for the industry designers (Hall et al., 2023). For example, designers might have to source recycled materials; explore how waste can be reduced during production with their suppliers; implement features that will encourage the customer to use it for longer (such as multifunctionality) and finally ensure all these choices do not prohibit the garment from entering recycling systems. Yet, communicating these efforts through internal levels from wholesale to the sales assistant and onto the consumer poses a different challenge.

The efforts made by design for circularity is complex. The research highlights how the information gets reduced through a selection process and details are lost as it filters through the sales systems. We can conclude that sustainability and circularity are not well understood by sales teams and becomes an additional but not necessarily integrated aspect that B2B sales teams have to communicate to their clients.

While the designers are 'selecting' circular design information to be used by salespeople, this appears to be treated as beneficial 'add on' rather than a fundamental part of their sales pitch. Thus, as the information filters down to the customer and via stores the information is also less likely to be highlighted. This challenge was also echoed by the store managers that the basic knowledge in this area is missing. Alongside this the customer also lacks but is interested in this knowledge but the sales assistants are not equipped to help answer their questions. Therefore, this research suggests that educating sales teams (B2B and B2C) with a fundamental understanding of circularity could help address these challenges, enabling them to both understand and communicate the more complex circular details embedded by design into the garments.

Furthermore, the findings go beyond pointing out the challenges and offer a range of methods to be explored in future research. The bestseller brands, through their efforts to establish communication during the circular design challenge, provide a range of examples to both educate and communicate to sales teams.

Firstly, the brands educated by providing an overview of the circular design framework (see Bestseller, 2022) and how it related to their specific design and secondly, they supported sales communication efforts by creating aids. The former (overview) was materialised mostly as a presentation. However, within this a range of visual methods where employed, such as physical items (plastic bottles to explain the recycling process); diagrams ('before and after' lay patterns demonstrating the reduction in waste); people (a model used to shoot digital samples spoke about her experience) and location (one brand shifted the location of a

presentation to emphasise the importance of the work being created).

The latter (communication aids) were threefold. First, a mini guide was proposed. A quick glance version of the circular design guide (Bestseller, 2022) as a reference. Second, QR codes on the garments so that both sales and clients (B2B) and customers (B2C) could access this information. Thirdly, related to the QR codes where the webpages themselves, which could be present without the QR code. This also stands to benefit the customer, as pointed out buy one in-store interviewee that this is where they actively go to seek information because she cannot get it via the sales assistants.

It is clear from our findings that aids alone, such as web pages, are not enough. Aside from the technical and time heavy challenges of producing these, both wholesale and those working in the shops require a basic understanding to support clients/customers to communicate the circular/sustainable value that have been embedded into garments by design teams. Therefore, to communicate outwardly, we recommend brands first look inward at how knowledge is transferred to sales as they have the potential to play a pivotal role in the transition to a circular economy. Thus, we advocate for further research to explore how a fundamental understanding of circular design can be imparted to sales (for example, if selectively of information must be done, what is selected B2B and B2C?). This is before aids can be employed to provide the details of how circularity has been embedded. Furthermore, if the sales role does hold this potential, further research could explore how they go beyond just communication and encourage circular practices such as maintaining, repairing, and repurposing to change behaviour/mindsets in the transition to a circular economy.

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References

Bestseller. (2022). Circular Design Guide. Bestseller. https://bestseller.com/media/i2fku0ct/bestseller_circular-design-guide_2022.pdf

Brydges, T. (2018). “Made in Canada”: Local production networks in the Canadian fashion industry. Canadian Geographies / Géographies Canadiennes, 62(2), 238–249. https://doi.org/10.1111/cag.12400

Brydges, T., Henninger, C. E., & Hanlon, M. (2022). Selling sustainability: Investigating how Swedish fashion brands communicate sustainability to consumers. Sustainability: Science, Practice and Policy, 18, 357–370. https://doi.org/10.1080/15487733.2022.2068225

Chan, R. Y. K. (2001). Determinants of Chinese consumers’ green purchase behavior. Psychology & Marketing, 18(4), 389–413. https://doi.org/10.1002/mar.1013

Chaudhary, P., Raut, N., Patil, H., & Kate, N. (2024). Up-Skilling in Fashion Retail (pp. 323–336). https://doi.org/10.1002/9781394200498

Diaz-Bustamante-Ventisca, M., Carcelén-García, S., Díaz-Soloaga, P., & Kolotouchkina, O. (2024). Greenwashing perception in Spanish fast-fashion brands’ communication: Modelling sustainable behaviours and attitudes. International Journal of Fashion Design, Technology and Education, 0(0), 1–11. https://doi.org/10.1080/17543266.2024.2343934

EMF. (2021). Circular Design for Fashion. Ellen MacArthur Foundation.

European Commission. (2023). Green claims. https://environment.ec.europa.eu/topics/circular-economy/green-claims_en

Flick, U. (2009). An Introduction to Qualitative Research. SAGE.

Gabler, C., Landers, V., & Itani, O. (2023). Sustainability and professional sales: A review and future research agenda. Journal of Personal Selling and Sales Management, 1–18. https://doi.org/10.1080/08853134.2023.2244675

Gelderman, C., Schijns, J., Lambrechts, W., & Vijgen, S. (2021). Green marketing as an environmental practice: The impact on green satisfaction and green loyalty in a business-to-business context. Business Strategy and the Environment, 30. https://doi.org/10.1002/bse.2732

Goworek, H., Fisher, T., Cooper, T., Woodward, S., & Hiller, A. (2012). The sustainable clothing market: An evaluation of potential strategies for UK retailers. International Journal of Retail & Distribution

Management, 40. https://doi.org/10.1108/09590551211274937

Hall, C. A., Hasling, K. M., & Ræbild, U. (2023). Learning Circular Design from within the Fashion Industry: A ReSuit project case study. 5th PLATE 2023 Conference Proceedings. PLATE, Espoo, Finland.

Han, S. L.-C., Henninger, C. E., Apeagyei, P., & Tyler, D. (2017). Determining Effective Sustainable Fashion Communication Strategies. In C. E. Henninger, P. J. Alevizou, H. Goworek, & D. Ryding (Eds.), Sustainability in Fashion (pp. 127–149). Springer International Publishing. https://doi.org/10.1007/978-3-319-51253-2_7

H&M. (2021). Circulator Guide. H&M Group. https://hmgroup.com/wp-content/uploads/2021/11/Circulator_Guide_v1.0.pdf

Jefkins, F. (1990). Dealer Activities. In F. Jefkins (Ed.), Modern Marketing Communications (pp. 85–89). Springer Netherlands. https://doi.org/10.1007/978-94-011-6868-7_12

Joore, P., Crul, M., Celik, S., Bakirlioglu, Y., Blackmore, E., DeEyto, A., Gisslen, A. V., Habermann, K., Jimenez, A., Lazzarini, B., Martens, J., McMahon, M., Obiols, A., O'Donnell, P., O'Riain, M., Ozkan, N., Santamaria, M., Segalas, J., Tejedor, G., … Wever, R. (2019). Teaching Circular Design—A Handbook for Educators. http://circulardesigneurope.eu/wp-content/uploads/2020/01/Handbook-in-IDfS.pdf

Knight, L., Goldsworthy, K., Visse, S., & Hall, C. A. (2023). Thinking beyond circles: Developing visual research methods for circularity in design education. 5th PLATE 2023 Conference Proceedings. PLATE, Espoo, Finland.

Kumar, B., Manrai, A. K., & Manrai, L. A. (2017). Purchasing behaviour for environmentally sustainable products: A conceptual framework and empirical study. Journal of Retailing and Consumer Services, 34, 1–9. https://doi.org/10.1016/j.jretconser.2016.09.004

Leslie, D., Brydges, T., & Brail, S. (2015). Qualifying aesthetic values in the experience economy: The role of independent fashion boutiques in curating slow fashion. In Spatial Dynamics in the Experience Economy. Routledge.

Mostafa, M. M. (2006). Antecedents of Egyptian Consumers' Green Purchase Intentions: A Hierarchical Multivariate Regression Model. Journal of International Consumer Marketing, 19(2), 97–126. https://doi.org/10.1300/J046v19n02_06

Newell, S. J., Wu, B., Leingpibul, D., & Jiang, Y. (2016). The importance of corporate and salesperson expertise and trust in building loyal business-to-business relationships in China. Journal of Personal Selling & Sales Management, 36(2), 160–173. https://doi.org/10.1080/08853134.2016.1190656

Rausch, T., & Kopplin, C. S. (2021). Bridge the gap: Consumers' purchase intention and behavior regarding sustainable clothing. Journal of Cleaner Production, 278. https://doi.org/10.1016/j.jclepro.2020.123882

Shah, M. H., Shah, M. W., & Gul, S. F. (2020). Employee training on customer satisfaction: Mediating Role of Employee Performance and the Moderating role of Job autonomy. Global Journal of Human Resource Management, 8(2), 33–57. https://doi.org/10.37745/gjhrm.vol8.no2.p33-57.2020

Sharma, A. (2020). Sustainability research in business-to-business markets: An agenda for inquiry. Industrial Marketing Management, 88, 323–329. https://doi.org/10.1016/j.indmarman.2020.05.037

Straub, L., Hartley, K., Dyakonov, I., Gupta, H., van Vuuren, D., & Kirchherr, J. (2023). Employee skills for circular business model implementation: A taxonomy. Journal of Cleaner Production, 410, 137027. https://doi.org/10.1016/j.jclepro.2023.137027

Turunen, L., & Halme, M. (2021). Communicating actionable sustainability information to consumers: The Shades of Green instrument for fashion. Journal of Cleaner Production, 297, 126605. https://doi.org/10.1016/j.jclepro.2021.126605

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Examining longevity in tools for a circular economy

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Keywords: Circular tools; Lifecycles; Open-ended design, Obsolescence, Design for a circular economy.

Abstract: Industrial production contributes significantly to ecological sustainability challenges. One guiding approach to address these challenges is the circular economy. Slowing down resource flows is one of the main strategies of the circular economy. This involves extending the lifespan of products within and across multiple life cycles and increasing their utilization intensity. Various tools have been developed to support companies in adopting circular economy practices. This study examines how these tools facilitate designing for product longevity.

Specifically, the study analyzes 10 tools — five recent tools identified in academic literature and five first emerging through internet scraping. These tools are annotated and coded to reveal qualitative insights regarding the level of longevity they address (theoretical and methodological insights) and how these tools help handling longevity-related aspects (practical and applied insights). The findings highlight how these tools contribute to extending product lifespans and identify the extent to which they could support slowing down resource flows.

Introduction

Industrial production contributes significantly to ecological sustainability challenges, including waste management, pollution, CO2 emissions, and resources shortage. In Europe a substantial amount of waste is generated from durable goods, an average of 16.6 kg of e-waste alone (excluding all other durables) per person was recorded in 2016), highlighting the urgent need to reduce production and consumption levels (Baldé et al., 2017; Cooper, 2020). The circular economy (CE) offers a potential approach to tackle ecological sustainability problems by focusing on closing, elongating, and narrowing resource flows (N. M. P. Bocken et al., 2016).

CE is gaining popularity among companies. However, despite its popularity the influx of virgin materials into the market remains unabated (Fraser et al., 2024). Product longevity is a critical yet fundamental element of the circular economy. Longevity entails extending the use of products in one lifecycle and across multiple lifecycles (over multiple users). It prevents new products entering the economy, thus slowing down resource flows which helps to counter waste generation and resource depletion (Iraldo et al., 2017). Companies have multiple motivations to engage with longevity such as: higher up mark for high quality products, reducing costs, future revenue from circular business models etc. (Cooper, 2020; Gnanapragasam et al., 2017; Løvbak Berg & Hebrok, 2024; Oguchi et al., 2016; Salvia et al., 2015). Companies may avoid engaging with longevity due to high cost of changing business models, customer rejection, high price points of long-lasting products and other reasons (Alzaydi, 2024; Cooper, 2020; Gnanapragasam et al., 2017; Jensen, 2023; Jensen, Laursen, et al., 2021; Laitala & Berg, 2023; Oguchi et al., 2016). Companies might not see the potential or might not know how to start applying CE strategies.

The longevity of a product is defined by technical factors (e.g., design choices affecting usability and relevance over time), business models (e.g., services to extend product lifespans), user interactions, and contextual influences such as legislation, norms, and beliefs (C. A. Bakker et al., 2021; N. M. P. Bocken et al., 2016; Gnanapragasam et al., 2017; Haase & Lythje, 2022; Jensen, 2023; Jensen, Haase, et al., 2021; Jensen, Laursen,

et al., 2021; Løvbak Berg & Hebrok, 2024; Salvia et al., 2015, 2021). Consequently, many stakeholders impact longevity. Given this, the role of companies and designers is significant, as they make key decisions regarding function, design, material selection, repairability, and upgradeability. These key decisions influence how the use phase evolves. Thus, companies share responsibility when potential changes, defects and (mis)uses in the multiple lifecycles of the product lead to a decrease in lifespan (Cooper, 2020; Cooper et al., 2010; Jensen, 2023; van Nes & Cramer, 2005).
Numerous tools have been developed to support circular design practices., Bocken et al. (2019) and Rexfelt & Selvefors (2024) gathered and analysed circular economy tools. Yet, these papers did not describe if these tools were slowing down resource flows. Royo et al. (2023) analyzed circular tools to see what parameters of life-extension were discussed in circular economy tools and found that only 14 out of 70 tools discussed some parameters of life-extension. This paper will extend this research, by revealing qualitive insights into how the most recent and most findable tools tackle life-extension aspects.

State of the art

Longevity and obsolescence

Longevity refers to “the lifespan of consumer products” (Cooper et al., 2010, p.3). Longevity is the time between acquisition by the first user and disposal by the last user, synonyms of longevity are (product) lifespan, life, life cycle, cycles and lifetimes (C. A. Bakker et al., 2021; Cooper et al., 2010; Eisenriegler et al., 2020; Hummen et al., 2023; Jensen, Laursen, et al., 2021; Park, 2009; van Hinte, 2004).

Factors impacting longevity

Product longevity is influenced by a multitude of aspects on product- (micro), consumer- (meso) and socio/economic - (macro) level (Cooper et al., 2010; van Nes & Cramer, 2005). These factors include product specifications, curative actions of the company, use context, etc. A list of factors can be found in Table 1.

Factors impacting longevity
Curative actions of the company: the service and product support the company provides after sales (Nyström et al., 2021)
Use context: the environment in which the product is used (natural elements as well as social elements (e.g. public space)) (Cooper et al., 2010; Den Hollander, 2018; Jensen, 2023; Ostuzzi, 2017)
Technological advancement: technological advancement of the product compared to or compatible with other products on the market (Cooper et al., 2010; Den Hollander, 2018; Jensen, 2023; Nyström et al., 2021).
Economic aspects: financial cost to keep a product in use compared to buying new product (Cooper et al., 2010).
Product’s appearance: the wear and tear and what is considered fashion and style (Bridgens & Lilley, 2017; Lilley et al., 2019)
Emotional aspects of the product: (e.g. the memories coupled with the product).
User behavior: the attitude and behavior of users in relation to product lifespans (Cooper et al., 2010; Jensen, 2023; Park, 2009; Shi et al., 2022; Wastling et al., 2018)
Consumer/ user preferences, needs and identity: match between the product features and the user needs and user identity (Alzaydi, 2024; Cooper et al., 2010; Haines-Gadd et al., 2018; Jensen, 2023; Jensen, Laursen, et al., 2021; Nyström et al., 2021)
Social aspects: social norms, trends and fads (Cooper et al., 2010; Nyström et al., 2021)
Legislation: legislative changes (Cooper et al., 2010; Nyström et al., 2021)

Table 1: Factors impacting longevity

Design for longevity

Multiple academics describe how to engage with longevity (C. Bakker et al., 2014; Den Hollander, 2018; Haase et al., 2023; Jensen, 2023; Jensen et al., 2023; Jensen, Laursen, et al., 2021; Løvbak Berg & Hebrok, 2024; Nyström et al., 2021, 2023; Park, 2009; Van Den Berg & Bakker, 2015).
Various circular economy strategies address (sub-)aspects of longevity, such as design for durability, reliability, performance, emotional durable design, attachment and trust, (ease) of maintenance and repair, upgradability and future expansion, anticipate legislation,

roadmap fit, refurbishment (N. M. P. Bocken et al., 2016; Chapman, 2005, 2009; Haines-Gadd et al., 2018; Kasarda et al., 2007; Nyström et al., 2021, 2023; Park, 2009; Van Den Berg & Bakker, 2015; Van Den Berge, 2024).

Method

A literature search and internet scraping approach were conducted to identify relevant circular economy tools. Following, a systematic coding analysis examined how these tools address longevity. Figure 1 provides an overview of the method used.

Data collection

A literature search on Web of Science was conducted on 12 November 2024. The following key string was used *TI= (((circular* AND (econom* OR design* OR product* OR business* OR innovation* OR future*)) OR circularity) AND ("design method" OR "design methods" OR "design methodology" OR guid* OR design support* OR tool* OR game* OR roadmap* OR "design process" OR software* OR canvas* OR map*)) – limited to 2024.*

In addition, the most accessible tools, methods and guides (further referred to as tools) were identified through an internet scraping approach, which simulates how companies might search for tools using Google. The search was conducted using Serper with the query 'circular economy tool' using the date range 'last year' (Serper, n.d.). The search was repeated for 4 countries in the north, east, south and west of Europe (Belgium, Sweden, Poland, Greece). Tools were ranked in order of appearance (tools listed first in Serper ended up first) and tools listed by multiple (from the 4 European countries) searches ended higher up in the ranking (last executed on 21 November 2024).

Scientific articles and websites were selected based on their explicit focus on supporting circular economy principles (e.g., general sustainability design tools were excluded). Only English tools accessible to researchers and applicable in an industrial-product-design context (e.g. excluding food and building industries or monitoring the circularity of regions) were considered. Papers and blogs listing multiple tools of third parties were excluded. The analysis included the five most recent tools identified in literature and the five most accessible tools from the internet scraping, resulting in a total of 10 tools for analysis.

Data analysis

Theoretical framework analysis

In the first round of analysis, each tool was examined using the guiding question "D*oes the tool mention or contain elements that link to slowing down resource flows?*". Text and visual elements referring to this concept were highlighted, and coded, following the annotated portfolio technique (Gaver, 2012; Sauerwein et al., 2018). These codes were then categorized into the following groups: (1) Broad circular economy concepts that inherently include slowing down resource flows (e.g., "environmental impacts of the organizations value chain"), (2) Direct references to slowing down resource flows (e.g., "All services relating to material or products after they have been used or while in use that help keep materials in the economy or that help keep the product in use for longer"), (3) Indirect mentions of longevity, further divided into keeping products in a loop for longer within one lifespan, closing loops over multiple lifespans, Intensifying product use and other emerging aspects of longevity.

The frequency of codes within each category was recorded and visualized in a graph, providing an indication of the depth at which each tool addresses longevity. This allowed for distinctions between tools that discussed circular economy in a broad sense (potentially encompassing longevity) and those that engaged more explicitly with specific aspects of longevity.

Practical support for longevity

In the second round of analysis, the tools were examined for content providing practical guidelines, advice or exercises aimed at extending product lifespans. Any instructions or recommendations supporting the slowing down of resource flows were identified, marked, and coded using the guiding question *"what tangible support (example: advice, guideline, exercise, etc.) does the tool give to slow down resource flows?"*.

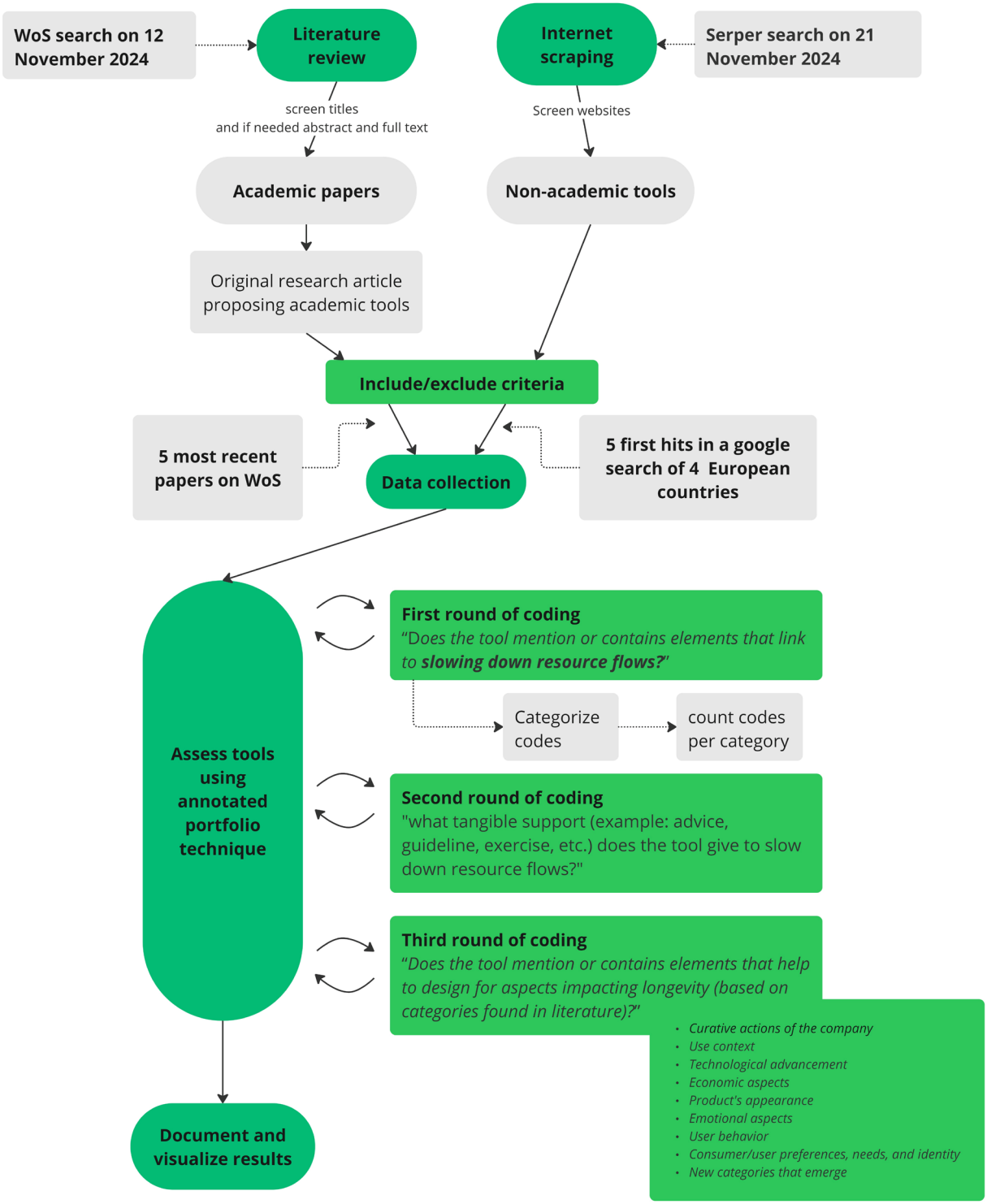


Figure 1: The applied method

Practical support for elements influencing longevity

The third round of analysis systematically scanned for support towards elements influencing slowing down resource flows. These influencing elements were based on categories found in the state-of-the-art (see Table 1). The guiding question of "practical support for longevity" was further narrowed down based on the categories. To illustrate, for the category "product specifications" the question was narrowed down towards *"what tangible support (example: advice, guideline, exercise, etc.) does the tool give towards managing product specifications (that influence product longevity)?"* All identified elements were coded and categorized.

Results

Analyzed tools

Table 2 depicts an overview of the found and analyzed tools.

	Literature or internet scraping	**Name tool**	**Author**
1	Literature	Circular economy roadmapping	(Abu-Bakar & Charnley, 2024)
2	Literature	Cradle-to-cradle business model tool	(Hoang & Böckel, 2024)
3	Literature	Circular design tool (CD-tool)	(Dagilienė et al., 2024)
4	Literature	Circularity design methodology for urban factories	(Ijassi et al., 2024)
5	Literature	Modularity and circular economy tool (MCE-tool)	(Machado et al., 2024)
6	Internet scraping	The circular design guide	(Foundation, Ellen MacArthur, n.d.)
7	Internet scraping	Circulytics	(Foundation, Ellen MacArthur, n.d.)
8	Internet scraping	CTI tool	(IQ, Circular, n.d.)
9	Internet scraping	The circular rebound tool	(Das et al., 2023)
10	Internet scraping	Circulab academy – the value chain canvas	(circulab academy, n.d.)

Table 2: The 10 tools analyzed in this study

Theoretical Framework Analysis

Figure 2 shows notable variations in how tools address theoretical aspects. On one hand, 5 tools mention explicitly slowing down resource flows (Tools 5, 6, 7, 8 and 9). To illustrate, Tool 7 mentions "Keep products and materials in use. All services relating to material or products after they have been used or while in use that keep materials in the economy, or that help keep the product in use for longer." On the other hand, some tools barely speak about aspects of slowing down resource flows (Tools 1, 3, 4).

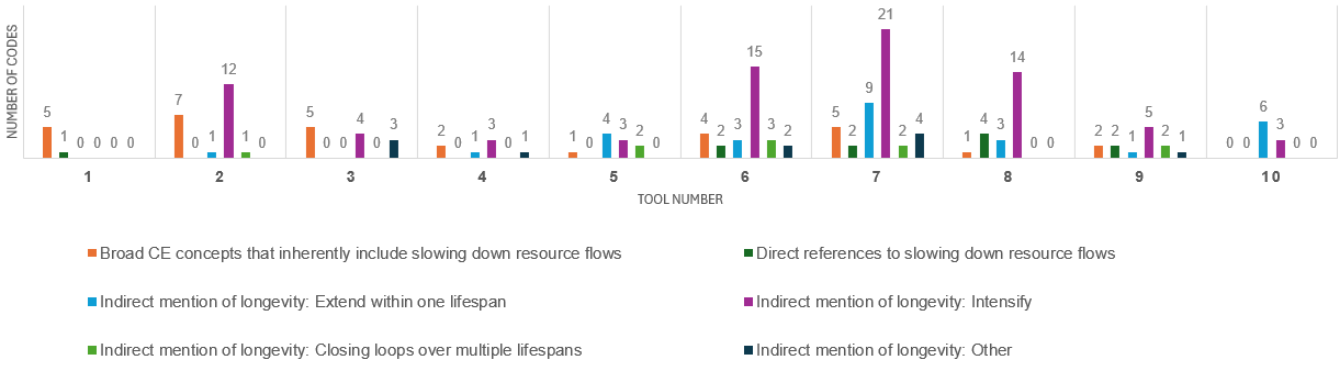


Figure 2: Longevity mentions per category

8 tools mention at least one longevity aspect (Tool 2,3,5,6,7,8,9,10). Among them “closing loops for longer lifespans” is more emphasized, compared to "keeping products in the loop for longer within one cycle" and "intensifying product use". Tools 1, 3, 4, 8 and 10 don’t mention any aspects of intensifying product use. Tool 1, 3 does not mention any longevity aspect about “extend within one lifespan”.

Practical Support for Longevity

The tools offer varied practical support for increasing longevity including brief inquiries, scoring mechanisms that assess the current circularity state of the company, scoring the circularity of a product, theoretical explanations, mapping the lifecycle or value chain exercises, specific questions integrated in a business model canvas and illustrative cards demonstrating concepts, examples and rebound effects of strategies such as repurposing and remanufacturing.

The tools barely mention longevity aspects (Tool 1, 3, 4) don’t provide specific help for longevity. In one of the tools (tool 8) longevity aspects are explained, yet the **tool provides barely practical support besides the theoretical explanation**. Tool 8 assesses the current circularity of a product similar to a simplified life cycle analysis. Longevity aspects are important in a life cycle assessment, yet the tool ignores aspects such as the real lifespan of a product in its calculations.

The support provided is sometimes superficial. For example, tools might ask broad inspiring guiding questions, yet limits tool-users in answering these questions. To demonstrate, in tool 2 tool-users need to sketch multiple elements to answer a broad question yet limit the user to a single Excel box to sketch this complex content. Tool 6 shows another example, the tool asks, in the context of prolonging product life, if the product can become a service in some way, yet the tool-user only needs to answer Yes or No and list a possible barrier. A similar example can be found in Tool 7, where tool users only need to input percentage of mass that for example get reused or redistributed.

Remarkably, strategies intended to intensify product use such as "product-service-systems" are mentioned in some tools, **without questioning if this results in slowing down of resource flows**. For example, in tool 2, following code emerged “Can costs be avoided, reduced or distributed, e.g. by product-service-systems, renting or other options”. The tool speaks about avoiding costs for the company (or user) and does not refer to reducing ecological impact. Similar can be observed in a worksheet of tool 6, where the tool-user is asked to describe the user needs and how these needs can be met without owning the product. No reflection is made if this then reduces the flow of products.

It can be observed that questions are posed from the companies’ point of view, leading to an **ideal or hypothetical point of view**. To illustrate, in Tool 6, the tool-user sketches what happens in the multiple uses of the product. Which triggers the tool-user to think in multiple lifecycles. Yet, likely preferred/ideal scenarios will be sketched rather than scenarios that happen in reality. Similar in Tool 2, the tool-user is asked “How can they [technical nutrients] be returned to their cycle”. Tool 8 asks the “recovery potential” of reuse. Both examples illustrate the hypothetical nature of the questions.

Practical Support for Elements Influencing Longevity

A further analysis highlights gaps in the tools regarding elements influencing longevity. Several factors remain unaddressed, including the use context, technological advancements, product appearance, emotional attributes, and social considerations.

Interestingly, Tools can indirectly provide support for factors that influence the slowing down of resource flows without explicitly referencing this concept (Tool 3). To illustrate, tool 3 asks to systematically map user-, usage- and after usage- ecosystems. Although longevity is not specifically mentioned, the mapping of the users and usage might aid in detecting for example use behavior impacting longevity.

New categories that influence longevity emerged from the analysis, including consumer and user knowledge on longevity, corporate marketing strategies, and the accessibility of product and material information related to longevity.

Discussion and conclusions

The analysis of the tools does not give an answer whether the tools can be a useful tool to transition to a circular economy, nor was this the scope of the study. Yet, one of the main strategies for circularity (slowing down resource flows by elongating lifespans in one and over multiple lifespans) was barely mentioned in three of the analyzed tools. In the tools that mention and provide support for longevity, the focus is on closing loops rather than elongating the lifespan within one loop or intensifying use.

Strategies to intensify product use such as "product-service-systems" can be expected to be used as a means to slow down resource flows, yet in the tools it is sometimes decoupled from resource flows. Similar can be observed for the closing of loops.

Tools that do tackle (indirect) aspects of elongation within and over multiple lifespans and tackle aspects of intensifying use, have the potential to reduce ecological impact using longevity strategies. Yet, the tools use guiding questions, giga mapping exercises and lifecycle mapping exercises with a hypothetical/abstract starting point often aiming for initial ideation of ideas. Reality aspects impacting longevity such as how users really behave, how products and their context change over time, are barely touched upon.

Thus, even though the analyzed tools (7 out of 10) speak about longevity aspects and 6 out of 10 provide practical support for longevity. The tools support in slowing down resource flows is somehow superficial.

The emerging new categories influencing longevity can be further analyzed to consider in the development of comprehensive tools for supporting the slowing down of resource flows.

Future studies can do a more extensive and in-depth analysis of the tools on longevity aspects and observe tools and methods companies indicate to use.

References

Abu-Bakar, H., & Charnley, F. (2024). Developing a Strategic Methodology for Circular Economy Roadmapping: A Theoretical Framework. *Sustainability (Switzerland)*, *16*(15). https://doi.org/10.3390/su16156682

Alzaydi, A. (2024). Balancing creativity and longevity: The ambiguous role of obsolescence in product design. *Journal of Cleaner Production*, *445*. https://doi.org/10.1016/j.jclepro.2024.141239

Bakker, C. A., Mugge, R., Boks, C., & Oguchi, M. (2021). Understanding and managing product lifetimes in support of a circular economy. *Journal of Cleaner Production*, *279*. https://doi.org/10.1016/j.jclepro.2020.123764

Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: Exploring product life extension through design. *Journal of Cleaner Production*, *69*, 10–16. https://doi.org/10.1016/j.jclepro.2014.01.028

Baldé, C. P. ., Forti, V. ., Gray, V. ., Kuehr, R. ., & Stegmann, P. . (2017). *The global e-waste monitor 2017 : quantities, flows, and resources*. International Telecommunication Union.

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bocken, N., Strupeit, L., Whalen, K., & Nußholz, J. (2019). A review and evaluation of circular business model innovation tools. In *Sustainability (Switzerland)* (Vol. 11, Issue 8). MDPI. https://doi.org/10.3390/su11082210

Bridgens, B., & Lilley, D. (2017). Understanding material change design for appropriate product lifetimes. *PLATE, Product Lifetimes and the Environment*, 54–59.

Chapman, J. (2005). *Emotionally Durable Design: Objects, Experiences and Empathy*.

Chapman, J. (2009). Design for (Emotional) Durability. In *Source: Design Issues* (Vol. 25, Issue 4). http://www.product-life.

Cooper, T. (2020). Slower Cycles: An Essential Characteristic of the Circular Economy. In S. Eisenriegler (Ed.), *The Circular Economy in the European Union: An Interim Review* (pp. 99–116). Springer International Publishing. https://doi.org/10.1007/978-3-030-50239-3_9

Cooper, T., Burns, B., Chapman, J., Christer, K., Curran, A., Ervine, C., Evans, S., Fisher, T., Fuad-Luke, A., Garnett, K., Mackenzie, D., Park, M., Peattie, K., Shipton, J., Simon, M., Stahel, W. R., Twigg-Flesner, C., & van Nes, N. (2010). *Longer Lasting Products*.

Gower publishing limited and Ashgate publishing company.

Dagilienė, L., Čeičytė-Pranskūnė, J., Telešienė, A., Valušytė, R., & Varžinskas, V. (2024). Developing a circular design framework: Co-creation and validation of a circular product and service design tool. *Journal of Industrial Ecology*, *28*(4), 783–799. https://doi.org/10.1111/jiec.13494

Das, A., Konietzko, J., Bocken, N., & Dijk, M. (2023). The Circular Rebound Tool: A tool to move companies towards more sustainable circular business models. *Resources, Conservation and Recycling Advances*, *20*. https://doi.org/10.1016/j.rcradv.2023.200185

Den Hollander, M. (2018). *Design for Managing Obsolescence-A design methodology for preserving product integrity in a circular economy* [Delft University of Technology]. https://www.researchgate.net/publication/326368488

Eisenriegler, S., Schally, H.-M., Stahel, W. R., Webster, K., Lohan Cillian, Pietikäinen, S., Bonafe, S., Wachholz, C., Mandl, S., Tröger, N., Cooper, T., Bocken, N., Brand, U., Wissen, M., Frank-Stocker, A., Shields, K., Nagel, M., Paech, N., Holzinger, H., & Bhardwaj, A. (2020). *The Circular Economy in the European Union*.

Fraser, M., Conde, À., Haigh, L., Bailey, L., Veillet Lavalellee, M., Valli Shankar, A., Birliga Sutherland, A., & Murdie, M. (2024). *CIRCULARITY GAP REPORT*. www.deloitte.com.

Gaver, W. (2012). What should we expect from research through design? *Conference on Human Factors in Computing Systems - Proceedings*, 937–946. https://doi.org/10.1145/2207676.2208538

Gnanapragasam, A., Oguci, M., Cole, C., & Cooper, T. (2017). Consumer expectations of product lifetimes around the world: a review of global research findings and methods. *Product Lifetimes And The Environment 2017 - Conference Proceedings*, 464–469.

Haase, L. M., & Lythje, L. S. (2022). User Strategies for Prolonging Product Lifetimes: A New Starting Point for Circular Conceptual Design. *Sustainability (Switzerland)*, *14*(22). https://doi.org/10.3390/su142215133

Haase, L. M., Lythje, L. S., & Jensen, P. B. (2023). Designed to Last: Reframing Strategies for Designing Value Propositions that Support Product Longevity in 17 Best Practice Companies. *Circular Economy and Sustainability*, *3*(4), 2009–2035. https://doi.org/10.1007/s43615-022-00244-z

Haines-Gadd, M., Chapman, J., Lloyd, P., Mason, J., & Aliakseyeu, D. (2018). Emotional durability design Nine-A tool for product longevity. *Sustainability (Switzerland)*, *10*(6). https://doi.org/10.3390/su10061948

Hoang, K. M., & Böckel, A. (2024). Cradle-to-cradle business model tool: Innovating circular business models for startups. *Journal of Cleaner Production*, *467*. https://doi.org/10.1016/j.jclepro.2024.142949

Hummen, T., Hellweg, S., & Roshandel, R. (2023). Optimizing Lifespan of Circular Products: A Generic Dynamic Programming Approach for Energy-Using Products. *Energies*, *16*(18). https://doi.org/10.3390/en16186711

Ijassi, W., Evrard, D., & Zwolinski, P. (2024). Development of a circularity design methodology for urban factories based on systemic thinking and stakeholders engagement. *Sustainable Production and Consumption*, *46*, 600–616. https://doi.org/10.1016/j.spc.2024.02.031

Iraldo, F., Facheris, C., & Nucci, B. (2017). Is product durability better for environment and for economic efficiency? A comparative assessment applying LCA and LCC to two energy-intensive products. *Journal of Cleaner Production*, *140*, 1353–1364. https://doi.org/10.1016/j.jclepro.2016.10.017

Jensen, P. B. (2023). *Designed to Last: A Study to Support Increased Product Longevity* [Aalborg University]. https://doi.org/10.54337/aau528217970

Jensen, P. B., Haase, L. M., Cooper, T., Steward, J., Marsh, P., & Laursen, L. N. (2023). The LaST Tool – The Longevity and Sustainable Transition Tool. *Lecture Notes in Mechanical Engineering*, 757–771. https://doi.org/10.1007/978-3-031-28839-5_85

Jensen, P. B., Haase, L. M., & Laursen, L. N. (2021). A practical approach to companies' transformation toward product longevity: A best-case study. *Sustainability (Switzerland)*, *13*(23). https://doi.org/10.3390/su132313312

Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021). Barriers to product longevity: A review of business, product development and user perspectives. *Journal of Cleaner Production*, *313*. https://doi.org/10.1016/j.jclepro.2021.127951

Kasarda, M. E., Terpenny, J. P., Inman, D., Precoda, K. R., Jelesko, J., Sahin, A., & Park, J. (2007). Design for adaptability (DFAD)-a new concept for achieving sustainable design. *Robotics and Computer-Integrated Manufacturing*, *23*(6), 727–734. https://doi.org/10.1016/j.rcim.2007.02.004

Laitala, K., & Berg, L. L. (2023). *Why won't you complain? Consumer rights and the unmet*

product lifespan requirements. http://urn.fi/URN:ISBN:978-952-64-1367-9

Lilley, D., Bridgens, B., Davies, A., & Holstov, A. (2019). Ageing (dis)gracefully: Enabling designers to understand material change. *Journal of Cleaner Production*, *220*, 417–430. https://doi.org/10.1016/j.jclepro.2019.01.304

Løvbak Berg, L., & Hebrok, M. (2024). Holding on or letting go: Conflicting narratives of product longevity. *Resources, Conservation and Recycling*, *210*. https://doi.org/10.1016/j.resconrec.2024.107834

Machado, N., Morioka, S. N., & Gohr, C. F. (2024). Can product modularity boost strategies for circular business models? A visual tool proposal representing benefits and barriers considering expert opinion. *Journal of Cleaner Production*, *448*. https://doi.org/10.1016/j.jclepro.2024.141522

Nyström, T., Selvefors, A., Diener, D., Algurén, P., Hallquist, L., Eriksson, M., Whalen, K., Boyer, R., Sellén, J., Linder, M., Williander, M., Ohnell, S., Östling, J., & Andersson, K. (2023). *FUTURE ADAPTIVE DESIGN How to create longer-lasting products for circular offerings AN INNOVATION GUIDE FOR CIRCULAR CHANGE AGENTS*. www.ri.se

Nyström, T., Whalen, K. A., Diener, D., Hollander, M. Den, & Boyer, R. H. W. (2021). Managing circular business model uncertainties with future adaptive design. *Sustainability (Switzerland)*, *13*(18). https://doi.org/10.3390/su131810361

Oguchi, M., Tasaki, T., Daigo, I., Cooper, T., Cole, C., & Gnanapragasam, A. (2016). Consumers' expectations for product lifetimes of consumer durables. *Electronics Goes Green 2016+*.

Ostuzzi, F. (2017). *Open-Ended Design. Explorative Studies on How to Intentionally Support Change by Designing with Imperfection*.

Park, M. B. (2009). *Product Life: Designing for Longer Lifespans*. Kingston University Londen.

Rexfelt, O., & Selvefors, A. (2024). Mapping the landscape of circular design tools. *Resources, Conservation and Recycling*, *209*. https://doi.org/10.1016/j.resconrec.2024.107783

Royo, M., Chulvi, V., Mulet, E., & Ruiz-Pastor, L. (2023). Analysis of parameters about useful life extension in 70 tools and methods related to eco-design and circular economy. *JOURNAL OF INDUSTRIAL ECOLOGY*, *27*(2), 562–586. https://doi.org/10.1111/jiec.13378

Salvia, G., Cooper, T., Fisher, T., & Harmer, L. (2015). What is broken? Expected lifetime, perception of brokenness and attitude towards maintenance and repair. *PLATE Conference Proceedings*. https://www.researchgate.net/publication/281268978

Salvia, G., Zimmermann, N., Willan, C., Hale, J., Gitau, H., Muindi, K., Gichana, E., & Davies, M. (2021). The wicked problem of waste management: An attention-based analysis of stakeholder behaviours. *Journal of Cleaner Production*, *326*. https://doi.org/10.1016/j.jclepro.2021.129200

Sauerwein, M., Bakker, C., & Balkenende, R. (2018, June 28). *Annotated Portfolios as a Method to Analyse Interviews*. https://doi.org/10.21606/drs.2018.510

Shi, T., Huang, R., & Sarigöllü, E. (2022). Consumer product use behavior throughout the product lifespan: A literature review and research agenda. *Journal of Environmental Management*, *302*. https://doi.org/10.1016/j.jenvman.2021.114114

Van Den Berg, M. R., & Bakker, C. A. (2015). *A product design framework for a circular economy*. *17*.

Van Den Berge, R. B. R. (2024). *Product lifetime extension through design Encouraging consumers to repair electronic products in a circular economy*. https://doi.org/10.4233/uuid:ab99217e-5ae7-4322-b4c9-311547a3feb9

van Hinte, E. (2004). *Eternally Yours: Time in Design: Product, Value, Sustenance*. 010 Publishers.

van Nes, N., & Cramer, J. (2005). Influencing product lifetime through product design. *Business Strategy and the Environment*, *14*(5), 286–299. https://doi.org/10.1002/bse.491

Wastling, T., Charnley, F., & Moreno, M. (2018). Design for circular behaviour: Considering users in a circular economy. *Sustainability (Switzerland)*, *10*(6). https://doi.org/10.3390/su10061743

Research paper
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Development of a Digital Product Passport for iPads to Enhance Student Sustainability Practices

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Keywords: Digital Product Passport; Product Lifetime Extension; End-of-Life Management, Sustainability.

Abstract: This paper proposes a generic framework for the design and development of Digital Product Passports (DPPs) applicable across various products, sectors, and developers. The framework, established considering information requirements and existing approaches identified in DPP literature, comprises four key phases: (1) Defining the Foundations; (2) Design and Development; (3) Testing and Refinement; (4) Deployment and Evaluation. Its application is demonstrated through the development of a Digital iPad Product Passport for the University of Kentucky iPad initiative (UK-DiPP). An app-based UK-DiPP prototype is presented with three core intended functionalities: (1) Charging Pattern, (2) Battery Usage, and (3) iPad Lifecycle, aiming to promote sustainable charging practices, extend battery lifetime, support end-of-life (EoL) management, enhance sustainability awareness on campus, and mitigate the negative environmental impacts associated with iPad use and disposal. Challenges as a third-party DPP developer, including limited data accessibility and technical obstacles, are discussed with potential workarounds and solutions. This research contributes to the practical development and implementation of DPPs by offering a versatile framework and showcasing real-world application.

Introduction

The Digital Product Passport (DPP), introduced by the European Union (EU) under the Circular Economy (CE) Action Plan, aims to enhance transparency throughout a product's lifecycle covering pre-manufacturing (PM), manufacturing (M), use (U), and post-use (PU) stages (EC, 2020). The DPP is a tool for providing electronically accessible information about a specific product (e.g., origin, composition, maintenance and repair guidelines, and end-of-life (EoL) management options) to stakeholders across the entire value chain (EPC 2024). Relevant stakeholders, while complying with privacy and proprietary concerns, can access and exchange data through the DPP for agreed upon criteria (Adisorn et al., 2021). Through such data sharing, a DPP creates valuable feedback loops and supports the design, production, use, as well as EoL management of products in a more sustainable way.

While the concept is promising, fully-deployed DPPs remain limited due to various challenges. One issue is the lack of standardization and consistency in the development, management, and data sharing (Cetin et al., 2023). The feasibility and value of a standardized DPP to attain a unified format across sectors is debated due to concerns about complexity and resource demands (Voulgaridis et al., 2024). Several studies explored the information requirements for DPPs (Lopes and Barata, 2024; Plociennik et al., 2022; Adisorn et al., 2021) but also highlighted that these requirements can vary depending on the sector or product type. This raises the question of how to determine the most relevant information for a DPP tailored to a specific product. Intellectual property (IP) concerns further complicate data accessibility and availability, especially when developed by a third-party (Ducuing and Reich, 2023). Additional obstacles include poor platform interoperability (Jansen et al., 2023), data security and confidentiality (Berger et al., 2023), and trustworthy data exchange (Lopes and Barata, 2024). Despite its challenges, when developed, DPPs could help enhance sustainable production and consumption.

This research employs the concept of DPP to enhance campus sustainability and educate students on sustainable practices for their

iPads at the University of Kentucky (UK). The UK iPad Initiative was launched in 2019 to make the UK an innovative campus in technology use, managed by the Smart Campus Program (SPC). UK provides an iPad to every incoming undergraduate student with more than 30,000 currently in use. While the SPC collaborates with a third-party service platform (GSX) to handle iPad service and repair, it lacks the capability to track or monitor usage data of these devices, such as charging patterns, energy consumption, battery usage, defects, or how/where they are disposed of at EoL after students leave campus.

This research was inspired by the need to gather and share iPad lifecycle information with students and other stakeholders on/off campus. Access to this lifecycle data can enhance SCP's ability to promote more sustainable iPad use. Information such as optimal charging practices, battery usage guidelines, energy consumption, repair & maintenance guidelines, EoL management, etc., can help extend iPad lifetime and mitigate negative environmental impacts associated with their use and disposal. In addition, this can also increase students' awareness about sustainability and help them make reasonable decisions not only when using iPads but also with other products and activities. Therefore, two Research Objectives (ROs) are formulated:

- ***RO1****: Establish a framework for developing a DPP*
- ***RO2****: Develop an app-based Digital iPad Product Passport for UK-iPads (UK-DiPP)*

The remainder of the paper first examines relevant prior work related to DPPs. Next, a framework to guide the development of DPPs is presented. This is followed by a discussion of the preliminary UK-DiPP app, including the challenges faced during development. Finally, the key takeaways and directions for future research are presented.

Related Work

This section provides a brief discussion of previous research on information requirements and approaches for developing DPPs. Detailed discussion of the DPP concept can be found in EPC (2024), Lopes and Barata (2024), and Adisorn et al. (2021).

DPP Information Requirements

Adisorn et al. (2021) examined existing regulated and voluntary information-sharing tools (e.g., Energy Label, Material Passport, Asset Administration Shell, etc.) to explore the design requirements for DPPs. Manufacturers and suppliers are identified as primary providers of specific product information, with information flow being either uni- or multi-directional. They identified key information categories to include the origin, composition, repair, dismantling, and product handling at EoL, covering entire product lifecycle. They also emphasized the need to assess information requirements in a sector- or product-specific manner, given the DPP's intended broad applicability.

Through a literature review and by engaging practitioners, Plociennik et al. (2022) identified generic information requirements for DPPs. These are categorized into four types: Manufacturing data; Usage data; EoL data; Lifecycle data. They emphasize that information requirements depend on factors such as the product's complexity, lifecycle complexity, its value (monetary or ecological), and harm potential.

Lopes and Barata (2024) conducted a systematic literature review and bibliometric analysis of 40 studies since 2021 to identify key guidelines for DPP structure and requirements. The most commonly listed information requirements identified, regardless of product type, were: Product information; Environmental information; Manufacturing data; Utilization data; Life-cycle data; Supply chain information; Guidelines, manuals, and compliance information. They also found that the need for a robust regulatory framework is the most commonly mentioned requirement for DPPs.

These studies present the current understanding of possible DPP information needs, while also highlighting the sector- and product-specific nature of these requirements. This variability indicates the challenge of determining suitable information a DPP should encompass for a specific product. The absence of standardization and consistency in the development process adds further complexity to creating a new DPP.

Existing Approaches to DPP Development

Langley et al. (2023) proposed a framework for orchestrating the development of DPPs, outlining eight guiding principles. These principles offer useful guidance for implementing DPPs, but remain broad, focusing on system-level insights rather than product-level specifics.

A standardized framework for designing and developing the DPP system within the manufacturing industry was introduced by Psarommatis and May (2024). While their seven-step framework provides a useful roadmap for implementing the DPP system, its focus is limited to only the manufacturing sector. This does not consider the broader scope of a DPP, which is to provide total lifecycle information as described previously. The framework is also described in broad terms, making its operationalization difficult. Another gap is the lack of guidance on identifying the necessary data and desired functionalities, especially given that information requirements vary depending on products or sectors.

Legardeur and Ospital (2024) presented a methodology for designing a generic DPP for the fashion and textile sector. While the proposed methodology addresses essential conceptual aspects, it lacks technical details, such as interface design (e.g., web-based or app-based), and data storage and sharing system.

Prior research provides valuable insights into DPP information needs and development. Nevertheless, challenges persist in identifying appropriate information types for specific products, and existing development approaches face limitations in practical implementation. The potential role of third-party developers, as well as the varying needs for a DPP among different user groups (e.g., consumers, suppliers, etc.), are also often overlooked in existing literature. Therefore, this research first focused on establishing a generic framework for developing a DPP (RO1) adaptable across various products, sectors, and developers. The findings from above studies and insights from other DPP-related initiatives such as the EU Batteries Regulation (EPC, 2023) and Ecodesign for Sustainable Products Regulation (EPC, 2024) were considered to establish and apply the framework for developing an app-based UK-DiPP (RO2).

Approach and Methodology

Framework for DPP Development

Figure 1 illustrates the proposed framework for developing a DPP, consisting of four key phases: (1) Defining the Foundations; (2) Design and Development; (3) Testing and Refinement; (4) Deployment and Evaluation. Phase 1 establishes the groundwork by identifying the purpose(s) of the DPP, defining the target end user(s) and sector(s), and determining relevant stakeholders involved. Phase 2 decisions build on these outcomes.

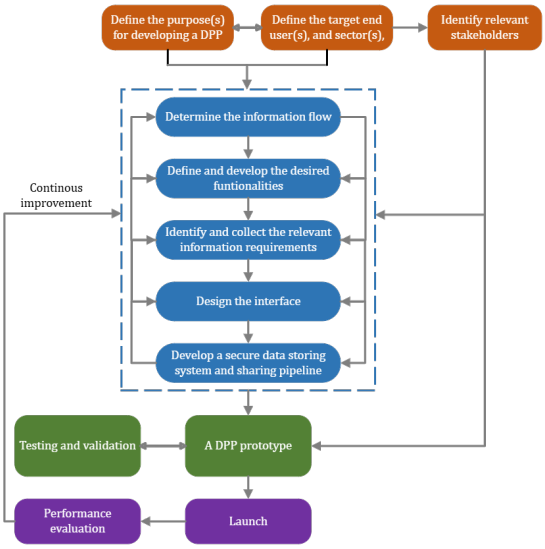


Figure 1. Framework for developing a DPP

Phase 2 focuses on creating the technical and functional backbone of the DPP. This includes determining the information flow (e.g., uni-, bi-, or multi-directional), defining desired functionalities, identifying requirements and collecting relevant information, designing the interface (e.g., web-based, app-based, etc.), and developing a secure data storing system (e.g., local, cloud-based, etc.) and the sharing pipeline. Each step in this phase is interconnected and iterative, requiring parallel consideration rather than a linear approach, as decisions in one area can influence others. For example, limited data availability or accessibility due to IP concerns may hinder achieving the initially defined DPP functionality. In such cases, the deliverable functionalities should be refined to align with the available resources. Engaging with relevant stakeholders in this phase is essential to verify identified information

requirements and collected data accuracy, especially when a DPP is developed by a third-party. The outcome of Phase 2 is a DPP prototype. In Phase 3, this prototype is tested and validated to ensure it meets the desired functionalities and stakeholder expectations. Finally, Phase 4 involves DPP launch and performance evaluation (e.g., performance metrics, user feedback, etc.) for continuous improvement. Conducting regular reviews and integrating technological advancements are also crucial to maintain relevancy and effectiveness of the DPP.

Framework Application for Developing a Digital Product Passport for UK iPads

The framework is applied to develop a DPP for the iPads on UK campus (targeted sector) (UK-DiPP). Figure 2 illustrates the architecture of the UK-DiPP. The targeted end users are the students and employees on campus who own iPads. The purposes for passport development include promoting the sustainable charging and use of iPads, extending battery lifetime, supporting EoL management, increasing sustainability awareness on campus, mitigating negative environmental impacts associated with iPad use and disposal. Relevant stakeholders are the targeted users, the SCP staff, Apple, suppliers, and repair and EoL service providers.

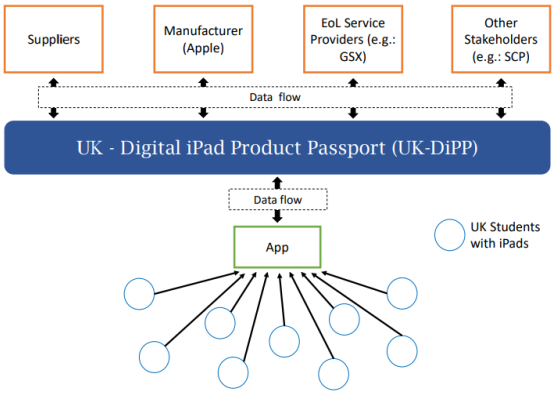


Figure 2. UK-DiPP Architecture

Building on these, Phase 2 was initiated. The information flow is multi-directional to enable data sharing among the relevant stakeholders. The desired functionalities include tracking and presenting charging patterns, monitoring and displaying the battery usage, and providing total iPad lifecycle information. Therefore, the relevant information requirements cover PM (e.g., the material origin and composition), M (e.g., energy usage, chemical usage, manufacturing waste, etc.), U (e.g., charging pattern data, battery usage, repair and service guidelines, etc.), and PU (e.g., take-back availability, EoL management, etc.) stages. An app-based interface was selected, alongside Firebase as the data storage system to ensure data security. The data-sharing pipeline is shown in Figure 2. An initial meeting was held with the Apple university representative to discuss access to data. A mutual non-disclosure agreement between UK and Apple could not be pursued at that time due to unforeseen circumstances. Therefore, it was decided that preliminary UK-DiPP development will be pursued with open-access data.

App Development Process

Figure 3 presents the app development process.

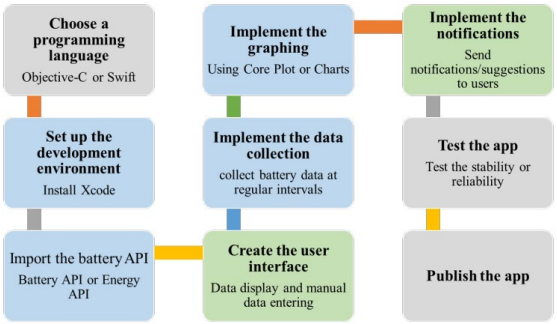


Figure 3. App development process

The app is developed using Xcode as the integrated development environment and Swift and SwiftUI for creating a modern, responsive user interface (UI). Firebase and Firestore are utilized for real-time data synchronization and storing, with Firebase Cloud Functions and Messaging enabling silent push notifications and background data collection. The app is designed to collect data from each user using anonymous identifiers, ensuring that no personally identifiable information is gathered during the process. The app follows the Model-View-ViewModel architecture, which ensures maintainable and scalable code by separating business logic, UI, and data management. The Model handles data processing and Application Programming Interface (API) calls, the View displays real-time battery data through interactive charts and tables, and the ViewModel dynamically updates data between the Model and View. A more detailed

discussion of the app development is beyond the scope of this paper and not included due to word limitation.

Preliminary Results

The results presented are preliminary, as the development is on-going due to challenges and limitations in accessing the necessary APIs and collecting the required data (further discussed in the Discussion section). Figure 4 demonstrates the user interface of the UK-DiPP prototype. The core functionalities described below are intended for this passport but are not yet fully developed. Additionally, some images in this section are mock-ups created for illustrative purposes (Figures 5, 6, 7, and 8).

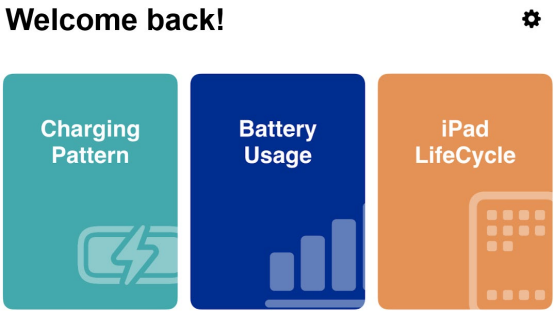


Figure 4. UK-DiPP: Prototype

- **Charging Pattern** (Figures 5 and 6): This feature monitors and displays the daily and weekly iPad charging patterns, including charging start time, duration, and a weekly summary of on-peak and off-peak charging duration. On-peak hours are periods of high electricity demand (higher costs), while off-peak hours are times of lower demand, typically at night, with reduced electricity rates (LGE-KU, 2024). These hours also differ based on seasons. This feature is aimed at guiding users toward more energy-efficient and cost-effective charging practices. This not only helps the users lower their electricity bills but also reduces strain on the power grid during peak periods. Suggesting optimal times for charging and showing daily as well as weekly energy consumption are considered for future implementations.

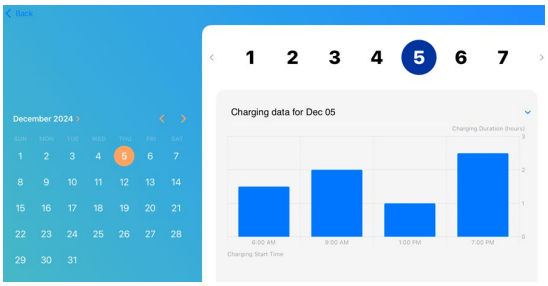


Figure 5. UK-DiPP: Daily Charging Pattern

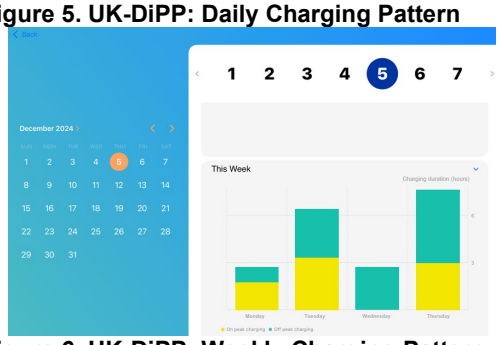


Figure 6. UK-DiPP: Weekly Charging Pattern (Yellow: On-Peak, Green: Off-Peak)

- **Battery Usage** (Figures 7 and 8): This feature promotes optimal battery health to extend its lifetime, reduce the need for frequent replacement and mitigate the negative environmental impacts associated with battery manufacturing and disposal. It monitors users' battery management on a daily and weekly basis by tracking how long the battery remains within different levels (0-20%, 20-40%, and 40-100%). Maintaining the battery level above 20% is critical for preserving its longevity, as frequently dropping below this threshold can reduce its life over time (Faisal et al., 2021; Su et al., 2019; Keeli and Sharma, 2012). The passport will send notifications when the battery falls below 40%, encouraging them to charge before it reaches the critical 20% threshold.

- **iPad Lifecycle:** This feature intends to provide comprehensive lifecycle information of an iPad, covering the PM, M, U, and PU stages. However, as a third-party developer, access to such information is limited. Therefore, this category presents static information gathered from publicly available sources, prioritizing those provided by Apple. It starts with the pre-manufacturing stage, detailing the materials used in iPads. The manufacturing stage shows data such as clean energy use during manufacturing. The use-stage information includes guidelines on maximizing battery longevity, tips for optimal

device performance, and instructions for repair and service. Finally, it outlines the EoL options, explaining how iPads can be recycled or reused, and who handles this process.

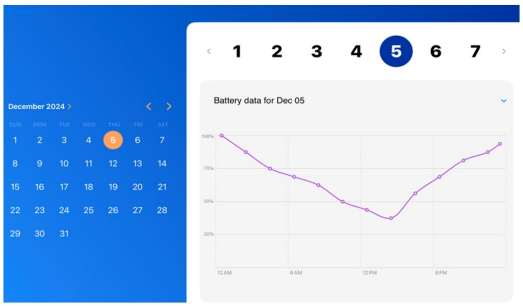


Figure 7. UK-DiPP: Daily Battery Usage



Figure 8. UK-DiPP: Weekly Battery Usage

Discussion

This section discusses the challenges and limitations faced in developing the desired functionalities for the UK-DiPP. Unlike typical DPPs created by Original Equipment Manufacturers (OEMs) for their products, the UK-DiPP is developed by a third-party. Therefore, the challenges outlined here are distinct from those typically encountered by OEMs.

One significant challenge faced in this research is the restricted access to APIs as a third-party developer. While Apple devices provide basic battery level and activity data through their default settings, this information lacks details on on-peak and off-peak charging durations and does not offer detailed insights into battery usage. The UK-DiPP app aims to address these gaps with its Charging Pattern and Battery Usage features. Implementing these features in real-time requires direct access to specific battery APIs, which are classified as private and inaccessible to third-party developers.

Another obstacle is the limitation on background data collection. Without access to battery APIs, the app needs to run continuously in the background to collect and display battery and charging data in real-time. However, Apple policies restrict third-party apps from operating continuously in the background to preserve battery life and prevent misuse. As a result, while the UK-DiPP functions as expected when open, the process stops when the app is closed or moves to the background.

To address this limitation, the use of silent push notifications via the Apple Notification Service is being explored. These notifications would wake the app at specific intervals to allow for data collection and chart updates. However, this approach is inherently limited by Apple's restrictions on the frequency of push notifications. Excessive notifications risk throttling or blocking by Apple, which would further limit the app's ability to provide consistent background updates. Consequently, this solution would only support periodic rather than real-time data collection, undermining the app's intended functionality.

A third challenge lies in the limited access to lifecycle information for iPads, which complicates the development of the app's iPad Lifecycle feature. Given these constraints, the team is exploring collaboration with Apple to gain access to restricted APIs or developing a custom approach that aligns with Apple's policies while meeting the app's requirements.

Conclusions and Future Work

This paper proposes a generic framework for designing and developing DPPs that can be applied across diverse products and sectors, established based on current literature and initiatives. Using this framework, the UK-DiPP was designed, and a prototype was developed. Despite challenges such as limited data access and technical constraints, the preliminary UK-DiPP demonstrates the potential for promoting sustainable usage behaviors of iPads, extending their lifetime, supporting EoL management, and enhancing sustainability awareness on UK campus. The UK-DiPP can also contribute to mitigating environmental impacts associated with iPad usage and disposal. This research further advances the

practical implementation of DPPs by offering a versatile DPP development framework and showcasing its application in real-world contexts.

Future work will focus on addressing technical barriers to fully develop the desired functionalities of UK-DIPP. Testing and validation will involve UK students with iPads to ensure the app meets its intended purposes and user needs. After refinement, the UK-DiPP will be launched on the App Store, followed by performance evaluations to support continuous improvement. A detailed analysis of students' charging habits and battery usage will also be conducted to enhance the SCP's ability to promote more sustainable iPad use on campus.

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References

Adisorn, T., Tholen, L., & Götz, T. (2021). Towards a digital product passport fit for contributing to a circular economy. *Energies*, *14*(8), 2289. https://doi.org/10.3390/en14082289

Berger, K., Baumgartner, R. J., Weinzerl, M., Bachler, J. & Schöggl, J. P. (2023). Factors of digital product passport adoption to enable circular information flows along the battery value chain. *Procedia CIRP, 116*, 528-533. https://doi.org/10.1016/j.procir.2023.02.089

Çetin, S., Raghu, D., Honic, M., Straub, A. & Gruis, V. (2023). Data requirements and availabilities for material passports: A digitally enabled framework for improving the circularity of existing buildings. *Sustainable Production and Consumption, 40*, 422-437. https://doi.org/10.1016/j.spc.2023.07.011

European Commission. (2020). *Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. A new Circular Economy Action Plan. For a cleaner and more competitive Europe.* European Commission. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

European Parliament and Council of the European Union (EPC). (2023). *Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC.* Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1542

European Parliament and Council of the European Union (EPC). (2024). *Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC.* Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401781

Ducuing, C. & Reich, R. H. (2023). Data governance: Digital product passports as a case study. *Competition and Regulation in Network Industries*, *24*(1). https://doi.org/10.1177/17835917231152799

Faisal, M., Hannan, M. A., Ker, P. J., Lipu, M. S. H., & Uddin, M. N. (2021). Fuzzy-based charging–discharging controller for lithium-Ion battery in microgrid applications. *IEEE Transactions on Industry Applications, 57*(4), 4187-4195. https://doi.org/10.1109/TIA.2021.3072875

Jensen, S. F., Kristensen, J. H., Adamsen, S., Christensen, A. & Waehrens, B. V. (2023). Digital product passports for a circular economy: Data needs for product life cycle decision-making. *Sustainable Production and Consumption, 37*, 242-255. https://doi.org/10.1016/j.spc.2023.02.021

Keeli, A. & Sharma, R. K. (2012). Optimal use of second life battery for peak load management and improving the life of the battery. *2012 IEEE International Electric Vehicle Conference, USA*, 1-6. https://doi.org/10.1109/IEVC.2012.6183276

Langley, D. J., Rosca, E., Angelopoulos, M., Kamminga, O., & Hooijer, C. (2023). Orchestrating a smart circular economy: Guiding principles for digital product passports. *Journal of Business Research, 169*, 114259. https://doi.org/10.1016/j.jbusres.2023.114259

Legardeur, J., & Ospital, P. (2024). *Digital product passport for the textile sector.* European Parliament. https://www.europarl.europa.eu/RegData/etudes/STUD/2024/757808/EPRS_STU(2024)757808_EN.pdf

LG&E & KU. (2024). *Residential time of day rates*. Retrieved December 3, 2024, from https://lge-ku.com/residential/billing/time-of-day-rates

Lopes, C. & Barata, J. (2024). Digital Product Passport: A review and research agenda. *Proceida Computer Science, 246*, 981-990. https://doi.org/10.1016/j.procs.2024.09.517

Plociennik, C., Pourjafarian, M., Saleh, S., Hagedorn, T., Lopes, A. C. P., Vogelgesang, M., Baehr, J., Kellerer, B., Jansen, M., Berg, H., Ruskowski, M., Schebek, L., & Ciroth, A. (2022). Requirements for a digital product passport to boost the circular economy. *Informatik 2022, Germany.* https://doi.org/10.18420/inf2022_127

Psarommatis, F., & May, G. (2024). Digital product passport: A pathway to circularity and sustainability in modern manufacturing. *Sustainability, 16*(1), 396. https://doi.org/10.3390/su16010396

Saari, L., Heilala, J., Heikkilä, T., Kääriäinen, J., Pulkkinen, A., & Rantala, T. (2022). Digital Product Passport promotes sustainable manufacturing. *VTT Technical Research Centre of Finland, 2022*.

Su, J., Lin, M., Wang, S., Li, J., Coffie-Ken, J., & Xie, F. (2019). An equivalent circuit model analysis for the lithium-ion battery pack in pure electric vehicles. *Measurement and Control*, *52*(3-4), 193-201. https://doi.org/10.1177/0020294019827338

Voulgaridis, K., Lagkas, T., Angelopoulos, C. M., Boulogeorgos, A.-A. A., Argyriou, V., & Sarigiannidis, P. (2024). Digital product passports as enablers of digital circular economy: A framework based on technological perspective. *Telecommunication Systems, 85*, 699–715. https://doi.org/10.1007/s11235-024-01104-x

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Citizen Engagement Activities: Applying Behaviour Change Techniques in Sustainable Clothing Consumption

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Keywords: Sustainable Clothing Consumption; Citizen Engagement; Behaviour Change Techniques; Lifetime Extension.

Abstract: The study explores the application of Behaviour Change Techniques (BCTs) in promoting sustainable clothing consumption. The fashion industry significantly impacts the environment, and despite consumer interest in sustainable options, adoption remains low, and a green gap persists. This research aims to identify effective methods to encourage sustainable behaviours. BCTs, a theoretical framework originally used in health contexts, are applied here to sustainable clothing consumption. Four citizen engagement activities were conducted, each incorporating different BCTs. Surveys were conducted before and after the activities to measure their effectiveness. The study found that certain BCTs (providing information on social and environmental consequences, education, and instructions on how to perform behaviours), significantly correlated with participants' intentions to adopt sustainable clothing consumption behaviours. These findings suggest that interventions combining impact awareness through information with action are most effective. The study highlights the potential of BCTs to guide and evaluate interventions aimed at reducing the green gap in sustainable clothing consumption.

Introduction

The fashion industry has proven alarming impacts on the environment and climate (Niinimäki et al., 2020). While planetary boundaries are being exceeded, it is urgent to find ways to reduce production and consumption (Garcia-Ortega et al., 2023). On the consumption side, although consumers express interest in sustainable offerings, they do not necessarily adopt them. Similarly, consumption levels are not decreasing. This phenomenon is conceptually known as the green gap (ElHaffar et al., 2020) and is present in sustainable fashion consumption (Park & Lin, 2020). Research provides little insight into the levers for reducing this gap. Therefore, the following question remains open: how can behaviours be changed, and action encouraged to prompt the adoption of a more sustainable fashion consumption, aimed at extending the use of clothing as much as possible? Using the theoretical framework of behaviour change techniques, this research brings insights through an exploratory study.

Literature Review and Theoretical Framework

Behaviour Change Techniques

To categorize methods aiming to change people's behaviour, Michie et al. (2013; 2015) introduced a comprehensive list of behaviour change techniques (BCTs). Interventions that use these BCTs can be defined as “behaviour change interventions”, “a coordinated set of activities designed to change specified behaviour patterns” (Michie et al., 2011, p.1). The original purpose of the BCTs has been in the field of health, however, the BCT taxonomy can be applied in other fields (Michie et al., 2013). Examples regarding sustainable consumption behaviours explored packaging, food, or energy (Addo et al., 2018; Allison et al., 2022; Graça et al., 2019). The context of this study is behaviour change interventions to make clothing consumption more sustainable through clothing use and disposal. Table 1 lists the relevant BCTs, as well as their definition.

BCT	Definition	Source
Shaping knowledge	Instructions on how to perform a behaviour, skills training	Michie et al., 2013; 2015
Behavioural rehearsal, practice	Practice and rehearse behaviour one or more times to increase skills	Michie et al., 2013; 2015
Education	Improving awareness or comprehension related to the target behaviour	Michie et al., 2011
Enablement	Create the opportunity to perform behaviour by minimising obstacles and providing resources	Michie et al., 2011
Information about social and environmental consequences	Provision of information (e.g. written, verbal, visual) about social and environmental consequences related to the target behaviour	Michie et al., 2013; 2015
Comparison of behaviour / Modelling of behaviour	Comparing own behaviour to a sample, to others' performance, receiving information about others' approval	Michie et al., 2013; 2015
Association - Exposure	Confrontation with a stimulus to encourage response resulting in target behaviour	Michie et al., 2013; 2015

Table 1. Behaviour Change Techniques used in this Study.

These BCTs were used to categorise and evaluate different interventions about sustainable clothing consumption. We assessed their effectiveness in encouraging consumers to perform the target behaviour, i.e. to reduce the green gap.

Citizen Engagement Activities as forms of intervention

This study focuses on citizen engagement activities (CEAs) as forms of behaviour change interventions. CEAs refer to in-person workshops or community events that engage citizens to interact on aspects of sustainable consumption. Previous research has shown that providing consumers with information does not necessarily lead to a change in action as consumers need to connect information and their own behaviours (Peattie, 2010). Furthermore, regarding sustainable behaviour, research has mainly focused on building theoretical models of interventions (Davoodian et al., 2014; Falcone & Fiorentino, 2024), with only few studies testing out the interventions in practice (Betzler & Kempen, 2024; May & Fearne, 2024). This study therefore focuses CEAs that actively engage citizens in the following target behaviour: to use and dispose clothing items in a more circular and sustainable way. In doing so, this research is a form of intervention research.

Methods

Four CEAs, each incorporating different BCTs, were identified and selected. First, a "Textile fresco" workshop (CEA1), where participants, guided by a facilitator, read and organized cards containing information about the fashion industry and its impacts, before discussing the topic and their consumption habits. Next, a clothing repair workshop (CEA2), where participants, guided by a facilitator, learned four repair techniques and applied these to their own garments. Then, a swapping event (CEA3), where participants, guided by a stylist, exchanged clothes they no longer wore. Finally, a visit to a sorting and recycling centre (CEA4), where participants, guided by the centre's manager, discovered the clothing sorting process, asked questions, and engaged in discussions. These four CEAs took place in France, in the Paris region in October and November 2024. Prior to the CEAs, interviews were held with the organizers of each CEA to identify the BCTs at play. For each CEA, table 2 presents the BCTs.

In order to test the effectiveness of the different BCTs for each CEA, a survey was conducted before the activity and right after the activity (Cozby & Bates, 2024). The participants could also leave their email address for a third follow-up survey three months after the activity. The target group of the survey were the participants that signed up for the different CEAs, following a purposive sampling method. The survey was translated from English to French to ensure the participants' understanding of the questions. The questions of the first survey (pre-activity) consisted of demographic questions, followed by Likert-style questions (Eichhorn, 2022) about their awareness of the impact of the textile industry and their sustainable values.

BCTs	CEA 1	CEA 2	CEA 3	CEA 4
Education	✓	✓		✓
Information on social and environmental consequences	✓			✓
Feedback on behaviour	✓	✓		
Behavioural rehearsal/practice		✓		
Comparison of behaviour/Social Comparison/Modelling		✓	✓	
Instructions on how to perform the behaviour		✓		✓
Enablement		✓	✓	
Association – Exposure				✓

Table 2. Behaviour Change Techniques identified in each CEA.

Participants then answered multiple-choice questions about their current use and disposal behaviour of textiles. The questions of the second survey (post-activity) were focused on identifying the effectiveness of each BCT used in the respective CEA, as well as identifying the participants intention to perform the target behaviour of each CEA, through Likert-style and single-choice questions. Participants also had the opportunity to specify their answers through a comment field. Due to the timeline, the third survey has not contributed to the results of this paper.

The responses were analysed using quantitative methods, through SPSS. Descriptive statistical tests were used to get an overview of participants' knowledge and behaviour prior to the activity. To test the relation between the individual BCTs and the intention to perform the target behaviour, Spearman's rank correlation for non-parametric tests was used, due to the small sample size (Agresti, 2018).

Results

The following section presents the results of the correlation analysis (see Table 4 in the appendix), supported by descriptive results (see Table 5 in the appendix). Sociodemographic characteristics of participants of all CEAs can be found in Table 3 in the appendix.

CEA1 – Textile Fresco

Activity 1 had a total of 7 active participants, out of which 6 responded to the survey. Before the CEA, participants awareness of the textile industry's environmental impact was mainly neutral, and they were neutral or disagreed regarding considering sustainability when purchasing and disposing of clothing items.

The effectiveness of each BCT on the participants' intention to perform the target behaviour was measured using Spearman's correlation for non-parametric tests. Results show that *Education*, in this case, learning about new options of what to do with the clothes they do not wear anymore, does not correlate with the intention to perform the target behaviour (dispose or use clothing items in a more circular and sustainable way in the future). *Information* does strongly correlate with the intention to use and dispose clothing more sustainably and is statistically significant at the 0.01 level. For the BCT *Feedback on behaviour*, all participants responded that the information from the workshop offered them feedback on their current clothing disposal practices. Since there is no variation in the responses, the correlation with the intention to perform the target behaviour could not be tested. However, respondents specified their answers (open-ended question), mentioning that the workshop made them think about more circular solutions, reflect on their own consumption and what they can do as an individual, as well inspire them to create a responsible wardrobe through buying more second-hand or recycled items. These comments show a strong intention to consume more sustainably due to the feedback they received on their current consumption and disposal practices in the CEA.

CEA2 – Repair Workshop

Activity 2 had a total of 8 participants, out of which 7 responded to the survey.

Before the CEA, most participants stated that they were aware of the textile industry's environmental impact and agreed regarding considering sustainability when purchasing and disposing of clothing items. More than half of the participants stated that they have previously repaired clothes or gotten clothing repaired or altered.

Results show that *Education*, in this case, learning about new options of what to do with the clothes they do not wear anymore, correlates strongly (0,79) with the intention to perform the target behaviour, and is significant

at the 0.05 level. For *Behavioural rehearsal/practice* the correlation could not be tested, since all participants responded with "yes" to the question if practicing garment repair as part of the workshop encouraged them to repair garments, which shows their intention to perform the target behaviour in the future (see Table 5). The test of Spearman's correlation showed that the BCT *Feedback* is not significantly correlated to the intention to perform the target behaviour. *Comparison* did also not yield a statistically significant correlation with the intention to perform the target behaviour, however, 85% of respondents agreed that the provision of repair examples helped them compare their repair results with others and encouraged them to repair more in the future. A correlation between *Instructions on how to perform the behaviour* and the intention to perform it was not possible to test, since there was no variance in responses ("yes" only). This however shows that the instructions on how to perform the target behaviour were successful. *Enablement* can also not be tested for correlation, but all respondents agreed that the workshop enabled them to repair more of their clothes themselves, as well as that it helped to bring their own garments to learn how to best repair it. 85% of participants also said that they would not have repaired that garment if it was not in the context of the workshop, which shows that this workshop was successful in enabling repair behaviour (see Table 5).

CEA3 – Swapping Event

Activity 3 only had one survey that participants filled out during the event. A total of 11 people answered the survey. Participants showed previous awareness of the impact of the textile industry, while on average neither disagreeing or agreeing with considering sustainable values with buying or disposing of clothing. None of the participants had attended a similar clothing swap event previously, but all of them plan on attending one in the future.

Comparison of behaviour/social comparison/modelling in this case describes the context of the event, by comparing your own swapping behaviour to others, receiving information about others' swaps or others approval of your clothes, as well including a circular fashion stylist in the event to help style swapped items. This BCT did not show a statistically significant correlation with the intention to perform the target behaviour (see Table 4), but on average the respondents agreed that the context of the activity encouraged them to take part in more circular and sustainable clothing consumption practices in the future. *Enablement* was represented in the survey by an open question on what participants would have done with the clothes if they would not have swapped them in this event. Most of the participants would have sold the items on second-hand platforms or donated them.

CEA4 – Sorting and Recycling Centre Visit

9 participants attended the visit to the sorting and recycling centre. They already showed awareness of the textile industry's impact before the activity, while being neutral about considering sustainability when purchasing new textile items. However, they were positively considering sustainability when disposing of textile items. When asked how they usually dispose of still usable textile items, the majority mentioned giving (family, friends) or donating (charities, second-hand stores), followed by selling them. Participants were most likely to dispose their non-usable textile waste in the textile waste collection bins.

The target behaviour in this activity was to dispose or use clothing items in a circular and sustainable way. On average participants agreed that the CEA motivated them to do so in the future. The BCT *Instructions on how to perform the behaviour* was displayed by three different questions. The first focused on participants learning what to do with clothes they do not wear anymore. This question correlated strongly with the intention to perform the target behaviour with a significance at the 0.01 level. The second question was focused on learning about how to dispose unusable textile waste properly and the third on learning how to consume and dispose clothing in a more sustainable way in general. Both did not significantly correlate with the participants intention to perform the target behaviour. *Education*, in this case by learning about what happens with the disposed textiles, did not correlate with statistical significance with the intention to perform the target behaviour. Information on social and environmental consequences did not significantly correlate neither. The BCT *Association – Exposure* was an open question in the survey. Participants were asked what stuck in their head after the visit. Responses like "the % of clothing intended for export", "quantity", or "only 10% of recovered textiles goes back to second-hand stores" shows that the exposure to the sorting

process and the amount of textile waste has an impact on people, which could lead to change in actions.

Discussion

The results of this exploratory study based on four different CEA highlight that certain BCTs are particularly effective in encouraging more sustainable clothing consumption behaviours. The most effective CEAs were the repair workshop and the Textile Fresco. These small group, in-person workshops with group interactions allowed participants to learn something new in a community setting while actively taking parts in it. The BCTs that showed a significant correlation with the intention to perform the target behaviour are information on social and environmental consequences, education, and instructions on how to perform the behaviour. These results suggest that interventions are most effective when consumers can combine impact awareness with the information provided and their own actions. The importance of that combination was already pointed out in the Design for Sustainable Behaviour framework (Bhamra et al., 2011).

Applying the theory of BCTs in the context of sustainable clothing consumption shows that BCTs can have a dual role: guiding the design of interventions beforehand and evaluating them afterwards on their contribution to green gap reduction. This contributes to the literature on sustainable behaviours in general and sustainable clothing consumption in particular by introducing and testing out a specific intervention model in practice. Instead of proposing a new theoretical model of interventions, we introduce BCTs (Michie et al., 2013; 2015), a model effective regarding health behaviours and already proposed to be applied in other fields (Michie et al., 2013). Furthermore, we evaluated its efficiency regarding the green gap empirically – which most other research on the topic does not do. Finally, introducing BCTs in the context of sustainable clothing consumption also has managerial contributions, as well as for policymakers. Indeed, it offers a framework to create effective CEA as well as an evaluation tool for companies wishing to raise their consumers awareness, or in the context of national or international public campaigns.

However, this research is not without limitations. The number of participants is not sufficient to generalize the findings of this exploratory research. However, the small in-person groups CEAs encouraged interactions between participants and close connections with the facilitators, making the workshops more impactful. A third survey evaluation is also still necessary to measure the impact of the CEAS through the actions and behaviours changes of participants after a certain amount of time – currently, it is only possible to draw conclusions about their intentions to perform the target behaviour. This third survey is in progress.

Conclusions

The study introduces Behaviour Change Techniques (BCTs) to promote sustainable clothing consumption and reduce the green gap. Through an exploratory study based on citizen engagement activities and surveys before and after each activity, it highlights the efficiency of three BCTs: providing information on social and environmental consequences, education, and instructions on how to perform behaviours. The study demonstrates how BCTs can effectively help construct and assess interventions designed to close the green gap in sustainable clothing consumption.

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References

Addo, I. B., Thoms, M. C., & Parsons, M. (2018). Household Water Use and Conservation Behavior: A Meta-Analysis. *Water Resources Research*, *54*(10), 8381-8400. https://doi.org/ 10.1029/2018WR023306

Agresti, A. (2018). Statistical Methods for the Social Sciences (5th ed.). Pearson.

Allison, A. L., Baird, H. M., Lorencatto, F., Webb, T. L., & Michie, S. (2022). Reducing plastic waste: A meta-analysis of influences on behaviour and interventions. *Journal of Cleaner Production*, *380*, 134860. https://doi.org/ 10.1016/j.jclepro.2022.134860

Betzler, S., & Kempen, R. (2024). Strengthening sustainable consumption behavior in high school students: Evaluation of an experiential training intervention targeting psychological determinants. *Environmental*

Education Research, 1-19. https://doi.org/10.1080/13504622.2024.2383751

Bhamra, T., Tang, T., & Lilley, D. (2011). Design for Sustainable Behaviour: Using Products to Change Consumer Behaviour. The Design Journal, 14(4), 427-445. https://doi.org/10.2752/175630611X13091688930453

Cozby, P. C., & Bates, S. C. (2024). Methods in Behavioral Research (15 ed.). McGrawHill.

Davoodian, A., Zafarmand, S. J., & Fateminia, M. (2024). Developing A Behavioural Model for Designers to Encourage Sustainable Consumption. *Journal of Design Thinking*. 10.22059/jdt.2024.380961.1130

Eichhorn, J. (2022). Survey Research and Sampling. SAGE Publications.

ElHaffar, G., Durif, F., & Dubé, L. (2020). Towards closing the attitude-intention-behavior gap in green consumption: A narrative review of the literature and an overview of future research directions. *Journal of Cleaner Production*, *275*, 122556. https://doi.org/10.1016/j.jclepro.2020.122556

Falcone, P. M., & Fiorentino, R. (2024). Nudging towards sustainability: Exploring the role of behavioral interventions in circular bio-economy development for the fashion industry. *Corporate Social Responsibility and Environmental Management*, *n/a*(n/a). /https://doi.org/10.1002/csr.2983

Garcia-Ortega, B., Galan-Cubillo, J., Llorens-Montes, F. J., & De-Miguel-Molina, B. (2023). Sufficient consumption as a missing link toward sustainability: The case of fast fashion. *Journal of Cleaner Production*, *399*. https://doi.org/10.1016/j.jclepro.2023.136678

Graça, J., Godinho, C. A., & Truninger, M. (2019). Reducing meat consumption and following plant-based diets: Current evidence and future directions to inform integrated transitions. *Trends in Food Science & Technology*, *91*, 380-390. https://doi.org/10.1016/j.tifs.2019.07.046

May, C., & Fearne, A. (2024). Sustainable purchasing behavior and the consumer: Pre- and in-store interventions to facilitate the use of carbon labelling. *European Journal of Sustainable Development Research*, *8*(4). https://doi.org/10.29333/ejosdr/15136

Michie, S., Johnston, M., Richardson, M., & Abraham, C. (2013). The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions. *Annals of Behaviour Medicine*, *46*, 81-95. https://doi.org/10.1007/s12160-013-9486-6

Michie, S., West, R., & Van Stralen, M. M. (2011). The Behaviour Change Wheel: a new method for characterising and designing behaviour change interventions. *Implementation Science*, *42*(6), 1-11. https://doi.org/10.1186/1748-5908-6-42

Michie, S., Wood, C. E., Johnston, M., Abraham, C., Francis, J. J., & Hardeman, W. (2015). Behaviour change techniques: the development and evaluation of a taxonomic method for reporting and describing behaviour change interventions (a suite of five studies involving consensus methods, randomised controlled trials and analysis of qualitative data). *Health Technology Assessment*, *19*(99). /https://doi.org/10.3310/hta19990

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, *1*(4), 189-200. https://doi.org/10.1038/s43017-020-0039-9

Park, H. J., & Lin, L. M. (2020). Exploring attitude–behavior gap in sustainable consumption: comparison of recycled and upcycled fashion products. *Journal of Business Research*, *117*, 623-628. https://doi.org/10.1016/j.jbusres.2018.08.025

Peattie, K. (2010). Green Consumption: Behavior and Norms. *Annual Review of Environment and Resources*, *35*(Volume 35, 2010), 195-228. https://doi.org/10.1146/annurev-environ-032609-094328.

Appendix

Variable		CEA1 (N=6)	CEA2 (N=7)	CEA3 (N=11)	CEA4 (N=9)
Gender	Female	4 (67%)	7 (100%)	9 (82%)	8 (89%)
	Male	2 (33%)	-	2 (18%)	1 (11%)
	Other	-	-	-	-
Age	18-24	2 (33%)	4 (57%)	6 (55%)	3 (33%)
	25-34	1 (17%)	3 (43%)	4 (36%)	2 (22%)
	35-44	3 (50%)	-	-	3 (33%)
	45-54	-	-	1 (9%)	-
	55-64	-	-	-	1 (12%)
	65+	-	-	-	-
Living location	Rural area (>5.000)	-	-	-	-
	Town (5.000-50.000)	1 (17%)	-	-	3 (33%)
	City (>50.000)	5 (83%)	7 (100%)	11 (100%)	6 (67%)

Table 3. Sociodemographic characteristics of sample.

Independent variable (BCT)	CEA 1 (ρ)	p-value	CEA 2 (ρ)	p-value	CEA 3 (ρ)	p-value	CEA 4 (ρ)	p-value
Education	0.000	1	0.794	0.03	-	-	0.221	0.6
Information on social and environmental consequences	1.000	0.01	-	-	-	-	0.332	0.422
Feedback	-	-	0.227	0.63	-	-	-	-
Comparison of behaviour	-	-	-0.642	0.12	-	-	-	-
Instructions on how to perform the behaviour	-	-	-	-	-	-	0.891; 0.617; -0.034	0.003; 0.103; 0.937
Social comparison /Modelling	-	-	-	-	0.382	0.25	-	-

Table 4. Correlation analysis results of BCTs to intention to perform target behaviour.

Independent variable (BCT)	CEA1	CEA2	CEA3	CEA4
Behavioural rehearsal/practice	-	Effective	-	-
Enablement	-	Successfully implemented	Implemented	-
Association - Exposure	-	-	-	Successfully implemented

Table 5. Effectiveness of BCTs to intention to perform target behaviour (descriptive analysis).

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Entrepreneurship and Waste Management: Cultivating Sustainable Solutions Through Education

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Keywords: waste management; entrepreneurship; environment; sustainability; innovation; social

Abstract This paper examines the critical intersection of waste management and entrepreneurship within the context of sustainability-focused education, emphasizing the importance of integrating these themes into academic curricula to address pressing global environmental challenges. As the world grapples with issues such as resource depletion, excessive waste generation, and unsustainable business practices, the transformative role of education becomes increasingly evident. This study highlights how equipping students with the knowledge, skills, and entrepreneurial mindset to innovate for sustainability can serve as a powerful catalyst for change.
The paper proposes a multidimensional pedagogical approach that combines theoretical understanding with practical application, fostering critical and innovative thinking. The paper also explores the role of experiential learning methodologies, such as problem-based learning, design thinking, and value co-creation, in fostering collaboration across disciplines and engaging stakeholders. By doing so, it seeks to prepare the next generation of environmentally conscious entrepreneurs capable of addressing waste management challenges while contributing to a more sustainable future.

Introduction

The integration of sustainability into education is increasingly recognized as a necessity to align with the global push for sustainable development, as underscored by the United Nations Sustainable Development Goals (SDGs). Waste management, as a critical aspect of sustainability, presents unique opportunities for entrepreneurship, enabling economic growth while promoting environmental stewardship. By introducing concepts such as the circular economy, students are equipped to analyze waste as a resource rather than a burden, thus shifting traditional perceptions of waste management to one of opportunity.

The growing emphasis on Environmental, Social, and Governance (ESG) metrics further underscores the importance of sustainability in business. Companies are increasingly measured on their ESG scores, with compliance reflecting their commitment to environmental stewardship, social responsibility, and governance practices. By introducing ESG principles into entrepreneurship education, students gain a deeper understanding of how sustainable practices impact business performance and stakeholder trust.

Oliveira Silva & Morais (2022) notes that a large part of the textile and fashion industry operates on a linear economy model i.e. extraction of natural resources, production of goods, sold to consumers and then shortly thereafter discarded. The research notes that fast fashion is characterized by mass production, variety, agility, low prices and short life cycles generating high levels of waste that are inappropriately disposed of in the environment.

Oliveira Silva & Morais (2022) describes companies as having two types of Circular Business Models (CBM) which they refer to as Adopters and Incumbents. Adopters follow the traditional principles of a linear approach but transitioning towards a circular economy model whereas Incumbents, on the other hand, are companies whose businesses are based on the outset on the principles of the circular economy. The Incumbents face the following challenges one, to have a clear circularity strategy which is a double edge sword viz doing what is good for business and at the same time following principles of circularity. Secondly, they would

then outsource production where they have limited control over the conformance to circularity. Then the decision on outsourcing is not done with care.

Literature review

In their research, Rasheed et al. (2024) investigate the crucial roles of waste management and green innovations within green supply chain management, exploring how these practices contribute to what they refer to as "enviropreneurship performance." The term "enviropreneurship," as coined by Albhirat et al. (2024), blends "environment" and "entrepreneurship" to describe innovative business approaches that prioritize sustainability and environmental improvement. This concept positions businesses to capitalize on opportunities that emerge from addressing environmental challenges. Small businesses are well-suited to embrace enviropreneurship due to their flexibility and ability to adapt quickly to sustainable practices. In this sense, small enterprises can act as pioneers of green innovations, often introducing new business models that integrate ecological responsibility into their core operations.

Rasheed et al. (2024) further emphasize the growing significance of consumer preferences in shaping business strategies. They argue that shifts in consumer behavior present significant opportunities for entrepreneurs to offer eco-friendly solutions that cater to an increasingly environmentally conscious market. This demand for eco-friendly products has grown in recent years, with consumers seeking products and services that align with sustainable practices. This surge in eco-conscious consumption has created new niches for businesses, particularly in areas like sustainable transportation and fashion. As Rasheed et al. highlight, businesses that can innovate and offer solutions to these emerging demands will be well-positioned for growth. Entrepreneurs who can provide sustainable alternatives not only respond to these shifts but also lead the way in creating more environmentally responsible products and services Hirvonen & Johansson (2025).

This perspective aligns with the findings of Petrova et al. (2025), who investigate the role of consumer perception in driving the green economy. They find that businesses that actively communicate their sustainability efforts through green marketing campaigns are more likely to build brand loyalty and consumer trust, thus securing a competitive advantage. Similarly, Singh et al. (2024) discuss the role of sustainable product design in shaping consumer preferences, emphasizing the need for businesses to incorporate lifecycle assessments in product development.

Drawing on the work of Salinas-Navarro et al. (2022), Rasheed et al. (2024) present a visual model in Figure 1 that illustrates the complexity of a sustainable supply chain. The research highlights the necessity of a well-developed management system capable of addressing the full cycle of waste management. Rasheed et al. emphasize that efficient waste handling is not merely a matter of collection and disposal; it involves establishing robust protocols, routines, and information systems to ensure that waste is properly managed at every stage of its lifecycle. This approach is critical to minimizing environmental impacts, particularly within industries that generate significant amounts of waste, such as manufacturing and logistics. The study reinforces that adopting comprehensive waste management systems contributes to the sustainability goals of businesses and enhances their capacity to operate responsibly within green supply chains.Complementing this, Gupta and Bansal (2024) examine the intersection of waste management and financial performance, demonstrating that firms that adopt circular economy practices not only improve their sustainability outcomes but also achieve cost savings and higher profitability. Their research suggests that strategic investments in zero-waste initiatives yield long- term financial benefits, encouraging broader adoption of sustainable business practices.

In addition to waste management, Rasheed et al. (2024) explore how entrepreneurship education can further support businesses in achieving sustainable outcomes. As part of their research, they had students conduct surveys among potential customers to gauge their responses to new product ideas. This process allows entrepreneurs to gather critical feedback and adjust their product offerings to meet customer expectations while ensuring that the products align with sustainability principles. The methodology used by Rasheed et al.



Figure 1. Sustainable supply chain in today's world, (Salinas-Navarro et al., 2022)

(2024) follows a strategy similar to that employed by Re and Magnani (2022), who studied entrepreneurs committed to circular principles from the outset of their businesses. Re and Magnani's research highlights the importance of value co-creation, wherein various stakeholders, including customers, collaborate in the development and refinement of products and services. The value of this approach lies in the way stakeholders—not only customers—become integral to the innovation process, effectively "buying into" the sustainable concepts at the heart of the business. By engaging stakeholders early in the process, entrepreneurs can create products that not only meet market demands but also foster a sense of shared responsibility towards sustainability.

Thus, Rasheed et al. (2024) underscore that the integration of waste management and green innovations, alongside a strong entrepreneurial framework, can lead to significant improvements in environmental performance. By embracing sustainable practices and engaging stakeholders in value co-creation, entrepreneurs can drive the development of eco-friendly solutions that address the evolving needs of consumers and contribute to a more sustainable future. Del Vecchio et al. (2021) note that programs that increase skills in the Circular Economy field also create new opportunities and jobs, identifying different education patterns in entrepreneurship education. Expanding on this, Berman and Hargrove (2025) and Wicaksono (2025) highlight that university incubators and accelerator programs focusing on sustainable business models are playing an increasingly important role in shaping the next generation of enviropreneurs, equipping them with the necessary skills to drive impactful environmental change.

Aim and objectives

The aim of the research is to propose a multidimensional pedagogical approach for academics that fosters innovative thinking and addresses waste management challenges within the context of sustainability, entrepreneurship, and the circular economy. The research seeks to outline an educational framework that integrates key strategies and frameworks to encourage students to think creatively, critically, and collaboratively about waste management, while developing the skills needed to contribute to sustainable practices and entrepreneurial innovation.

The objectives of the research are as follows:

1. To explore environment entrepreneurship as a means of integrating sustainability with

innovation for effective waste management in academia.

2. To identify and implement teaching strategies that encourage students to develop creative, interdisciplinary, and entrepreneurial solutions to waste.

3. To promote hands-on learning methods that measure entrepreneurial skills while addressing real-world sustainability issues.

Methodological Approach

The study implemented various strategies to integrate sustainability-focused entrepreneurship education with practical applications in waste management. Experiential learning played a key role, incorporating problem-based learning, design thinking, and value co-creation to engage students in developing waste reduction initiatives. An interdisciplinary approach was adopted by embedding circular economy principles, sustainable supply chain management, and ESG (Environmental, Social, and Governance) metrics into business curricula. Entrepreneurial innovation was encouraged, prompting students to view waste as a resource and develop sustainable business models addressing the challenges of fast fashion waste. Additionally, stakeholder collaboration was emphasized, engaging industry partners and local communities in co-creating solutions for waste management.

To assess the effectiveness of these strategies, a combination of qualitative and quantitative data was generated and analyzed. Surveys and questionnaires were conducted among students to evaluate their perceptions of sustainability and circular economy practices. Content analysis of curriculum implementation and student project outcomes provided insights into the integration of sustainable entrepreneurship principles.

Through this empirical investigation, the study successfully fulfilled its research objectives. It assessed the role of entrepreneurship education in equipping students with sustainability-driven skills and identified key challenges in implementing circular economy practices. The empirical validation of sustainable entrepreneurship concepts was evident in the engagement and learning outcomes of students, as reflected in surveys, and project analyses.

Sampling and Participants

The study targets students from a university of technology in the field of clothing and textiles enrolled in programs related to engineering and the built environment. A purposive sampling strategy was used to select participants who are currently involved in entrepreneurship, sustainability, or waste management-focused courses and subjects. Waste arises at various stages of the value chain and in different forms and complexity. Therefore, levels of knowledge required to deal with different types of waste and how to manage this need to be considered. This can start from a very basic approach to capturing and collecting waste to dealing with waste arising at various stages in a production process by managing and accounting for waste at a macro level viz. ESG. This ensures that participants have the relevant background to engage with the proposed pedagogical strategies effectively.

Data Collection Methods

Surveys and Questionnaires: These were used to collect quantitative data from final year students before and after the course interventions. Questions focused on students' knowledge and application of waste management, sustainable practices, entrepreneurial mindset, and their willingness to innovate with sustainability in mind.

Interviews and Focus Groups: Semi-structured interviews and focus group discussions were conducted with a subset of students to gain deeper insights into their experiences with the pedagogical approach. These qualitative methods explored students' perspectives on the value of the innovative teaching strategies (problem-based learning, value co-creation, design thinking, etc.), and how these strategies influenced their understanding of waste management and entrepreneurship.

Project-based Assessments: Students completed projects that involve designing a sustainable product with a focus on waste management. The outcomes of these projects were assessed based on creativity, sustainability, feasibility, and innovation.

Intervention Framework
The pedagogical strategies were implemented through a series of interventions, including:

Problem-Based Learning (PBL): Students worked in groups to tackle real-world waste management issues, developing solutions that balance economic viability and environmental impact.

Value Co-Creation: Students collaborated with local businesses and/or SMMEs to design sustainable products, ensuring reproducibility, confirming that the solutions meet market needs and fulfil sustainability criteria.

Design Thinking Workshops: A series of workshops were held guiding students through the design thinking process, from ideation to prototyping, with a specific focus on sustainability and waste management.

Data Analysis
Statistical analysis was conducted on the survey and questionnaire data to measure changes in students' knowledge, attitudes, and behaviors regarding sustainability, waste management, and innovation. These included pre and post- intervention comparisons to assess the impact of the pedagogical strategies.

Qualitative Analysis: Thematic analysis was applied to interview and focus group data to identify key themes related to students' perceptions of the pedagogical approach. This helped in understanding how students engaged and applied the concepts of entrepreneurship, sustainability, and waste management.

Findings
Findings showed increased student awareness and innovation, industry-relevant curriculum improvements, and successful waste-to-value projects. Stronger academia-industry collaborations were also established. Future research focused on assessing entrepreneurship competencies and evaluating the long-term impact of student projects. Based on the data collected through the outlined methodology, the following are the findings came up strongly:

Better Understanding of Enviropreneurship and Sustainability
The research was expected to find students' understanding of **enviropreneurship** after participating in the pedagogical interventions. By combining environmental sustainability with entrepreneurial innovation, students recognized the potential of integrating sustainable practices into business models. This aligns with what previous research by Rasheed et al. (2024) and Albhirat et al. (2024) emphasized on, that enviropreneurship is a valuable framework for addressing environmental challenges through entrepreneurship.

Enhanced Critical Thinking and Innovative Problem-Solving
The implementation of problem-based learning (PBL) and design thinking is likely to foster higher levels of critical thinking and innovative problem-solving skills. Students demonstrated the ability to approach waste management issues with creativity and a sustainability-oriented mindset, addressing both environmental and economic challenges. This reflected in the development of practical, sustainable solutions during the assessments.

Positive Shifts in Attitudes Toward Sustainability
Data from surveys and focus groups revealed a positive shift in students' attitudes towards sustainability and waste management. Students showed increased awareness of the importance of waste management practices and their role as **future enviropreneurs**. This shift in mindset reflected through their willingness to incorporate sustainability into their business ideas and career aspirations.

Improved Practical Application of Sustainable Practices
Through project-based assessments and case study analysis, students demonstrated the ability to apply their learning to real-world scenarios. The findings suggest that students are more capable of developing sustainable business models and waste management solutions after exposure to hands-on, practical learning experiences. The inclusion of case studies of successful businesses will further reinforce this practical knowledge, showing how sustainable practices can be integrated into business strategies to achieve

competitive advantage.

Growth in Entrepreneurial Mindset

The research shows that students, particularly in business and entrepreneurship-focused courses, experience a growth in entrepreneurial mindset, where they view waste not as a problem but as an opportunity for innovation. The integration of sustainability and waste management into the curriculum contributed to a broader understanding of how entrepreneurship can drive positive environmental impact. The students could see themselves going for a start-up in future.

Holistic Understanding of Waste Management

By integrating sustainability topics across disciplines, students gained a holistic understanding of waste management, recognizing the interconnectedness of business operations, product design, and environmental science. This multidisciplinary approach equipped students with comprehensive skill sets to address waste management challenges from multiple angles.

These findings contributed to the development of effective pedagogical strategies that prepared students to become innovative and responsible entrepreneurs capable of tackling global sustainability challenges, particularly in waste management.

Potential challenges

The pedagogical approach faced several potential challenges that could impact its design, implementation and outcomes. A significant hurdle lied in differences in background knowledge and familiarity with sustainability concepts may lead to disparities in participation and engagement, while communication barriers arising from distinct terminologies and methodologies further complicated the collaboration.

Engaging external stakeholders for value co-creation activities proved difficult, as building relationships for engagement with businesses and other stakeholders was time intensive. Students struggled to access and engage with these stakeholders due to limited networks or right communication skills.

Assessment complexity was another potential issue, as measuring the effectiveness of the pedagogical approach in fostering innovative thinking and sustainability-oriented entrepreneurship didn't come easy. Creativity and critical thinking are difficult to quantify, and balancing assessments of both technical competencies and entrepreneurial skills required sophisticated rubrics and considerable effort from instructors. Time constraints further complicated matters, as the limited duration of academic courses does not allow for the depth needed to fully engage with complex sustainability challenges.

Real-world projects, which involved stakeholder engagement and prototyping, required extended timelines that does not always align with academic schedules. Student engagement and motivation also pose risks to the success of the approach. Not all students found sustainability or entrepreneurship topics equally compelling, potentially affecting their participation. Fear of failure inhibited students from proposing innovative solutions or experimenting with new ideas. Cultural and contextual differences added another layer of complexity, as the effectiveness of the approach varied depending on the cultural, economic, and institutional context. For instance, students in resource-rich settings had different perspectives on waste management than those in resource-constrained environments.

Integrating sustainability concepts across disciplines presented its own set of challenges. Overloaded curricula made students resistant to adding more content, while balancing the depth and breadth of interdisciplinary topics. Finally, resource limitations, such as unequal access to technology, hindered the implementation of critical activities like stakeholder collaborations and product making.

Addressing these challenges required careful planning, institutional support, and a flexible approach. Mitigation strategies could include providing faculty training, leveraging digital tools for stakeholder engagement, and designing adaptive assessment methods. By proactively tackling these barriers, the proposed pedagogical framework can be more effectively implemented, ultimately fostering

innovative thinking and sustainable practices among students

Conclusions

This research highlights the importance of a multidimensional pedagogical approach in fostering innovative thinking and addressing waste management within academic settings. By integrating principles of sustainability, entrepreneurship, and the circular economy, the proposed framework empowers students to tackle real-world challenges with creativity, critical thinking, and collaboration. The findings underscore the potential of pedagogical strategies such as problem-based learning, value co-creation, and design thinking to equip students with the skills and mindset necessary to address environmental issues while fostering entrepreneurial innovation.

The research demonstrates that integrating sustainability topics across disciplines provides students with a holistic understanding of the interconnected challenges of waste management, business practices, and environmental impact. Practical applications, including project-based assessments and case study analysis, enable students to bridge the gap between theoretical knowledge and real- world implementation, preparing them to create sustainable business models and innovative waste management solutions. Moreover, the emphasis on an entrepreneurial mindset and interdisciplinary collaboration not only enhances students' ability to think creatively but also prepares them to engage with diverse stakeholders.

In conclusion, this work provides a roadmap for academics to develop and implement teaching strategies that address critical sustainability issues while fostering the next generation of environmentally conscious innovators. By adopting such approaches, educators can play a pivotal role in equipping students to navigate and address the complex challenges of waste management and contribute to a more sustainable future.

Potential for future research

The proposed pedagogical approach offers significant opportunities for future research aimed at enhancing the understanding of how innovative teaching strategies can address waste management challenges while fostering sustainability and entrepreneurship. One area for exploration involves longitudinal studies that evaluate the long-term impact of such pedagogies on students' knowledge, skills, and attitudes. These studies could track how students apply sustainability and enviropreneurship concepts in their careers or entrepreneurial ventures, providing insights into the sustained benefits of this educational approach. Additionally, investigating the adaptability and effectiveness of this framework across disciplines, including business, engineering, environmental sciences, and design, could shed light on how interdisciplinary collaborations shape student outcomes and which fields derive the most benefit.

Another promising avenue lies in examining how the pedagogical framework performs in diverse cultural and regional contexts. Variations in sustainability perceptions and practices across geographic and socio-economic settings present a valuable opportunity to analyze its effectiveness in different environments, such as resource-rich versus resource-constrained areas. Similarly, future research could delve into the integration of digital tools and technology within this pedagogical approach. For instance, virtual simulations, augmented reality, and digital collaboration platforms could facilitate stakeholder engagement and design thinking processes, offering a more dynamic learning experience.

Stakeholder engagement models also warrant further investigation. Research could focus on developing and testing partnerships with local businesses, policymakers, and non-profits to enhance value co-creation activities. The impact of these collaborations on student learning and the feasibility of scaling such initiatives across institutions would be valuable contributions to the field. Moreover, innovative assessment methods need exploration to measure critical yet subjective outcomes, such as creativity, critical thinking, and sustainability- oriented entrepreneurship. Designing reliable rubrics and tools for these qualitative skills could improve the evaluation of learning outcomes.

The scalability of the pedagogical approach across different educational levels, such as

high schools and vocational training, and its alignment with systemic educational policies, is another area ripe for research. Additionally, studies could assess the tangible impact of student-led projects on sustainability metrics, such as reductions in waste generation or improved recycling rates, to demonstrate the real-world significance of these educational innovations.

Integrating emotional intelligence and ethical decision-making into the framework could also be explored to understand their influence on students' ability to innovate responsibly and sustainably. Comparative studies evaluating this pedagogical approach against traditional or other innovative methods, like flipped classrooms or experiential learning, could further refine its implementation. Lastly, gathering feedback from industry stakeholders who engage with students during value co- creation projects could help adapt the approach to better align academic training with real-world needs and industry expectations.

Future research on these aspects has immense potential to advance educational practices, management, and nurture environmentally conscious entrepreneurs. By addressing these areas, researchers can contribute to shaping innovative, sustainable pedagogies that drive meaningful development and prepare students to meet the demands of a rapidly changing world

References

Del Vecchio, P., Secundo, G., Mele, G., Passiante, G., 2021. Sustainable entrepreneurship education for circular economy: emerging perspectives in Europe. International Journal of Entrepreneurial Behavior & Research. 27(8): 2096-2124. https://doi.org/10.1108/IJEBR-03-2021-0210

Ellen MacArthur Foundation. (2017). A New Textiles Economy: Redesigning Fashion's Future".https://www.ellenmacarthurfoundation.org/a-new-textiles-economy

Oliveira Silva, W.D., Morais, D.C. (2022). Impacts and insights of circular business models' outsourcing decisions on textile and fashion waste management: A multi-criteria decision model for sorting circular strategies. *Journal of Cleaner Production.* https://doi.org/10.1016/j.jclepro.2022.133551

Albhirat, M.M., Rashid, A., Rasheed, R., Rasool, S., Zulkiffli, S.N.A., Zia-Ul-Haq, H.M., Mohammad, A.M. (2024). The PRISMA statement in enviropreneurship study: a systematic literature and a research agenda. *Cleaner Engineering and Technology.* https://doi.org/10.1016/j.clet.2024.100721

Salinas-Navarro, D.E., Mejia-Argueta, C., Montesinos, L., Rodriguez-Calvo, E.Z., (2022). Experiential learning for sustainability in supply chain management education. *Sustainability* 14 (20)

Re, B., Magnani, G. (2022). Value co-creation in circular entrepreneurship: An exploratory study on born circular SMEs. *Journal of Business Research.* 189-207. https://doi.org/10.1016/j.jbusres.2022.03.090

Wicaksono, t. (2025). Green entrepreneurship: transforming challenges into profitable solutions. *jurnal pengabdian dan kewirausahaan*, *9*(1).

Hirvonen, R., & Johansson, M. (2025). Integration of Environmental Sustainability in Startups Business Models?: A qualitative study on startup companies in the clean technology industry in Sweden (Dissertation). Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:hig:diva-46428

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Impact of Robotic Circular Wood Processing: lessons from the "One Plank" Challenge – using the AUAS Circular Wood KPI Framework

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Keywords: Upcycling, wood, digital design, robotic production, impact.

Abstract: Wood is an increasingly demanded renewable resource and an important raw material for construction and materials. Demands are rising, with a growing attention for re-use and upcycling, opening up opportunities for new business models, empowered by the use of digital design and technologies. A KPI framework was developed to evaluate the environmental, social, and economic aspects of using recycled wood in robotic manufacturing. This paper explores the use of this framework, focusing on a case study: the "One Plank" Challenge. The study reveals that environmental gains from using waste wood are comparable to production burdens, with significant variation depending on wood type. Production time, encompassing both human and robotic aspects, significantly impacts cost-effectiveness. The findings underscore the importance of considering lifecycle impacts in promoting sustainable robotic manufacturing practices.

Introduction

Wood is a valuable and sustainable material within the circular and biobased economy, because it can store CO_2 if grown and harvested correctly (Szulecka, 2019). Consequently, construction, interior architecture and product design are re-discovering timber wood as a sustainable material, creating increasingly higher demands. In a high-growth scenario, total European wood demands are expected to increase with more than 50% in 2030, compared to the 2000-2012 average (Jonsson et al., 2018).

Yet, 25% of the wood used turns into waste after its first lifecycle (van Bruggen & van der Zwaag, 2017), and mostly ends up in landfills or co-firing plants, and to smaller extent is downcycled into chips for particle or fibre board (Besserer et al., 2021). To retain value and enable material and cost savings, cascading and repurposing waste and residual wood are important circular business model strategies (Lüdeke‐Freund et al., 2019). In fact, waste wood is increasingly being harvested for re-use during building renovations or demolitions, at waste collection sites or at wood-related industries (that have left-over pieces from production).

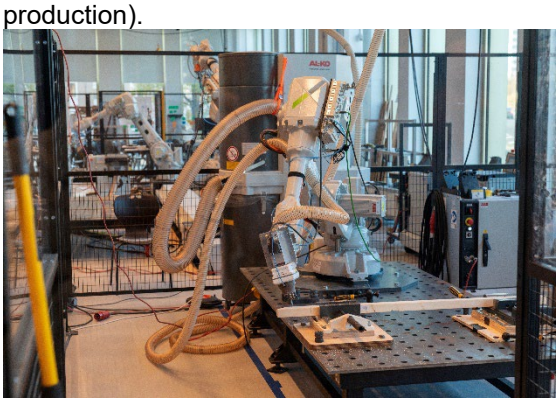


Figure 1. Robotic production with wood at the DPRG Robot Lab

An important strategy to create value from waste and residual wood is the use of digital design and robotic production technologies (Figure 1), as these are especially suited for generating innovative concepts and applications from an uneven wood waste stream (such as left-overs wood from wood manufacturers) which involve a broad variety of pieces with different size, wood type and finishing (Malé-Alemany et al., 2022). Digital design and robotic production can thus support

new business models for furniture, interior and building sectors, including direct end-user involvement in design and manufacturing. However, to encourage practitioners to successfully develop circular business models around applications made with waste and residual wood, insight is required on the impact that such applications can make, not only related to environmental (or sustainability) aspects, but also in terms of business and society.

Many tools exist to evaluate the impact of circular applications, on specific aspects like life-cycle analysis (J. Vogtländer, 2014) or material flow analysis (Brunner & Rechberger, 2016). Yet, these tools are not specifically focussed on circular wood use, and the approach used in many of these tools is often too time-consuming (and expensive) to use in practice, thus a more practical tool is needed for business and designers. With the aim to combine existing tools, making them accessible and adding specific wood indicators, the Digital Production Research Group (DGPR) of the Amsterdam University of Applied Sciences (AUAS) composed one integral framework which enables circular wood businesses to select the most appropriate applications and business models for their portfolio. The developed framework (Schoen et al., 2023) intends to support designers to make choices that consider impact not only related to environmental (or sustainability) aspects, but also in terms of business and society.

This paper presents the integral framework ("KPI-framework"), applies it to a concrete research case and briefly addresses specific points for further development.

Research approach

A Key Performance Indicator, or KPI, is a measurable value (which can be both quantitatively and qualitatively measured) that demonstrates how effectively a business, product, employee etc., is achieving their (key) objectives. To assess the impact of a specific application from waste wood, an integral KPI-framework was developed as part of the 'Circular Wood for the Neighbourhood' project (CW4N), coordinated by DPRG. The framework can be used as a tool for the evaluation and comparison of specific applications from waste wood.

The current KPI-framework is a set of nine indicators (see Table 1), derived from a longlist of twenty in total, which can be used to analyse the impact of a circular application made of waste wood using advanced production robotic production systems. In the framework, a specific application (e.g. a stool digitally produced from residual wood) can be benchmarked with a reference application (e.g. a comparable, standard IKEA stool).

Material	
Reused material	% of the product that consists of locally harvested wood
	% of material that is wasted during production process
Circularity potential	% of components which can easily be reused at the end of function
Environmental	
Avoided impacts	Avoided embedded impact from avoided virgin materials
Created impacts	Emissions during production of product
Socio-cultural	
Job creation	(local) Jobs created (high and low educated)
Economic	
Avoided costs	Avoided costs of virgin material use
Created costs	Production costs
	Costs for maintenance and operation or the product

Table 1. Overview of the nine indicators in the KPI-Framework

To calculate the indicators, validated models, databases and calculation methods are used, where available. The actual calculation is performed in an excel model, built and designed with a dashboard to visually summarize the scores. In the next sections, the nine indicators are briefly described, applied to upcycling of waste or left-over wood.

KPI 1.1 Reused material percentage - The percentage of the object (measured in weight) that consists of directly reused materials (mostly wood) in their harvested form. This excludes recycled content in new materials (e.g. new particle board, which can be composed of up to 70% of recycled feedstock).

KPI 1.2 Waste percentage - Calculated as the percentage of material that is lost during production (measured in weight), mostly caused by milling the reused wood.

KPI 2.1 Circularity potential - The percentage of the application that can be easily re-used at the end of its current life cycle. To calculate this, the releasability index method ("losmaakbaar-

heidsscore") is used (van Vliet et al., 2021) which focuses on how easily the individual parts of the application can be taken apart again at the end of its lifetime.

KPI 3.1 Avoided impacts - This indicator analyses the avoided environmental impact of using circular materials (predominantly wood), instead of using virgin materials. To calculate this indicator, data from the ecoinvent database is used (Wernet et al., 2016). This database contains embedded CO_2 equivalents (Gohar & Shine, 2007) and eco-costs (J. G. Vogtländer et al., 2002) associated with the specific type of material. This indicator looks only on the material level. It does not consider the environmental impacts related to the harvesting and transportation of the material, nor the impact of the production of the application. This is covered in the following KPI.

KPI 4.1 Emissions during production of the object - Counterpart of KPI 3.1. Where the first one looks at emissions saved by not using virgin materials, KPI 4.1 analyses "the effect of the use of circular materials and robotic production". Here, three sources of emissions are distinguished:

1. Harvesting the circular material
2. Transportation of the material to the production site
3. (Robotic) production of the application

What is not considered is the energy needed from post-production, to transport the application to its final use destination.

KPI 6.1 Job creation - This indicator originates from the common (mis)conception that 'robots will take over human labour'. To analyse the actual impact from robotic production, this indicator calculates the time needed for all activities related to the design and production of the application. This includes time for sourcing, harvesting, and processing of circular materials. The KPI-framework allows for the evaluation of larger numbers of products, spreading one-time indirect activities such as design, planning and management over the production of multiple units.

KPI 8.1 Avoided costs from re-using materials - This indicator looks at the costs saved by not-using virgin materials, without considering costs associated to the harvesting or processing of the circular material. These are covered in the next KPI (9.1).

KPI 9.1 Costs of production - This indicator looks at all costs items, associated to the making of the application. Six cost categories are distinguished: 1. Labour, 2. Material, 3. Energy, 4. Transport, 5. Consumables, and 6. Machines (robots, end-effectors (e.g. milling head), handheld tools). Labour costs are directly associated to KPI 5.1 'Job Creation' and thus also include indirect costs for design, planning and management. They also include time spent on harvesting, transporting, and processing of circular wood. Similar to KPI 4.1 'Emission', post-production costs (transport-tation of the application to its final use destination) are not considered.

KPI 9.2 Annual costs for maintenance of the product – Calculation of this KPI is still in its infancy and is not addressed in this paper.

Applying the KPI Framework to the "One Plank" challenge

In 2024, the AUAS Digital Production Research Group (DPRG) together with HMC (Hout en Meubileringscollege) Amsterdam, and Stayokay Dutch Hostels organized two "One Plank" challenges for students of the Minor Robotic Production and Circular Materials, offered at the AUAS Robot Lab. In this challenge, students were to design and make an application for hospitality, each from one identical piece of wood. The wood was harvested from the renovation of the bedrooms of one of the hostels of Stayokay. Every year, Stayokay renovates two of their hostels, implying that this material stream will come

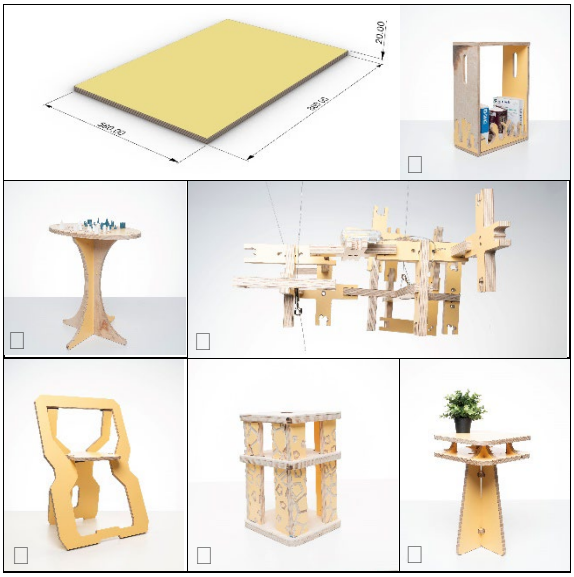


Figure 2. First challenge; the original plywood (top) and the six resulting objects

available continuously during the upcoming years.

In the first challenge, the students were given a rectangular piece of plywood with yellow melamine cover. In the second challenge, they received a bunkbed end board, consisting of two beech poles and two veneer-covered plywood planks. In the first challenge, the focus was on the design and production of a *discrete* object, whereas in the second challenge the students were instructed to design a product *system*, suitable to create a family of objects. Results of the challenges are given in Figure 2 and Figure 3.

During the making of the objects, students were asked to carefully measure all data needed to calculate the KPI's (e.g. weight of the plank, weight of the object, design time, production time, milling time, etc.). Comparing the KPI's for six different objects made from the same material can give valuable insights into the impact of robotic production from circular materials.

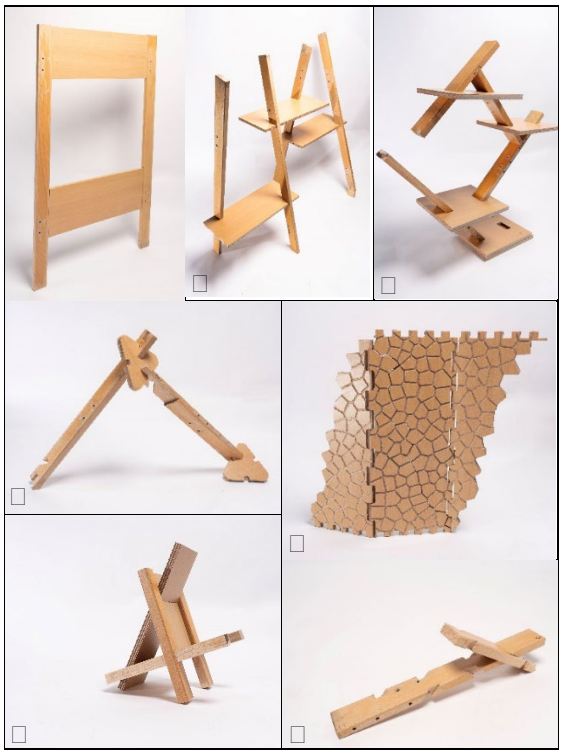


Figure 3. Second challenge: the original bunkbed end board (top, left) and resulting objects

An important difference between the two challenges was, that in first challenge all students worked with the same amount and type of wood, whereas in the second challenge, students selected and used a variable amount and type of wood. Some chose to only use the poles, others focused on the boards. Some used two, or even three poles and boards, others only one element.

Impact analysis

Environmental impact of wood reuse

Reusing waste or left-over wood has a positive impact on the environment, by saving the use of virgin material, thus saving on the harvesting, transportation and processing of trees. Environmental gains are partly offset by the environmental burdens of processing the materials into applications. Figure 4 shows the balance for the first challenge (numbers

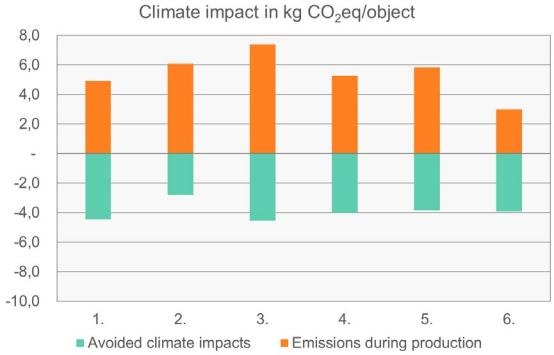


Figure 4. Environmental gains (green) vs. production burdens (red) for the first challenge

referring to the objects shown in Figure 2).

From this figure it becomes clear that the gains are the same order of magnitude as the burdens. Reusing waste wood had noteworthy impact.

In the second challenge the relationship between gain and burden is less clear (Figure 5).

The gain strongly depends on the specific amount and type of reused wood. The environmental impact of beech wood (0,17 kg

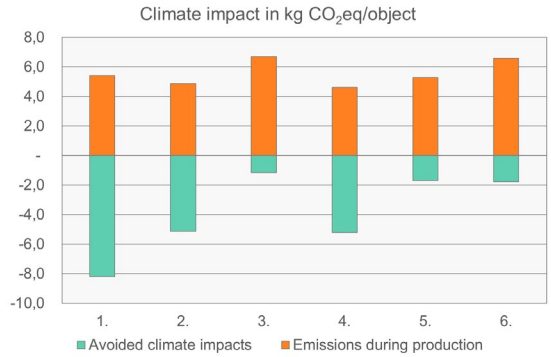


Figure 5. Environmental gains (green) vs. production burden (red) for the second challenge

CO_2eq/kg[1]) is much lower than that of plywood (0,82 kg CO_2eq/kg[1]). Reusing the poles has thus far less environmental gains than reusing the boards. Object 1 reuses three poles and boards, leading to high impact gains, object 6 uses only one pole[2].
From this analysis it becomes clear that the type of waste wood can have a large impact on environmental impact. Determining wood type prior to the harvesting process can help focusing on the materials with the highest impact.

Robotic production costs

In the KPI framework, production costs are calculated using a range of categories. Figure 6 shows the resulting scores broken down into the categories. Within each challenge, there is a range of production costs, related to the complexity of the object. Main cost components are labour costs and robot costs. Both are strongly correlated with production time.

Labour costs are calculated not only from production time, but also from design, pre-, and post-production times, which are not easy to assess without having the total production process and the number of objects produced in mind. Design time per object will decrease as more objects are produced. Moreover, within the environment of the Robot Lab, production is continuously monitored, leading to high estimates of labour costs for production. In a more realistic factory setting, robotic production will run unsupervised, reducing labour costs substantially. Labour costs in the "One Plank" Challenge are thus higher than is to be expected in a factory setting.
Robot costs are calculated using an average CAPEX[3] costs per hour, derived from previous research into the business case of robotic production (Vrutaal et al., 2024). For the main robot used for the challenges, an ABB IRB 2600, these costs are estimated € 27,50 per hour.

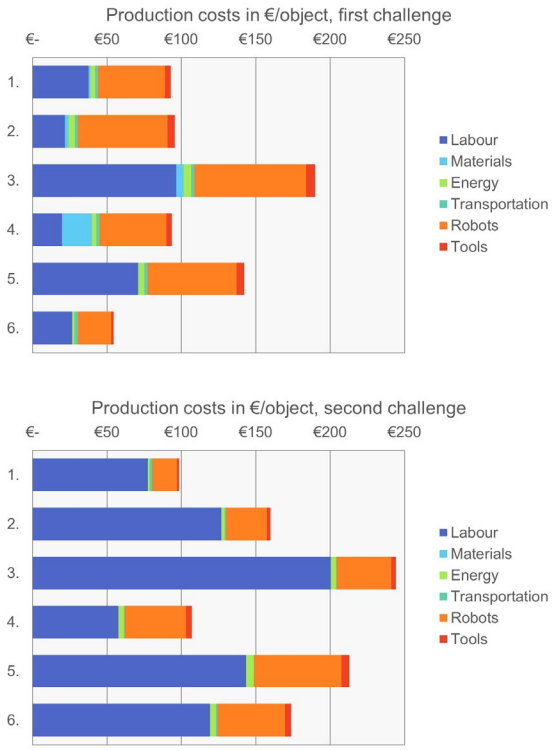


Figure 6. Production costs breakdown for first challenge (top) and second challenge (below)

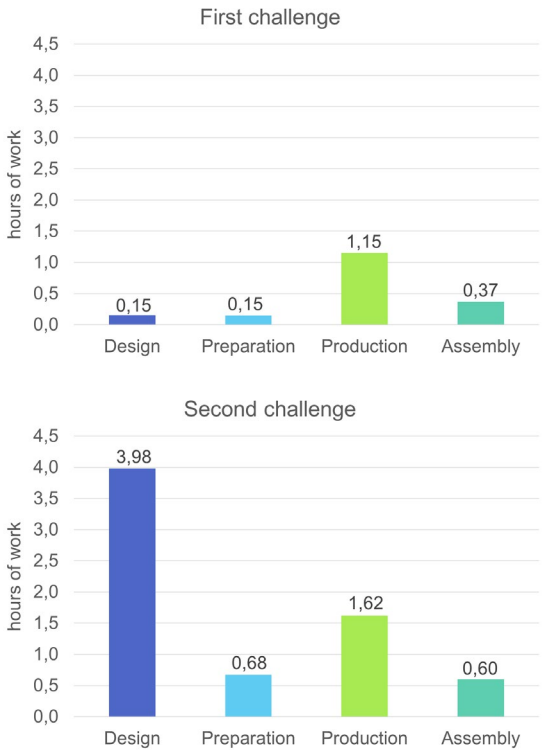


Figure 7. Breakdown of hours of work (average per challenge)

[1] Data from Ecoinvent (2024)
[2] The low gain score for object 5 is unclear, it is assumed to be a calculation error
[3] Capital Expenditure, i.e. depreciation costs of the robot

In a real production settings, robot use costs will be substantially higher, since they will include OPEX[4] in the costs per hour. Comparing the first and the second challenge, the results shown in Figure 6 indicate that the main cost difference is caused by labour costs.
Figure 7 shows the related breakdown of underlying hours of work in the four categories (Design, Preparation, Production and Assembly). Clearly, in the second challenge more time was spent on design. This was partially caused by the specific question to create a (parametric) system from multiple pieces of wood, more than to design and make just one discrete object.
Overall, from this KPI it becomes clear that production time is key to create economically feasible applications from waste wood. Both the human time and robotic time should be addressed. Human time could be reduced by developing stand-alone production set-ups which do not need supervision. Robotic time could be reduced by optimizing toolpaths, increasing milling speed and working with multiple clamping stations to avoid idle time, when different robots are working together.

Conclusions and Outlook

Wood is an increasingly demanded renewable resource and an important raw material for construction and materials. Demands are thus rising, with a growing attention for re-use and upcycling. To assess the impact of waste wood re-use and upcycling for applications such as furniture, interiors and buildings, a framework of indicators was defined and developed. Applying this framework to the actual digital design and production of a range of applications from circular wood, shows how the framework can be used to compare series of different applications, towards finding out where the main drivers are to enhance the uptake of robotic production with circular materials. In the case of the "One Plank" Challenge, main findings are:

- The environmental gains of using waste wood are of the same order of magnitude as the environmental burdens of the robotic production of connected applications. Wood upcycling has noteworthy impact.
- The environmental gains of using waste wood can strongly vary, depending on the type of wood used. Determining wood type during the harvesting process can help focusing on the materials with the highest impact.
- Production time is key to create economically feasible applications from waste wood. Both the human time and robotic time should be addressed.

For further developments, the following lines are being pursued:

1) Developing the KPI-framework into a more advanced design tool that integrates impact calculation into parametric design software, to allow changes in the design of a circular application to be immediately reflected a "dashboard" summarizing impact score.
2) Connecting the KPI-framework to digital twin software for robotic production (Tao et al., 2019), in which various production set-ups can be simulated. This will allow for further optimization of production costs, one of the main cost components of robotic production.
3) Expanding the KPI-framework to incorporate other materials and production technologies into a more generic tool for impact evaluation for circular applications.

Acknowledgments

The development of the Circular Wood KPI-framework was done within the projects 'Circular Wood for the Neighborhood' (completed in July'22) and ' Circular Wood 4.0' (to be completed in Jan'25), both co-financed through RAAK funds of Regieorgaan SIA, part of the Netherlands Organization for Scientific Research (NWO).

References

Besserer, A., Troilo, S., Girods, P., Rogaume, Y., & Brosse, N. (2021). Cascading Recycling of Wood Waste: A Review. In Polymers (Vol. 13, Issue 11). https://doi.org/10.3390/polym13111752

Brunner, P. H., & Rechberger, H. (2016). Handbook of Material Flow Analysis : For Environmental, Resource, and Waste Engineers, Second Edition. https://doi.org/10.1201/9781315313450

Gohar, L. K., & Shine, K. P. (2007). Equivalent CO2 and its use in understanding the climate effects of increased greenhouse gas

[4] Operational Expenditure associated to robot use, i.e. maintenance, energy use, space rent, indirect staff

concentrations. Weather, 62(11), 307–311. https://doi.org/https://doi.org/10.1002/wea.103

Jonsson, R., Blujdea, V. N., Fiorese, G., Pilli, R., Rinaldi, F., Baranzelli, C., & Camia, A. (2018). Outlook of the European forest-based sector: forest growth, harvest demand, wood-product markets, and forest carbon dynamics implications. IForest - Biogeosciences and Forestry, 11(2), 315–328. http://www.sisef.it/iforest/contents/?id=ifor2636-011

Lüdeke‐Freund, F., Gold, S., & Bocken, N. M. P. (2019). A review and typology of circular economy business model patterns. Journal of Industrial Ecology, 23(1), 36‐61. DOI: 10.1111/jiec.12763

Malé-Alemany, M., Schoen, T., Galli, M., Bors, V., Kozhevnikova, A., & Dijk, L. Van. (2022). “ Once my front door – now my coffee table ”; Advanced computational design and robotic production with waste wood. AMS Scientific Conference “Reinventing the City” (Available Online).

Schoen, T., Malé-Alemany, M., Mulder, M., & Schouten, N. (2023). The Circular Wood KPI-framework. New Business Models Conference Proceedings. https://doi.org/10.26481/mup.2302.41

Szulecka, J. (2019). Towards Sustainable Wood-Based Energy: Evaluation and Strategies for Mainstreaming Sustainability in the Sector. In Sustainability (Vol. 11, Issue 2). https://doi.org/10.3390/su11020493

Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital Twin in Industry: State-of-the-Art. IEEE Transactions on Industrial Informatics, 15(4), 2405–2415. https://doi.org/10.1109/TII.2018.2873186

van Bruggen, R., & van der Zwaag, N. (2017). Knelpuntenanalyse houtrecycling. Tauw.

van Vliet, M., van Grinsven, J., & Teunizen, J. (2021). Circular Buildings – een meetmethodiek voor losmaakbaarheid, versie 2.0.

Vogtländer, J. (2014). LCA - a practical guide for students, designers and business managers. Delft Academic Press.

Vogtländer, J. G., Bijma, A., & Brezet, H. C. (2002). Communicating the eco-efficiency of products and services by means of the eco-costs/value model. Journal of Cleaner Production, 10(1), 57–67. https://doi.org/https://doi.org/10.1016/S0959-6526(01)00013-0

Vrutaal, C., Aardenburg, S., Bugdayci, S., & Koller, S. (2024). From waste wood to innovation: an analysis of the feasibility and future potential of the CW4.0 Stool as a Business Case.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, 21, 1218–1230. DOI: 10.1007/s11367-016-1087-8

Research paper
6th PLATE 2025 Conference
Aalborg, Denmark, 2-4 July 2025

Waste What? — A game to communicate about local circular economy practices

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Keywords: Circular Economy; Educational Games; Scientific Communication; Waste Prevention; R-Strategies.

Abstract:
Waste What? is a card game, intended to communicate about linear economy while highlighting sustainable alternatives of local circular economy (CE) practices offered by grassroot initiatives. The objective of this article is to present the applied co-creative game development process and to show identified CE enablers included in the game. Based on the results, lessons learned and recommendations for future projects are formulated. The project that developed Waste What? used a co-creative development process with four phases: 1. Field Trips: That collected perspectives, insights, and impressions from local CE-Stakeholders. 2. Prototyping: Developed the game concept based on observations. 3. Testing & Design: Prototypes are developed into the final game by including the perspectives of stakeholders in testing sessions. 4. Dissemination and Documentation**:** The game was documented and published with an open-source license and disseminated at events. With an individual design of 110 cards, a game board, chips, and a manual, Waste What? communicates an experience of involvement in local CE- practices. In the game, players from two teams take the perspective of CE-initiatives. They are active in the re-use of items of the categories: Textiles, Electronics, Food, Furniture, Construction Materials and Bicycles. Players have several options, including selling, donating, storing, combining or incinerating items. The game communicates observed CE-enablers connected to people, items, and infrastructure. The study concludes that CE-games can communicate principles and people are interested in the approach. However, it is recommended to tailor games to specific target groups and plan extensive dissemination efforts to maximize its impact.

Introduction:

Waste What? is a card game resulting from the science-communication project “Trash Games - Playing with the Circular Economy Transition at the HdM”, financed by the Berlin University Alliance in 2021-2022 (Rotter et al., 2024). The objective of this project was to develop an open-source game which opens the field of circular economy to new target groups. It is intended to display a realistic picture of the current waste management system as part of the linear economy, while highlighting sustainable alternatives of local circular economy (CE) practices offered by grassroot CE - initiatives. This was done with the intention to increase recognition of such CE-initiatives, and to motivate players to reflect on their waste generation habits and hopefully nudge them into CE-practices. CE-initiatives are small and medium-sized civil based companies, or associations that engage in CE- practices known as the R-strategies: Re-use, Re-fuse, Re-purpose, Re-furbish and Re-cycle (Scholz, Vosse, et al., 2023). Initiatives engage specifically with waste prevention by preparing wasted or used items for reuse and making them available for the public by purchase or donation.

The implementation of R-strategies is part of the European Circular Economy Action plan (EUROPEAN COMMISSION, 2020). In the EU, an increasing number of CE-initiatives are visible, but they still face similar challenges and lack recognition from the public and local authorities(Partnership on Circular Economy, 2019; Rexfelt & Ordoñez, 2017; Scholz, Ordonez, et al., 2023). Part of this movement is the “Haus der Materialisierung” (HdM), a civic platform that groups several CE-initiatives from Berlin (Grundlach, 2024), and is an associated partner in the Trash Games project. It is part of the Haus der Statistik, a flagship project for community-oriented neighborhood development in Berlin (HdS, 2023).

The project successfully developed the game *Waste What? using co-creation methodology*. Games and gamification are increasingly used to represent circular challenges and opportunities (Selvefors et al., 2023; Whalen et al., 2018).. Games have been classified into serious games and entertainment games by (Susi et al., 2007). Serious games are effective instruction methods, by increasing the learner's engagement, encourage experimentation, and train critical thinking and problem-solving skills (Manshoven & Gillabel, 2021). Serious games set their focus on problem-solving experiences with elements of learning and a realistic simulation, including realistic communication between stakeholders. For entertainment games, the focus is set on experiencing a specific dynamic, which is hopefully also fun. To enjoy the game, simplified simulation processes are required, and a perfect (often simplified) communication between stakeholders is used (Susi et al., 2007).

The Trash Games project decided to aim at the development of an entertainment game with educational and scientific communication purposes. The team targeted a self-explaining and enjoyable gaming experience, which motivates players to interact with the content, without the requirement of a guided session. The idea: it needs to be fun to be able to disseminate well. The project applied a co-creative game development approach, involving perspectives of the CE-initiatives and waste management professionals from Berlin. The development was documented, and the resulting game was presented as part of the exhibition at the PLATE2023 conference (Niinimäki & Cura, 2023).

The objective of this article is to present the co-creative game development process and to show insights about the identified CE enablers included in the game. Based on the results, lessons learned and recommendations for future projects are formulated.

Methodology: Developing *Waste What?*

The project consortium consisted of two different disciplines: The chair of Circular Economy and Recycling Technologies of the Technische Universität Berlin (TU) and the Institute for Urban Anthropology from the Humbolt Universität Berlin (HU). In this interdisciplinary cooperation, the TU group delivered knowledge about waste management, CE-practices and CE-initiatives. The HU group provided their expertise in game development, game dynamics and science communication. The co-creation process of the game was two-fold, on one hand, the interdisciplinary collaboration between the recycling technologies and urban anthropology departments, and on the other hand, the transdisciplinary involvement of different CE-initiatives and waste management actors through field trips and game testing sessions. The game development process was structured into four phases:

Phase 1: Field Trips

Five field trips were organized to create a common knowledge base for the project team and to involve local stakeholders and their perspectives on the existing CE and waste management structure. The locations visited were: the local waste incineration plant, a second hand mall, run by the public waste management company, several re-use marketplaces, a non-profit textile sorting company and the HdM. In all places, guided tours and unstructured interviews with the management were conducted. From the observations key CE-enablers were identified.

Phase 2: Prototyping

Based on the observations and impressions from phase 1, several initial prototypes were developed. One prototype was selected and developed into the first playable version.

Phase 3: Design & Testing

The playable version of the game was used for several game tests. For the testing sessions, the stakeholders visited during the field trips were invited to reflect on the game and how their operations were represented in it. Two structured game test sessions were organized and used as key input sessions for the game iteration. One was with CE-initiatives at the HdM, and the other with waste management professionals at TU-Berlin, assuring that all organizations could share their opinion about how material reuse, recycling, and incineration were represented in the game. A constant exchange between testing and design led to the resulting game.

Phase 4: Dissemination and Documentation

The final design was professionally printed with 50 copies made in German and 50 in English, distributed among the project partners for their use and further dissemination. An open-source, downloadable version was published on the project webpage, with DIY printing instructions. The game development process was documented through a video, also available on the project-webpage (Rotter et al., 2024). Several presentations and game sessions of

Waste What? were organized at fairs, conferences or other events. Reactions, observations and feedback from players were summarized to formulate the lessons learned.

Results: *Waste What?*

In *Waste What?* players take the role of a CE-initiative, drafting three skills from the areas of Textiles, Bicycles, Construction Material, Food, Furniture, Electronics and the Creative Community. Two players or teams are confronted with the residues of the linear economy, which should create the feeling of an unstoppable wave of waste. Players must collaborate to find sustainable solutions for the items that are drawn each round. They must sell, donate, repurpose, store, recycle or incinerate the items they draw. Since capacities and skills are limited, the challenge is to deal with a limitation of possible actions. Some actions will generate income (i.e., selling for reuse, incineration), while others will cost money (i.e., recycling of problematic waste, storage). To win, players should reach the end of round six being able to pay rent for their storage, while not having emitted the maximum of three CO_2 markers from waste incineration. The game is affected by event cards that players draw starting in the second round. The events are inspired based on experiences from the practitioners involved in the co-creation sessions. By randomization, a replayable experience is created. Figure 1 contains a picture of the *Waste What?* game set-up. Figure 2 and table 1 explain the gameboard, certain cards and game mechanics.

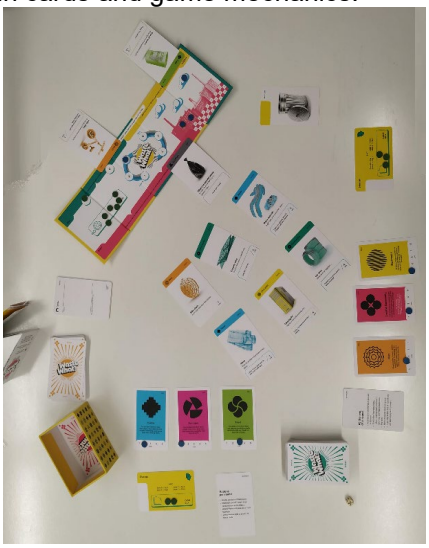


Figure 1. A picture of *Waste What? during a game session. Visible are the board, skills, waste cards, events, and the storage cards.*

Waste What? is designed to visualize the residues of the linear economy and encourages engaging with local CE-practices with a special focus on repair, reuse and repurpose. The key CE-enablers included in the game are:

- People and CE-initiatives
- Discarded items and their properties
- Infrastructure and storage space

Based on these CE-enablers, the following messages are part of the game mechanics:

CE-practices need affordable infrastructure and space: A crucial requirement for CE-practices is to be able to store, treat and offer items. It bridges the time between waste generation and re-use.

Complexity of CE-practices: Different types of items require different levels of expertise, infrastructure, and tools. CE-initiatives increase their expertise through their operations.

Synergies of skills: The application of CE-practices on complex items requires a combination of skills (i.e. E-Bikes require skills in bicycles and electronics).

Sharing is caring: CE-initiatives are widely engaged in charity and social services. Affordable items are offered or donated, and activities invite social and practical participation.

Creative community: Civil actors with their creativity can invent use cases for wasted items, outside regular perspectives.

Zero Waste – not yet an option: Many items resulting from the linear economy are waste and not suitable for reuse or recycling due to mixed waste, low quality or toxicity.

Waste incineration as a necessary infrastructure: Reuse and recycling are often not possible or not feasible. Waste incineration uses the calorific value of items to generate heat and electricity. At the same time, CO_2 and residues are generated.

Events can change everything: CE-initiatives are heavily influenced by positive or negative events. For these small companies in a challenging economic situation, the influence of events can be even more impactful.

The Trash Games project focused on the development and production of the game. The whole process took a little over a year. Just a marginal use and communication phase was included in the original time plan. The team presented the game on different occasions, but with limited follow-up on the actual effects of scientific communication. No concrete exploitation plan for the game was considered in the project timeline. The project team has evaluated the possibilities of doing a second edition of the game, including additional translations, and a print-on-demand option.

Scholz, J. R., Ordonez, I. & Rotter, V. S.
Waste What? - A game to communicate about local circular economy practices

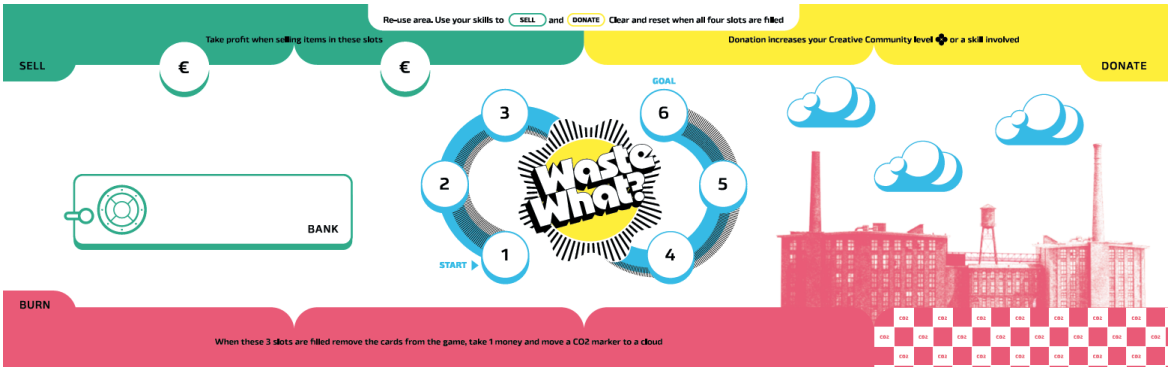


Figure 2. The game board (which is at the same time part of the game box) is used to manage the winning conditions, the bank, and the treatment options for waste cards. Winning conditions are to complete six rounds without emitting the three available CO_2 clouds. Treatment options for items are: 1. SELL items for money (Green), 2. DONATE items for an increased Creative Community (Yellow) and 3. BURN three items to emit one CO_2 marker, but also receive money due to the generation of heat and energy (red).

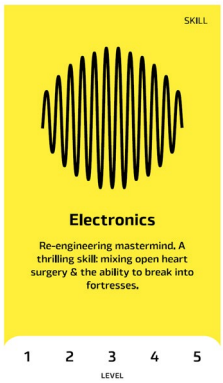
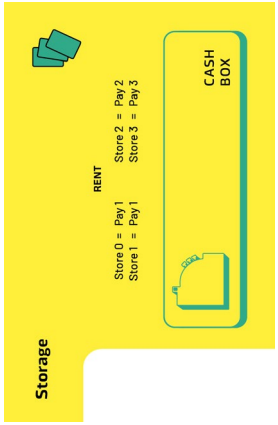
Description:	**Example of a card:**	**Description:**	**Example of a card:**
The Skill cards: The Skill cards are used to explain the specialization in one particular item category. Selected skills are: Textiles, Electronics, Construction Material, Bicycles, Food, and Furniture. During play, by reusing items, the skills are increased in their level, allowing the players to gradually process more items, and more complicated items. The teams can combine their skills to treat high-level items.		**The Waste cards:** In total, 72 waste cards describe items from 6 different waste categories. Each waste card is combined with a complexity level from 1 to 5. To be able to successfully treat the item, the player needs the required skill at the required level or higher. Some Waste cards come with additional conditions or restrictions (i.e., the need for an extra furniture skill to treat it).	
Storage card: The storage card organizes the cash, storage capacity and rent of each team. One losing condition is if one team is unable to pay rent. Basic rent is 1 cash. With each additional storage space, the rent increases. Players can share their storage capacity to be able to handle waste flows if desired, since it is a collaborative game.		**Just Waste cards:** Not all materials can be reused, recycled or stored. This is represented by the Just Waste cards. Players are forced to incinerate this mixed waste. The difficulty level of the game can be regulated by increasing the number of Just Waste cards available in the Waste cards deck, ranging from 9 to 18 cards in the deck.	

Table 1. Displayed are four different types of cards, representative of different game mechanics and dynamics implemented in the game. Displayed are Skill cards, Waste cards, Storage cards and Just Waste cards. In total, 110 cards are part of the game.

Discussion & lessons learned:

The discussion of the study is structured into the methodology of games as a tool for science communication, and the presented approach to experiencing local CE-practice enablers.

Methodology — Games as a successful tool for science communication

The development and application of games for scientific communication has turned out to be an ambitious objective.

The co-creative game development process led to a result that both CE-initiatives and waste management professionals agreed on. During the co-creation process, these stakeholders helped to create an abstract description of the system based on their experiences of real current practices. Their description of reuse, recycling and waste incineration processes, helped to shape how the game portrays waste management and CE-practices. What types of items come in the waste cards, and what events affect the players during the game, were all inspired directly from the experience of the stakeholders. Besides the stakeholders informing the game, the testing of early versions made them reflect on their role in the local CE, and to place themselves in a broader dynamic that they had not necessarily considered. The research team hopes that by participating in the early game tests, the stakeholders learned from how other stakeholders understand and relate to the items flowing through the city.

The intention to communicate the mechanics of complex systems with an entertaining game seems to be partly contradictory. To create a self-explaining and entertaining game with educational elements, it was required to create an enjoyable gaming experience, which is still able to communicate knowledge about a system. Game dynamics and fun vs. complexity of the system described should be balanced to allow an enjoyable, but still educational gaming experience. The challenge was selection, amount, balancing and explanation of the content. Especially in a complex system, where many processes, stakeholders, and connections exist, the trend to overload was evident during the first game prototypes. The simplification of the system and its dynamics is a difficult process, specifically deciding which elements should be cut out. If there is a mismatch and the rules or the contents are too complex or too trivial, the audience quickly loses motivation, and the objective of communication is not fulfilled.

It was noticeable that in *Waste What?* the number of topics and the complexity was relatively high, needing more than 30 minutes to explain the rules for the first time. Before the communication of the game content starts, people focus on the game mechanics. Due to this, less complexity is sometimes more communication. Defining a concrete target group for the game might help in clarifying the right balance between complexity of the system represented and enjoyment of the game.

Experience - Enabler for local CE -practices

Waste what? urges players to cooperatively plan and discuss how to survive the current wave of waste items. This requires creative thinking, understanding of waste cards and their properties while considering their own skills, capacities and the financial situation. Like this, the experience gets close to the actual waste management and the CE-practices of local CE-initiatives. The game uses several simplifications to display connections between stakeholders, items, and infrastructure. I.e. The positive side effects of waste incineration were appreciated by the local waste incineration plant.

The game lacks the ability to explain the difference between the game and reality to the player. In the current version, it is partly not obvious which messages are included and why certain game mechanics were implemented. E.g. It is printed on the game board that waste incineration provides money and emits CO_2, but it is not explained why this is the case. It was discussed in the project team to make an additional booklet, to provide the required information to fully understand the connections implied in the game. However, due to time and resource limitations, this never happened.

Conclusions and recommendations:

Tools and games developed in academia with educational purposes can contain important knowledge and perspectives combined with game mechanics and an individual design. However, to achieve widespread educational impact and demonstrate their effectiveness, these projects require more than just the game itself. An appealing design, well-written instructions, a qualitative or quantitative evaluation, a dissemination plan and a distribution plan. These aspects often involve activities similar to those undertaken by a startup and are out of the scope of a project in academia.

The dissemination of *Waste What*? led to a list of around 100 people interested in receiving a copy of the game. However, no further development or systematic use of the game has been made, since none of the project team members has had allocated time to implement this. No concrete exploitation plan has led to the game being "stopped" in its tracks, and no mainstream channels outside the peer group were approached. The Waste What? game has not been able to reach its full potential as a science communication tool. Based on the study described, the following recommendations for future projects in the field of CE game development are formulated:

Co-creation of games and communication: Involving stakeholders and their perspectives in a game development process is a recommended way of ensuring the game displays processes from reality. At the same time, the result includes the perspectives of practitioners and communicates to them as well.

Circular economy in games: The field of CE contains many mechanisms closely connected to players and their daily life. This can help to create attention and to activate engagement and creative thinking with a reflection of processes. Too much complexity in a game can hinder this process because players need to focus on game mechanics instead of the content.

Target group: Precise definition of a target group, including the expected level of knowledge, can help to design a game with an adequate level of complexity.

Dissemination plan: In research projects, a realistic dissemination plan with capacity to communicate the results is fundamental to reach a larger audience. For this, also leaving your own peer group and communicating with the mainstream media might be helpful.

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References

EUROPEAN COMMISSION. (2020). *A new Circular Economy Action Plan—For a cleaner and more competitive Europe* [COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS]. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

Grundlach, S., Vosse, Sachs. (2024). *HAUS DER MATERIALISIERUNG - Ein Transformationsort für Zirkuläre Praxis in Berlin* (1st ed.). https://drive.google.com/file/d/1F7oiKnu4l114zgo2RHmiIDMIyCyEJzD-/view

HdS. (2023). *Modellprojekt Haus der Statistik*. https://hausderstatistik.org/

Manshoven, S., & Gillabel, J. (2021). Learning through Play: A Serious Game as a Tool to Support Circular Economy Education and Business Model Innovation. *Sustainability*, *13*(23), 13277. https://doi.org/10.3390/su132313277

Partnership on Circular Economy. (2019). *Urban Resource Centres*. https://ec.europa.eu/futurium/en/system/files/ged/classification_of_urban_resource_centres_0_0.pdf

Rexfelt, O., & Ordoñez, I. (2017). Designing from the dumpster: Experiences of developing products using discards. *International Journal of Sustainable Design*, *3*(2), 61. https://doi.org/10.1504/IJSDES.2017.10012842

Rotter, V. S., Farías, I., Scholz, J. R., Criado, T. S., Ordoñez, I., Beck, P., Quack, S., & Escorza, M. (2024, December). *"Waste What?" A GAME ON THE MANY WAYS WE CAN REUSE STUFF*. Zenodo. https://doi.org/10.5281/zenodo.13941100

Scholz, J., Ordonez, I., & Rotter, V. S. (2023). Chaos and synergies: Review of the first three years at the "Haus der Materialisierung." *PROCEEDINGS 5th PLATE Conference Espoo, Finland*. https://www.plateconference.org/call-for-contributions-2/

Scholz, J., Vosse, C., Kellerhoff, S., & Rotter, S. (2023). Urbane Ressourcenzentren und Material-Initiativen als Katalysatoren nutzerzentrierter Abfallvermeidungsstrategien. *MÜLL Und ABFALL*, *8*. https://doi.org/10.37307/j.1863-9763.2023.08.04

Selvefors, A., Renström, S., Nordenö, H., Einebrant, E., Fallahi, S., Whalen, K. A., & Leivas, M. (2023). How can games aid co-design of user-centered circular offerings? *PROCEEDINGS 5th PLATE Conference Espoo, Finland*. https://www.plateconference.org/call-for-contributions-2/

Susi, T., Johannesson, M., & Backlund, P. (2007). *Serious Games—An Overview*.

Whalen, K. A., Berlin, C., Ekberg, J., Barletta, I., & Hammersberg, P. (2018). 'All they do is win': Lessons learned from use of a serious game for Circular Economy education. *Sustainable Resource Management and the Circular Economy*, *135*, 335–345. https://doi.org/10.1016/j.resconrec.2017.06.021

Research paper
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From Matching to Making: A Canvas for Collaborative Circular Value Creation

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Keywords: co-design; circular business model; circular economy; circular ecosystem innovation; collaborative innovation.

Abstract: Co-design, which involves end-users in the design process, has emerged as a promising strategy for developing circular offerings. However, creating such offerings requires collaboration not only with end-users but also between companies forming circular ecosystems centered on shared value propositions. While existing research highlights the importance of inter-company collaboration and co-design with end-users, tools supporting co-creation with both users and multiple stakeholders remain limited. This paper introduces and evaluates a prototype tool called the Collaborative Circular Value Creation Canvas. The tool is designed to facilitate company collaboration in generating concepts for circular offerings, which can serve as structured inputs for co-design with end-users. This paper reports on testing the canvas in a pilot workshop. Initial findings suggest the tool's potential to foster inter-company collaboration and generate valuable inputs for a co-design process with end-users. However, further research is needed to validate its role in a co-design process and its ability to foster business models focused on product longevity. Additionally, the implications of using the tool in a digital format should be further investigated.

Introduction

Increasingly, the idea of co-design, defined as a collaborative approach that involves end-users in the design process (Sanders & Stappers, 2014), has gained attention in circular business model literature (Fernandes et al., 2020; Whalen et al., 2024). Co-design is viewed as a potential strategy to create innovative circular offerings - defined as products or services designed to meet consumer needs in a circular consumption system (Gomes et al., 2022). By collaborating with users, companies can generate insights and create innovative user-centered solutions, as demonstrated by van Dam et al. (2021) who used co-design to enable the development of new circular-oriented service ideas for washing machines. Moreover, Pedersen and Clausen (2018) highlight its potential to integrate various stakeholder's perspectives into the design of circular solutions.

At the same time, recent research underscores the need for inter-company collaboration and partnerships to create circular eco-systems centered on product longevity (Konietzko et al., 2020b). An ecosystem can be described as a structured alignment of multiple partners who must collaborate for a central value proposition to take shape (Adner, 2017). Thus, for a circular eco-system to take place, actors must center their activites, positions, and links to each other around a shared circular value proposition. Trevisan et al. (2022) emphasize the system around firms and how multiple stakeholders interact – rather than focusing on the business model of a single firm.

By merging these two perspectives, an interesting focus emerges: on one hand, companies must collaborate to provide new circular offerings; on the other hand, these offerings must also be co-developed with end-users. This raises a critical question: how can companies align and work together to put forward new concepts to end-users that can then be refined through the co-design process?

Although tools and methods for collaboration exist (e.g., value mapping frameworks and circular innovation toolkits) (Rexfelt & Selvefors, 2024), none are specifically designed for inter-company collaboration with the goal of generating inputs for co-design with

users. Addressing this gap, this paper explores how companies can align and collaborate to generate concepts for circular offerings. These concepts can then be integrated into the co-design process to create offerings that support a circular economy.

This paper focuses on the development and initial testing of such a tool. Designed for the early stages of the design process, the tool intends to generate structured outputs that can serve as inputs for a co-design process with end-users. This work is part of the ongoing research project 'Game-Based Approaches to Create Circular Value Propositions' (henceforth referred to as CBM GAMES). The project explores how game-based methods can facilitate the co-design of user-centered circular offerings. Approaches for fostering inter-company partnerships align with the broader objectives of the project, as will be expanded on further in the next section.

Project context & approach

The CBM GAMES project builds on prior research in circular business models, serious games, and co-design. Findings from the project presented at the PLATE 2023 Conference indicate that games could be used in the co-design of user-centered circular offerings and experimentation of circular business models (Selvefors et al., 2023). However, it was noted that most existing games in the research area primarily focus on educating participants about circular economy concepts rather than providing a platform for direct co-creation with users. The research further highlighted that games could better support the co-design of user-centered circular offerings if they allowed for collaboration both with users and among multiple stakeholders within a business ecosystem.

Subsequent studies have focused on the roles users can take in the co-design of circular offerings (Selvefors et al., 2024) and examined how games might enable such roles in co-design processes (Whalen et al., 2024). Thus, while significant progress has been made in understanding user roles in co-design, how games can support collaboration among multiple stakeholders within a business ecosystem remains an open question. This paper makes an initial contribution to this area of research.

As depicted in Figure 1, the CBM GAMES framework enables companies and customers to collaborate in a digital game environment. Customers engage with challenges designed to gather user insights, which are then shared with companies. Since the companies are involved in shaping these challenges, the collected data aligns with their specific goals and objectives. Part of the game should also enable companies to work together to create challenges they can then pose to the customers. For this to work, we have identified three key steps:

1. **Match** – Companies are matched or paired with another company to explore potential collaboration opportunities.
2. **Create** – Companies collaborate to design a joint challenge aimed at collecting user insights and ideas.
3. **Review** – Companies analyze the user responses to the challenges and integrate the insights into their design processes.

This paper focuses on the second step: company-to-company exchange of ideas and the creation of co-design challenges. To support this process, the *Collaborative Circular Value Creation Canvas* (working title) was developed and tested. Although the final goal is a digital tool, a paper prototype canvas was developed to allow for rapid iteration and testing. This process, and the resulting canvas, is described in the following sections.

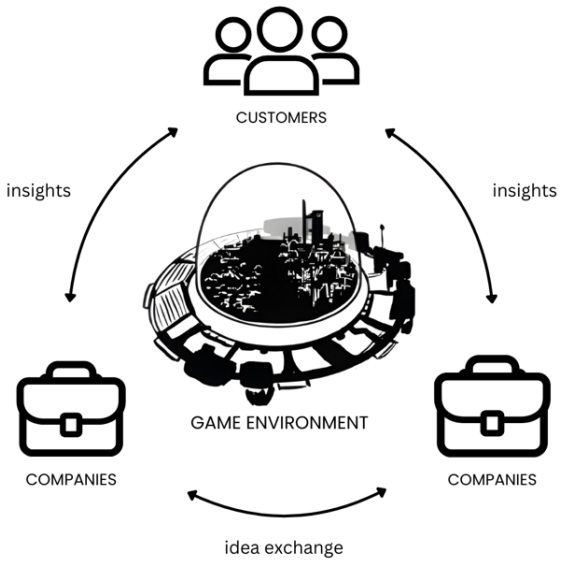


Figure 1. The CBM GAMES framework, depicting the exchange of information between companies and customers.

The collaborative circular value creation canvas

In May 2024, a benchmark analysis scanned relevant tools and methods including 1) approaches to support circular ecosystem design (e.g., Value Mapping Framework (Bocken et al., 2013); Circularity Deck (Konietzko et al., 2020a); 2) (collaborative) circular business model tools and methods (e.g., Circular Strategies Toolkit (Brown, Baldassarre, et al., 2021); BM^{3}C^2 (Boldrini & Antheaume, 2021); Circular Business Model Mapping Tool (Nußholz, 2018); and 3) circular design tools (e.g., Use2Use Toolkit (Rexfelt & Selvefors, 2021)). Review articles including Bocken et al. (2019), Pieroni et al. (2019), and Rexfelt & Sevlefors (2024) were also used to identify relevant tools and methods.

Key insights from the analysis identified existing methods typically involve at least two steps: (1) checking current circularity; and (2) identifying redesign opportunities, often based on a shared common vision.

Building on these methods, we concluded the canvas should enable companies to:

1. Map their current circular actions.
2. Identify overlaps and gaps with their partner company's actions.
3. Explore new opportunities for collaboration.

A finalized version of the canvas prototype is shown in Figure 2. Drawing on criteria from Selvefors et al. (2023), special attention was given to make the canvas simple and appropriate for people not familiar with circular economy terminology. The two main sections of the canvas are described in detail below.

Company Circularity Check

Companies start by completing the "Circularity Check," represented by the blue boxes on either side of the canvas. This check focuses on two aspects of existing company practices: circular flows (Rexfelt & Selvefors, 2021) and circular behaviors (Poppelaars et al., 2020; Selvefors et al., 2019). There is space for each company to individually fill in Step 1 and reflect

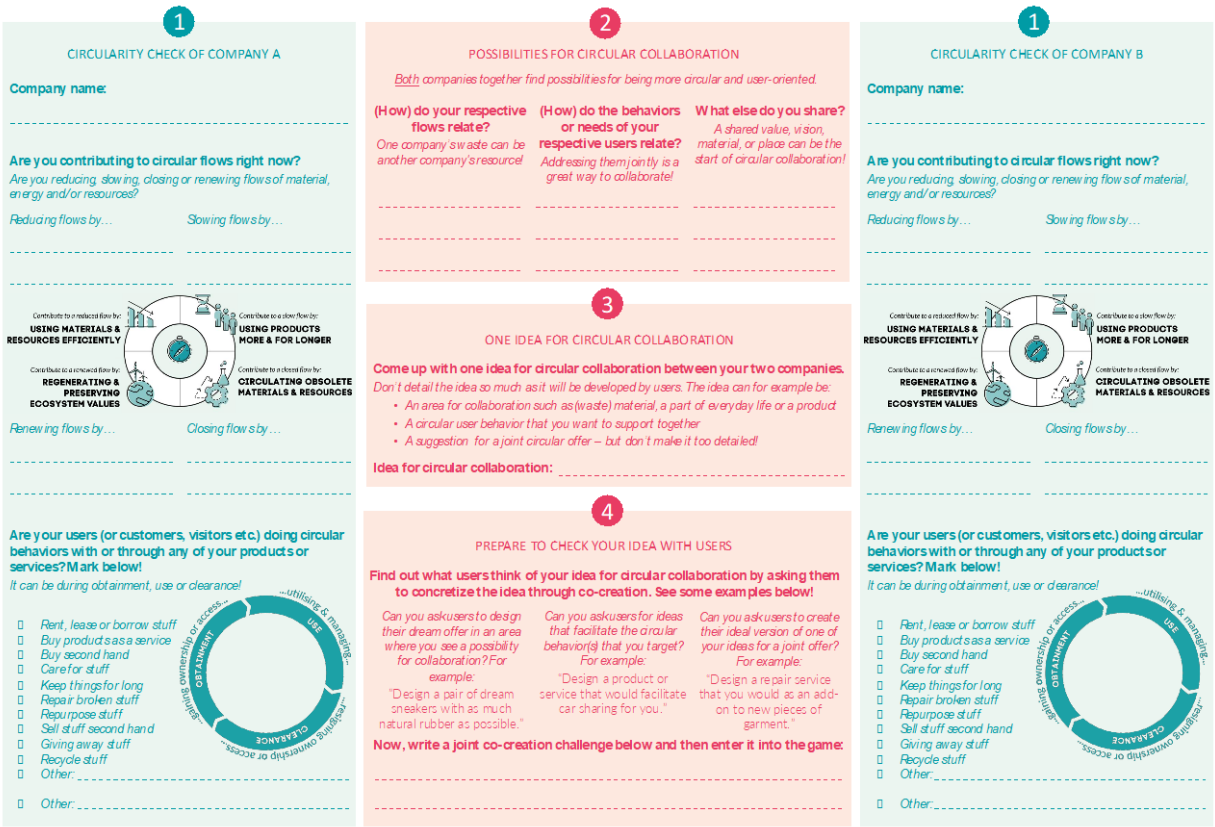


Figure 2. Collaborative Circular Value Creation Canvas.

on how their current business offerings contribute to circular strategies such as reducing, slowing, renewing, and closing material resource flows (Konietzko et al., 2020a). Next, they consider how their current business offerings support circular behaviors during the phases of circular consumption: obtainment, use, and clearance (Rexfelt & Selvefors, 2021; *The Circular Behavior Toolkit*, 2024).

Possibilities for Circular Collaboration

The center section of the canvas (in pink, Steps 2-4) is filled in jointly by both company representatives after they finish their individual circularity checks. Step 2 asks the representatives to reflect together and relate their existing flows, behaviors, goals, and company visions (Brown, Von Daniels, et al., 2021; Pedersen & Clausen, 2018, 2019; Selvefors et al., 2024). Afterwards, in Step 3, they brainstorm potential collaboration ideas. In the fourth and final step, they select one idea and reframe it in a way that can be communicated to end-users. The result is a joint challenge that can be shared with users in the next step of the co-design process.

Pilot test of canvas

The canvas was tested during a gamified workshop at the Design Research Society (DRS) Conference 2024. The workshop lasted 1.5 hours and involved 12 total participants. Six participants were asked to take on the role of companies. These participants selected fictional company profiles and role-played as designers/managers from these companies. The remaining six attendees participated as users, responding to the challenges generated by the companies. Participants were asked to respond to a short survey covering demographics, gaming experience, and experience in relation to circular economy.

During the workshop, the participants role-playing as companies used the canvas to map their circular actions, identify collaboration opportunities, and create a joint challenge. These challenges were then entered into a digital platform developed as part of the CBM GAMES project. The participants role-playing as users were then asked to respond to the challenges through the platform. The workshop concluded with a plenary reflection. Figure 3 shows participants using the canvas in the workshop setting. Drawing from Keebler et al. (2020), three main aspects were emphasized when reflecting specifically on the canvas, and these serve as the foundation for the reflections presented in the remainder of this paper:

1) Usability: Ease of use and intuitiveness of the canvas.
2) Engagement: Level of participant focus and enjoyment.
3) Collaboration: Effectiveness in fostering inter-company collaboration and generating user insights.

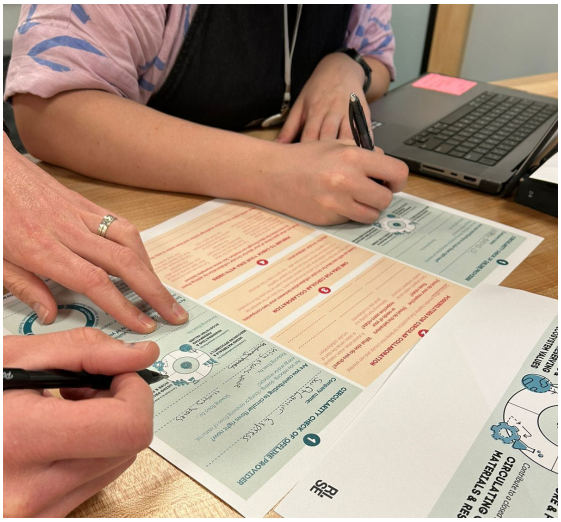


Figure 3. Workshop participants filling out the canvas.

Canvas' usability

The pilot revealed some confusion regarding Step 1, as participants struggled to connect the initial questions to the accompanying circular flows graphic. Adjusting the layout so it makes it clearer that the graphic is related to the first question was identified as an improvement for future revisions. Other than this, however, the participants were able to use the canvas without help from the facilitator. This is particularly noteworthy as most participants did not have research backgrounds in circular economy.

Engagement

Participants using the canvas appeared highly engaged, talking and laughing in their groups. When a latecomer joined an ongoing group filling out the canvas, she initially assumed the participants were actual employees of the companies rather than role-playing. This was due to how animated and immersed the group was, as they spoke convincingly from the

perspectives of the companies they were representing.

Collaboration ability
The tool facilitated inter-company collaboration in the current setting, but participants expressed a desire for more interaction with users. The limited functionality of this feature in the digital game platform may partly explain this observation. Nevertheless, it highlights the importance of fostering reciprocal collaboration not only between companies but also between companies and end-users. End-users should not only provide input to companies, as this could feel exploitative. Companies must also offer feedback and reflections to end-users, creating a more balanced and collaborative exchange.

Concluding Remarks

This paper has proposed and piloted a tool to support company collaboration and co-design of circular offerings with multiple stakeholders. Initial results suggest the tool's potential to foster company collaboration and generate valuable inputs for a co-design process with end-users. However, the research is still early stages, and much more in-depth research must be conducted to validate its role in a co-design process and ability to foster business models focused on product longevity. Further development and testing of a digital – instead of paper – prototype is also necessary to align with the growing need for digital collaboration tools in a post-COVID-19 world. To this end, several directions for future research have been identified:

How does the lack of physical presence affect engagement and perceived enjoyment? Participants playing as companies reported enjoying the workshop, with some noting that the role-playing aspect added an engaging dynamic. However, it remains unclear how much of this engagement was due to physical presence, the group dynamic, or the act of role-playing. Future research should test the tool with actual representatives from companies (rather than role-playing participants) and assess its performance in remote and asynchronous settings. Understanding how digital environments affect collaboration and enjoyment is important for adapting the tool for broader use.

How should matching between companies be executed?
In the pilot workshop, companies were randomly matched. While this was done for practical reasons, questions remain about how to do this in the real world. What should be criteria for matching companies? Matching could be based on shared values, complementary resource flows, circular strategies, or other factors (Boldrini & Antheaume, 2021; Konietzko et al., 2020b). Moreover, how should this occur? Companies could create profiles and 'swipe right' ala the popular dating app Tinder – or external facilitators could play matchmaker, setting companies up based on their characteristics. Other questions arise including: how much information are companies willing to share to facilitate meaningful matches, and how can potential concerns about confidentiality be addressed? Exploring these issues will help refine the matching process.

How do companies want to complete the canvas? In the pilot, participants worked together in physical groups where they were able to communicate directly in real time. Future research could investigate preferences for different formats, such as in-person workshops, synchronous online meetings, or asynchronous collaborations where notes and ideas are exchanged digitally over time (i.e. such as through an online whiteboard). Each format offers advantages and challenges, and determining the most effective method will enhance the tool's adaptability to various organizational contexts.

What features do and do not translate when digitalizing the canvas? Some of the tactile and collaborative aspects of the physical canvas may be lost when translated into a digital version. However, a digital version creates possibilities for new features such as automated data analysis, visualizations, or integration with other collaborative platforms. Identifying which features enhance and/or hinder the collaborative process will help guide the tool's future digital development.

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References

Adner, R. (2017). Ecosystem as Structure: An Actionable Construct for Strategy. *Journal of Management*, *43*(1), 39–58. https://doi.org/10.1177/0149206316678451

Bocken, N. M. P., Pauw, I., Bakker, C. A., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *J. Ind. Prod. Eng.*, *1015*.

Bocken, N., Short, S., Rana, P., & Evans, S. (2013). A value mapping tool for sustainable business modelling. *Corporate Governance*, *13*(5), 482–497. https://doi.org/10.1108/CG-06-2013-0078

Brown, P., Baldassarre, B., Konietzko, J., Bocken, N. M. P., & Balkenende, R. (2021). A tool for collaborative circular proposition design. *Journal of Cleaner Production*, *297*, 126354. https://doi.org/10.1016/j.jclepro.2021.126354

Fernandes, S. da C., Pigosso, D. C. A., McAloone, T. C., & Rozenfeld, H. (2020). Towards product-service system oriented to circular economy: A systematic review of value proposition design approaches. *Journal of Cleaner Production*, *257*, 120507. https://doi.org/10.1016/j.jclepro.2020.120507

Gomes, G. M., Moreira, N., & Ometto, A. R. (2022). Role of consumer mindsets, behaviour, and influencing factors in circular consumption systems: A systematic review. *Sustainable Production and Consumption*, *32*, 1–14. https://doi.org/10.1016/j.spc.2022.04.005

Keebler, J. R., Shelstad, W. J., Smith, D. C., Chaparro, B. S., & Phan, M. H. (2020). Validation of the GUESS-18: A short version of the game user experience satisfaction scale (GUESS). *J. Usability Studies*, *16*(1), 49–62.

Konietzko, J., Bocken, N., & Hultink, E. J. (2020a). A Tool to Analyze, Ideate and Develop Circular Innovation Ecosystems. *Sustainability*, *12*(1). https://doi.org/10.3390/su12010417

Konietzko, J., Bocken, N., & Hultink, E. J. (2020b). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, *253*, 119942. https://doi.org/10.1016/j.jclepro.2019.119942

Pedersen, S., & Clausen, C. (2018). *Co-designing For A Circular Economy*.

Pedersen, S., & Clausen, C. (2019). Staging Co-Design for a Circular Economy. *Proceedings of the Design Society: International Conference on Engineering Design*, *1*(1), 3371–3380. Cambridge Core. https://doi.org/10.1017/dsi.2019.344

Poppelaars, F., Bakker, C., & van Engelen, J. (2020). Design for Divestment in a Circular Economy: Stimulating Voluntary Return of Smartphones through Design. *Sustainability*, *12*(4). https://doi.org/10.3390/su12041488

Rexfelt, O., & Selvefors, A. (2021). The Use2Use Design Toolkit—Tools for User-Centred Circular Design. *Sustainability*, *13*(10), Article 10. https://doi.org/10.3390/su13105397

Rexfelt, O., & Selvefors, A. (2024). Mapping the landscape of circular design tools. *Resources, Conservation and Recycling*, *209*, 107783. https://doi.org/10.1016/j.resconrec.2024.107783

Sanders, E., & Stappers, P. J. (2014). Probes, toolkits and prototypes: Three approaches to making in codesigning. *CoDesign*, *10*(1), 5–14. https://doi.org/10.1080/15710882.2014.888183

Selvefors, A., Renström, S., Nordenö, H., Einebrant, E., Fallahi, S., Whalen, K. A., & Leivas, M. (2023, June 31). *How can games aid co-design of user-centered circular offerings?* Product lifetimes and the environment (PLATE), Espoo, Finland.

Selvefors, A., Renström, S., Whalen, K. A., Fallahi, S., Leivas, M., Nordenö, H., & Fransson, A. (2024). User-centered circular value propositions – approaches in practice and research. *Resources, Conservation and Recycling*, *207*, 107628. https://doi.org/10.1016/j.resconrec.2024.107628

Selvefors, A., Rexfelt, O., Renström, S., & Strömberg, H. (2019). Use to use – A user perspective on product circularity. *Journal of Cleaner Production*, *223*, 1014–1028. https://doi.org/10.1016/j.jclepro.2019.03.117

The Circular Behavior Toolkit. (2024, April 8). DDC – Danish Design Center. https://ddc.dk/tools/the-circular-behavior-toolkit/

Trevisan, A. H., Castro, C. G., Gomes, L. A. V., & Mascarenhas, J. (2022). Unlocking the circular ecosystem concept: Evolution, current research, and future directions. *Sustainable Production and Consumption*, *29*, 286–298. https://doi.org/10.1016/j.spc.2021.10.020

van Dam, S., Sleeswijk Visser, F., & Bakker, C. (2021). The Impact of Co-Creation on the Design of Circular Product-Service Systems: Learnings from a Case Study with

Washing Machines. *The Design Journal*, *24*(1), Article 1. https://doi.org/10.1080/14606925.2020.1851427

Whalen, K. A., Selvefors, A., Fransson, A., Fallahi, S., Renström, S., Nordenö, H., & Leivas, M. (2024). Opportunities for engaging users in co-design of circular offers through games. *Proceedings of the 9th International Conference on New Business Models NBM2024*. 9th International Conference on New Business Models NBM2024 Sustainable business models for the digital, green and inclusive transition.

Extended Abstract
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Navigating social sustainability in engineering education: student experiences and challenges of using a social impact audit tool in a product design project

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Keywords: Social sustainability, social impact analysis, engineering education, sustainable product design

Introduction

The social dimension of sustainable development, critical to achieving the first five Sustainable Development Goals (SDGs), remains underexplored in product design (Corsini & Moultrie, 2021). Design support for assessing the social sustainability of product concepts is limited and the social pillar remains the least developed in engineering education (Gould et al., 2017; Mesquita & Missimer, 2020).

Understanding social impacts is important for product lifetime extension as it ensures that interventions promote inclusivity, equity, and societal wellbeing. Product designers need tools that provide clear, reliable data to guide material and design choices, enabling the design of products with reduced long-term impacts.

Assessing social impacts is commonly done through Social Life Cycle Assessment (SLCA), which is well-established and various methods exist (Wu et al., 2014). Yet, SLCA is typically time- and resource-intensive, requiring detailed data that is limited in early-stage design. Tools that help designers assess social impacts during the design stage are still limited (Gould et al., 2017).

Emerging solutions, like the Social Impact Audit tool (SIAT) by Ansys (Ashby, Mike et al., 2019), can potentially bridge this gap. It provides a simplified and introductory approach to SLCA for design and engineering education. Using publicly available data, the tool ranks social impacts along production chains, from raw materials to end-of-life, enabling more informed and socially conscious design decisions.

The aim of this paper is to examine the challenges faced by industrial design engineering students using a social benchmarking tool during a bachelor-level product development course at Chalmers University of Technology. It explores the tool's potential to enhance critical thinking about social impacts and provide the next generation of product designers with the means to assess social impacts in the development of sustainable design solutions.

Methods

Research approach

A half-day workshop using the SIAT tool was held in the course Sustainable Development with 3rd year students in the industrial design engineering program at Chalmers University of Technology. In the course a total of 44 students divided over ten groups of 4-5 members each performed a qualitative sustainability analysis of an electrical consumer product and proposed measures to improve sustainability performance. Social impact was assessed using SIAT, a tool that analyzes publicly available data across 5 stakeholder groups (workers, consumers, local community, society, and value chain) and 31 social impact categories, converting them to a scale from 1 (least good practice) to 100 (best practice). The data and social impact categories are based on the UNEP/SETAC 'Guidelines for Social Life Cycle Assessment of Products'(United Nations Environment Programme, 2020). See figure 1 for an impression of the SIAT tool. The users select countries involved in the lifecycle phases of their product and set threshold limits to identify hotspots where impacts are unacceptable.

The workshop followed structured steps: (1) an introduction to social sustainability and SIAT, (2) an exercise refining a prior social impact analysis with different thresholds, and (3) an assignment applying SIAT to assess and improve the social impact of a student team's product. Groups worked on manufacturer-based scenarios using a baseline production chain. The session concluded with a survey to

gather feedback on tool usability and challenges.

Data collection and analysis

Data was collected in the form of completed Miro boards containing choices and reflections (n=8), survey responses (n=16), and observations by the workshop facilitator. Each Miro board was analysed and answers were captured (e.g., defined threshold value, prioritization of social impact indicators, written reflections about optimized production chain).

the tool's calculations, many struggled to define acceptable social impact values and prioritize categories. A crucial step in understanding and defining acceptable social impact was exploring data sources and aligning interpretations of social sustainability within groups. Furthermore, data reliability and transparency came up as a substantial challenge as some groups encountered values that they did not perceive to be correct, which raised uncertainty whether they could rely on the data.

5 Stakeholder groups, 31 Social Impact Categories →

201 Nations ↓

Stakeholders Categories	S1 Workers					S2 Consumers			
Nation \ Indicator	Hours worked per week	Women's share of labor force	Fatal accidents at work	Social protection expenditure	ITUC freedom of association	Public health spend per capita	Press freedom	Rule of law	Corruption perception index
Afghanistan (AFG)	70.0			10.8		17.9	32.5	3.0	3.0
Albania (ALB)	70.0	37.1	59.0	58.9	60.0	41.0	56.5	42.6	50.0
Algeria (ALG)	70.0	11.9	50.0	47.9	20.0	56.3	24.9	21.8	39.0
Andorra (AND)	70.0					76.8	81.5	90.1	
Angola (ANG)	31.0	89.1		38.6	40.0	24.7	29.8	12.9	8.0
Antigua and Barbuda (ANT)	70.0			68.2		47.3	78.8	63.4	
Argentina (ARG)	9.0	41.3	24.0		40.0	73.7	70.1	22.8	54.0
Armenia (ARM)	70.0	63.9	61.0	45.0		26.3	54.9	43.6	41.0
Aruba (ARU)								86.1	
Australia (AUS)	85.0		92.0	91.9	60.0	83.7	90.2	94.1	93.0

Set threshold limit
Unflag social hotspots
Copy rows to Report
Unselect all nations

	Stakeholders Categories	S1 Workers		
	Nation \ Indicator	Hours worked per week	Women's share of labor force	Fatal accidents at work
☐	Suriname (SUR)	16.0		21.0
☐	Swaziland (SWZ)	9.0		
☑	Sweden (SWE)	70.0	91.6	97.0
☐	Switzerland (SUI)	47.0	84.9	95.0
☑	Syria (SYR)	70.0	4.4	31.0
☐	Tajikistan (TJK)	70.0		72.0
☐	Tanzania (TAN)	16.0	100.0	

Figure 1. Impressions from the SIAT tool. Users can evaluate and compare social impact categories of 201 nations (top) and use threshold limits to identify social hotspots amongst impact categories and stakeholders. Image adapted from (Ashby, Mike et al., 2019).

Findings

Challenges of using the social benchmarking tool

The most prevalent challenges encountered by the students were (1) setting the threshold, (2)

balancing sustainability trade-offs, and (3) data reliability and transparency. The challenge of setting thresholds for social impact assessment emerged in written explanations, with half the groups arbitrarily selecting 50 as it implied the "better half" of impacts. Despite explanations of

Table 1. Challenges experienced by students during the workshop (n=16). Students were able to select a maximum of 3 challenges.

Challenge	% of respondents
Setting the threshold	50%
Balancing trade-offs between social, economic, and environmental sustainability	44%
Data reliability and transparancy	38%
Selecting social impact categories	31%
Comparing the data and scores	31%
Understanding how the social impacts relate to specific stages of the product lifecycle	19%
Prioritizing social issues and ethical considerations	19%

Experiences and reflections by the students

Overall, all the students agreed (75% strongly agreed, 25% agreed) that they found the tool helpful for assessing social impacts, and all could imagine using the tool again in future design projects and work. Most of the students saw the use of the tool primarily in the initial screening phase of the design process, to set social impacts constraints and eliminate unsuitable materials. When asked whether the workshop using the SIAT tool led to rethinking design choices (e.g., material choices) the students indicate a greater awareness of social impacts and reconsiderations of production location (see table 2).

Table 2. Answers by the students on the question whether the SIAT made them consider changes to the product design.

ID	Answer
1	*'Where we produce our materials and how the workers are affected by the social conditions. To change country maybe!'*
10	*'End of life, as I was very focused on the environmental impact of the production.'*
11	*'It did facilitate reasoning regarding design changes, even concerning categories I wouldn't have thought of without the tool.'*
14	*'Focus more on social rights, we thought more about environmental aspects before.'*

Conclusion

This paper examined the challenges experienced by students using a social impact audit tool in a sustainable product development project. Previous studies have noted the difficulty of systematically addressing social impacts in the product development process (Gould et al., 2017). The findings of the study indicate that the students see the tool as helpful in assessing social impacts during design projects. Experienced challenges relate primarily to setting thresholds of acceptable levels of social impact, balancing sustainability trade-offs, data reliability, and prioritizing social impact categories. Workshop observations indicate the potential of the tool in systematically identifying social hotspots but also emphasized the importance of allowing users to examine data sources and critically reflect on the various dimensions of social sustainability and how they are measured and quantified. A limitation is the small sample size, further research will consolidate findings through additional workshops. Limitations related to the tool may exist regarding perceived tool accuracy and integration with industry and other SLCA tools. Moreover, there is a need to understand potential tool risks such as oversimplifying social impacts e.g. by fixating on counting social hot spots rather than understanding the complexity of social impacts and setting thresholds for unacceptable countries that could lead to misconceptions of avoiding low-scoring regions entirely. Therefore, it is crucial to educate students that threshold values highlight risks rather than 'poor' practice, and that risks can be opportunities to enhance social sustainability amongst social impact categories.

References

Ashby, Mike, Brechbüchl, Eliane, Vakhitova, Tatiana, & Vallejo, Alicia. (2019). *Paper: Social Life-Cycle Assessment and Social Impact Audit Tool | Ansys*. https://www.ansys.com/academic/educators/education-resources/paper-social-lifecycle-assessment-and-social-impact-audit-tool

Corsini, L., & Moultrie, J. (2021). What Is Design for Social Sustainability? A Systematic Literature Review for Designers of Product-Service Systems. *Sustainability*, *13*(11), Article 11. https://doi.org/10.3390/su13115963

Gould, R., Missimer, M., & Mesquita, P. L. (2017). Using social sustainability principles to analyse activities of the extraction lifecycle phase: Learnings from designing support for concept selection. *Journal of Cleaner Production*, *140*, 267–276. https://doi.org/10.1016/j.jclepro.2016.08.004

Mesquita, P. L., & Missimer, M. (2020). SUPPORTING ENGINEERING STUDENTS IN ANALYSING SOCIAL SUSTAINABILITY OF A PRODUCT: LESSONS LEARNED. *Proceedings of the Design Society: DESIGN Conference*, *1*, 1755–1764. https://doi.org/10.1017/dsd.2020.266

United Nations Environment Programme. (2020). *Guidelines for Social Lifecycle Assessment of Products and Organizations*. https://www.lifecycleinitiative.org/wp-content/uploads/2021/01/Guidelines-for-Social-Life-Cycle-Assessment-of-Products-and-Organizations-2020-22.1.21sml.pdf

Wu, R., Yang, D., & Chen, J. (2014). Social Life Cycle Assessment Revisited. *Sustainability*, *6*(7), Article 7. https://doi.org/10.3390/su6074200

Extended Abstract
6th PLATE 2025 Conference
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Experiencing Design for Repair, educating circular practitioners

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Keywords: repair; design; education; didactic, productive failure.

Introduction

In the bachelor program of the faculty of Industrial Design Engineering, three courses on sustainability are offered. *Sustainable Impact* focuses on the basics of sustainability like ecodesign and LCA, *Design for the Circular Economy* focuses on circular business models and future design visions, and the *Sustainable Transitions* minor focuses on sustainable systems interventions. Although these courses score “more than satisfactory” on student evaluations (EvaSys), attendance is low and decreasing over the course. Besides, coordinators of the parallel running design projects notice that students struggle with the integration of sustainability into the design solutions. To make sustainability more applicable, we developed a new master elective related to design for repair, named Repair! (ID5422, 3EC over 8 weeks). In this course we explicitly implemented the theory of productive failure by Kapur & Bielaczyc (2012) and followed the course-design model for productive failure described in Persaud & Flipsen (2023). Contrary to traditional teaching, productive failure flips the process and starts with an explorative problem which students cannot solve without the right knowledge. This is followed by an instruction explaining the missing concept and filling the knowledge gap, after which students apply their learnings on their own project. This approach engages students in active problem-solving, with the goal to increase retention of the theoretical concepts and facilitate deep learning. In the Repair course respectively 24 and 36 students participated over the past two years. Students work on client-based products, focusing on a demonstration model to show the improved fit of the product within a circular economy. In this paper, we will present the course and its content, one of the workshops explaining the productive failure approach, and finalize with an analysis of the student’s learning experiences.

Course setup

This hands-on circular-design course is divided in seven weekly workshops and a final demonstration day. The course modules build upon each other, and addresses three perspectives on repair: product architecture, legislation, and human factors in design for repair. During the workshop sessions students are experiencing the weekly concepts through a weekly recurring case-study, a simple wired computer mouse, after which they are instructed on the tools and methods applied in the course. In the rest of the time, they apply their acquired knowledge to a client-based project, like a computer accessory (e.g. keyboard), kitchen appliance (e.g. blender), or multimedia device (e.g. headset, figure 1).



Figure 1. One of the results of student’s product, improved on repairability (week 7).

During week 1 to 3, students analyze a product on its ease-of-disassembly covering disassembly mapping (De Fazio et al., 2021), locating priority parts and key repair obstacles using hotspot mapping (Flipsen et al., 2020), and deep dive into optimizing their project with redesign strategies. During these weeks they learn to improve the product design for repair (Flipsen, 2023; Pozo Arcros et al., 2021; Dangal et al., 2019, Dangal et al., 2022). Week 4 gives students space to continue with the disassembly mapping and come up with

redesign solutions for observed hotspots using sketching and prototyping. During week 5 the design is addressed from the second perspective where the influence of legislation, directives, and repairability indicators on the design are discussed (FRI, 2022; Flipsen, et al. 2016). In week 6 the third perspective is addressed, and students learn about emotional, functional, social, epistemic, and conditional values influencing users to do repair (van den Berge et al., 2023). These three perspectives on repair result in different directions within the solution space and result in different and sometimes contradicting design changes. Week 7 and 8 is there to give students the space to finish their design and demonstrator, validate their findings, and present their solutions (figure 2).

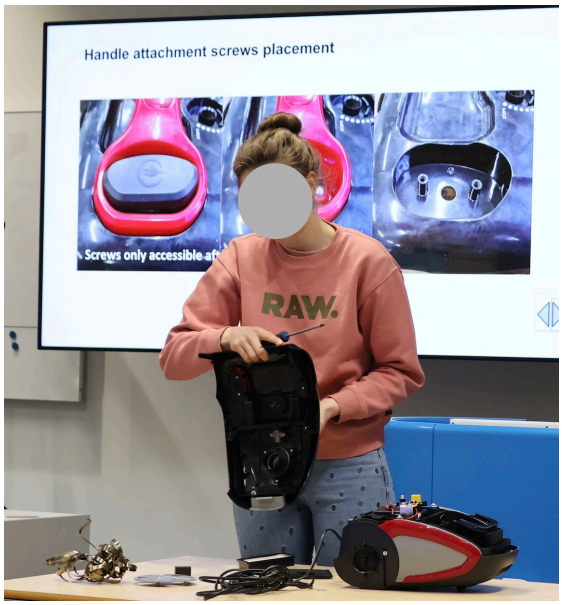


Figure 2. Demonstrating the improvements on a vacuum cleaner during demonstration day in week 8.

Productive Failure Workshop

Each week consists of a four-hour workshop, where we start with reflecting on previous weeks by means of a quiz. After the short introduction students deep dive immediately into an activity concerning the concept of that week using the recurring case-study, the simple wired computer mouse. For instance, in week 2 students are introduced to prioritizing activities and parts, where they need to rank the mouse's parts based on their own prior knowledge (figure 3). This exercise helps them to activate their brain and be involved in that week's learnings. While students fail to generate the correct solution, curiosity and a need-to-know develops. Only after a short period of failing and struggling, they are introduced to the method of hotspot mapping where it is explained to prioritize activities based on time and difficulty of the disassembly, and prioritize parts based on failure rate and its intrinsic economic and environmental value. In the following hours students are guided in applying their learnings to their own project, while during the rest of the week students implement further by designing and prototyping.

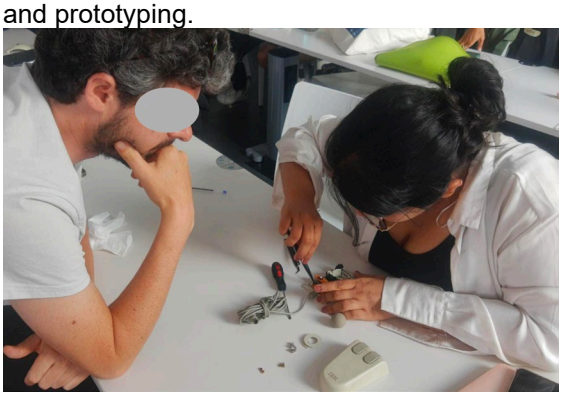


Figure 3. Dismantling a computer mouse and prioritization parts and activities (week 2).

Student experiences

For quality control of the different courses, we use EvaSys enquiries which are sent out to our students who can grade the course on delivery, feasibility in time, quality of teaching, organization, amount of challenge, and expectation for success. The results of the first student's evaluation (20 respondents) are very high and graded 8.53 out of 10, which is qualified as "very good". The course scores very high compared to other sustainability courses within our curriculum, demonstrating its effectiveness and appeal. Based on the results, students showed a high appreciation of the "quality of teaching, coaching and feedback" scoring 9.36, which refers to the didactical approach of productive failure. Furthermore, the learnings of the "practical skills in the circular economy", and the providing "students with critical design knowledge and skills" was highly appreciated by the students.

Throughout the course, students were highly engaged in making the circular economy more actionable. To get a grip on their understanding and motivation we asked both cohorts of

students to reflect on their project and their own learnings. We analyzed in total 60 written reflections, using NotebookLM (Google, 2024) to generalize, group, and summarize their work. We anonymized all reflections before the data was uploaded in the online tool. The student's reflections were analyzed on (1) learnings within the course, (2) experience of the course, and (3) applicability of the course content in future work:

(1) Learnings: students gained valuable insights into the multi-faceted nature of repair, going beyond simply "making things repairable". They gained a deeper understanding of product architecture through hands-on disassembly activities. The course highlighted the importance of considering the user's perspective in repair, emphasizing the need for clear instructions, accessible designs, and available spare parts. Additionally, students learned about the influence of policy and legislation on repairability, recognizing its potential to drive systemic change.

(2) Course Experience: students consistently praised the hands-on, practical approach of the course. Disassembling and analyzing real products provided valuable learning experiences and sparked curiosity about repair. Some students found the disassembly process initially daunting but ultimately rewarding. The interactive workshops and use of tools like disassembly maps and hotspot mapping facilitated their understanding of repairability.

(3) Future Applicability in Design: students expressed a strong intention to incorporate their learnings into future design practices. They recognize the importance of designing for repairability from the start, integrating user-centered considerations, and balancing repairability with other design factors. Some students plan to explore specific areas further, such as user engagement in repair, policy implications, and the integration of repairability with other circular economy strategies.

Outlook

In the fall of 24/25, we ran the course for the third time and introduced design for recycling (Van Dolderen et al., 2024) as a new concept. Students are introduced to Recycling mapping and explore the discrepancies between design-for-recycling and design-for-repair.

"This course overall is very interesting, and the teaching approach does get you very involved in the project." [Anonymous, 2025]

This continuous improvement ensures the course remains relevant and impactful for future learners. The course was, again, highly appreciated by our students with a score of 8.83 out of 10.

Acknowledgments

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References

Dangal, S., Balkenende, R., Faludi, J., Eisenriegler, S., Reichl, H., Haas, J., Neumerkel, A., Wild, J., Depypere, M., & Opsomer, T. (2019). *Design for physical durability, diagnosis, maintenance, and repair*, deliverable 4.3, EU Horizon 2020, PROMPT project.

Dangal, S., Faludi, J., & Balkenende, R. (2022). Design Aspects in Repairability Scoring Systems: Comparing Their Objectivity and Completeness. *Sustainability,* volume 14.

De Fazio, F., Bakker, C., Flipsen, B., & Balkenende, R. (2021). The Disassembly Map: A new method to enhance design for product repairability. *Journal of Cleaner Production*, volume 320.

Flipsen, B., Bakker, C. & van Bohemen, G., (2016)."Developing a reparability indicator for electronic products", Electronics Goes Green 2016+ (EGG), Berlin, Germany, 2016.

Flipsen B., Bakker, C., & de Pauw, I. (2020). "Hotspot Mapping for product disassembly: A circular product assessment method," Electronics Goes Green.

Flipsen, B. (2023). *Hotspot mapping – user guide,* lecture notes for Repair (ID5422).

FRI (2022). *Instructions manual for the display and the calculation of the repairability index of electrical and electronic equipments*, Ministere de la Transition ecologique

Google (2024-Dec 1), *Notebook LM, retrieved from: https://notebooklm.google.com/*.

Kapur, M., & Bielaczyc, K. (2012). *Designing for productive failure*, Journal of the Learning Sciences*, 21*(1).

Persaud, S., & Flipsen, B., (2023). *Productive Failure Pedagogy in Engineering Mechanics*. E&PDE 2023, 7-8 sept., Elisava University, School of Design and Engineering, Barcelona.

Pozo Arcos, B., Dangal, S., Bakker, C., Faludi, J., & Balkenende, R. (2021). Faults in consumer products are difficult to diagnose, and design is to blame: A user observation study, *Journal of Cleaner Production*, volume 319.

Van den Berge, R., Magnier, L., & Mugge, R. (2023). Sparking the Repair "Can-Do" Attitude: Enhancing Users' Willingness to Repair through Design Support in Fault Diagnostics. *International Journal of Design*, 17:3.

Van Dolderen, D.C., Aghaeian S., Bakker, C.A., & Balkenende, R. (2024). *Design for Recycling of Electronics: The Urgent Need for Better Methods*, Electronics Goes Green 2024+ (EGG), Berlin, Germany, June 18-20.

Extended Abstract
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From Clicks to Circular Behavior: A Smart City Mobile Application Leveraging AI and Gamification

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Keywords: Circular Economy; Behavior Change; Gamification; Artificial Intelligence; Smart City Mobile Application.

Introduction

To address today's environmental risks, the circular economy can help to establish new economic models that conserve resources and contribute to climate protection (EC 2020). While efforts often focus on production, consumption patterns are equally crucial for circular transformation (ibid). Fostering circular behaviors remains challenging, as behavior change requires overcoming entrenched routines and societal norms (Muranko et al., 2018).

Digital solutions have increasingly gained attention as tools to encourage more sustainable consumption behaviors (e.g., Berger et al., 2022; Hedin et al., 2019). However, two challenges remain: first, most tools address only isolated phases of the consumption cycle—such as product scanning tools that support information acquisition—without supporting users holistically across acquisition, use, and return or disposal. Second, the growing number of separate apps and platforms risks overwhelming users, making it difficult to navigate and engage meaningfully with circular practices.

From a circular consumption perspective, however, it is important to consider all phases of the product lifecycle to extend product lifespans, recover materials, and reduce emissions (Ellen MacArthur Foundation 2013).

Against this background, this research explores how digital tools can engage users comprehensively across the entire circular customer journey. Employing a design science research (DSR) approach (van Aken & Romme, 2009), it proposes a mobile app that integrates circular strategies across several lifecycle stages. Further, the app seeks to bundle key functionalities within one platform and reach users at a critical touchpoint—when they are already considering disposal and thus more receptive to reuse, repair, or conscious acquisition alternatives.

Theoretical Background

A Circular Perspective on the Customer Journey

The traditional customer journey—typically divided into pre-purchase, purchase, and post-purchase phases (Lemon & Verhoef, 2016)—offers useful insights into consumer behavior but overlooks key aspects of circular consumption. It often fails to capture the complexity of circular models, such as feedback loops, iterative decisions, and rebound effects (Lange et al., 2023). Moreover, it does not consider continued product use by others—a central strategy for closing material loops and extending product lifespans (Kirchherr et al., 2023). This research adopts a circular perspective on the customer journey, combining lifecycle-focused approaches with consumer decision-making by incorporating the R-strategies of the circular economy, such as refuse, reduce, reuse, repair, and recycle (Murakami et al., 2010; Potting et al., 2017).

Digital Tools for Circular Behavior Change

Digital tools for fostering circular behavior span various technologies, including software, platforms, and applications, and are categorized here by main purpose: promoting behavior change or enhancing awareness and knowledge.

Many behavior change tools target specific consumption phases. Examples include apps or platforms providing sustainable product suggestions, waste reduction tips, or repair and recycling guidance—often supported by AI or chatbots (Behrendt, Henseling & Sievi, 2024).

Tools for education and knowledge-building raise awareness and promote circular thinking through interactive serious games,

gamification, and immersive augmented or mixed reality applications (Jääskä, Aaltonen, & Kujala, 2021; Katika et al., 2022; Whalen et al., 2018).

Methodology

This study employs a DSR approach to foster circular behavior through the development of a multifunctional mobile app for a pilot city. DSR addresses practical challenges by iteratively designing and testing interventions in real-world contexts (van Aken & Romme, 2009). Figure 1 depicts the DSR cycle for this study (adapted from Brown et al., 2021; Coffay & Bocken, 2023).

Identification of Problem and Definition of Objectives for Solution

The DSR cycle began with a problem and objective definition, informed by literature and existing tool analysis. These revealed a lack of integrated digital solutions supporting circular behavior across the full consumption cycle. Expert and practitioner input clarified user needs and behavioral barriers, highlighting the value of a multifunctional tool that reaches users at key moments of the circular customer journey. The app builds on an existing municipal waste app and engages users when they are already considering disposal, opening a potential window of opportunity for reuse, repair, or sustainable purchase. The goal is to offer actionable support within a familiar infrastructure.

Design and Development

The tool was developed iteratively, guided by literature and practice. Initial concepts were shaped in team workshops, followed by Figma-based screens and a click dummy. The first functional prototype is currently being implemented by an external developer; a second iteration will follow user testing.

Demonstration, Evaluation, and Communication

The demonstration and evaluation follow a two-stage process combining expert input and user feedback. In 2024, the concept was tested through expert interviews and workshops with AI, gamification, and waste experts, alongside focus groups with residents of the German pilot city, a mid-sized urban area with an existing municipal waste management app, providing an ideal context for real-world testing and integration. A Figma-based click dummy supported early usability testing.

In 2025, the functional prototype is being tested through interviews and focus groups. These results will be presented at the PLATE Conference 2025.

A second prototype iteration will broaden testing through additional interviews and surveys beyond the pilot city and explore how the app functionalities interact. Insights will inform further refinements before public release in 2026.

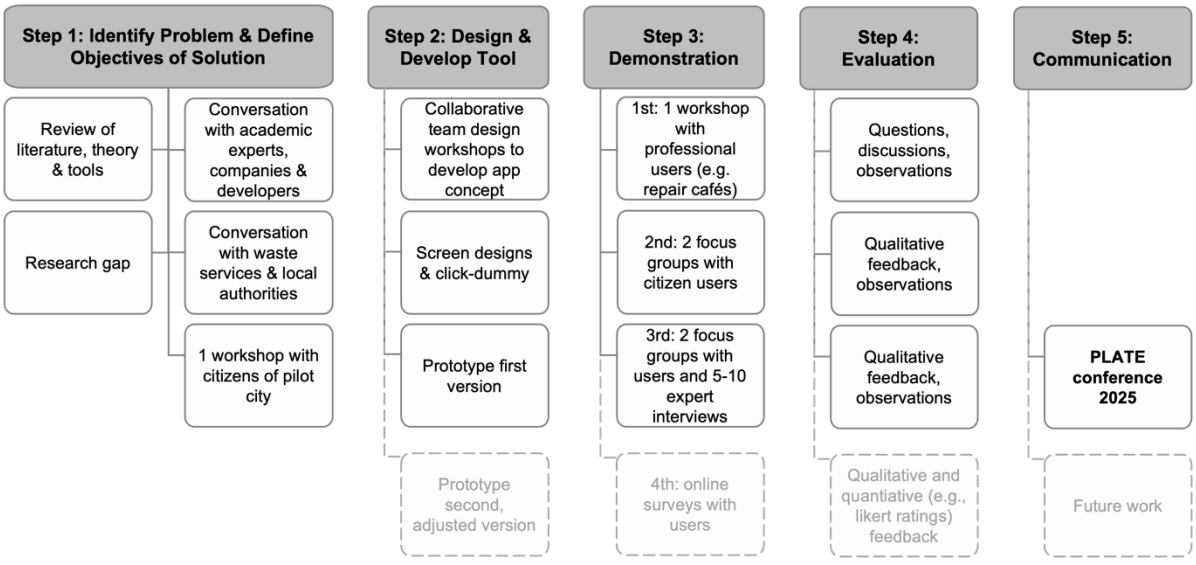


Figure 1. DSR cycle

Preliminary Results

The app integrates AI (module 1) and gamification (module 2) to support circularity across multiple stages of the consumer lifecycle. The AI module targets electronics, textiles, and furniture, primarily supporting mid-level R-strategies like reuse, repair, and refurbish, while also offering tailored guidance on disposal and recycling. The gamification module focuses on organic waste, especially food, aiming to improve sorting, and resource-saving behaviors. Both modules promote early-stage R-strategies such as refuse, rethink, and reduce through shopping tips and product information.

Module 1 leverages AI to support sustainable consumption decisions. Using image recognition or text input, it identifies products, assesses product conditions via follow-up questions, and delivers recommendations. Users are connected to local services like repair shops, resale platforms, or recycling centers through a map interface with location-based matching and contact options.

Module 2 uses gamification to enhance bio-waste sorting through interactive challenges, point-based rewards, and real-time feedback from sensor-equipped waste trucks. Users progress through learning levels on topics such as correct sorting, compost use, and the broader relevance of organic waste.

Together, both modules form a multifunctional system combining interactive engagement with data-driven insights, empowering residents to contribute to circular economy goals. By integrating the tool into an existing municipal waste app, it reaches users at a key moment, that is, when they are already thinking about disposal and potentially open to circular alternatives.

While implementation is currently limited to a single pilot city, future research should explore its broader applicability, long-term behavioral impact, and whether a single digital touchpoint can sustainably foster circular practices. The app is designed to be scalable and adaptable for other smart cities, offering a replicable solution to promote circular behavior.

References

Behrendt, S., Henseling, C., & Sievi, M. (2024). Bestandsaufnahme und Analyse der vorhandenen digitalen Ansätze zur Förderung eines nachhaltigen, zirkulären Konsums: Kurzfassung im Rahmen des Projektes "Konzeption und Planung digitaler Lösungen zur Förderung von nachhaltigem Konsum für eine Kreislaufwirtschaft." Internal Project Report. IZT, Berlin.

Berger, M., Lange, T., & Stahl, B. (2022). A digital push with real impact–Mapping effective digital nudging elements to contexts to promote environmentally sustainable behavior. Journal of Cleaner Production, 380, 134716. https://doi.org/10.1016/j.jclepro.2022.134716

Brown, P., Baldassarre, B., Konietzko, J., Bocken, N., Balkenende, R. (2021). A tool for collaborative circular proposition design. Journal of Cleaner Production, 297, 126354. https://doi.org/10.1016/j.jclepro.2021.126354.

Coffay, M., Bocken, N., 2023. Sustainable by design: an organizational design tool for sustainable business model innovation. Journal of Cleaner Production, 427, 139294. https://doi.org/10.1016/j.jclepro.2023.139294.

Ellen MacArthur Foundation (2013). Towards the circular economy Vol. 2: Opportunities for the consumer goods sector.

European Commission (EC) (2020). A new Circular Economy Action Plan. For a cleaner and more competitive Europe. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

Hedin, B., Katzeff, C., Eriksson, E., & Pargman, D. (2019). A systematic review of digital behaviour change interventions for more sustainable food consumption. Sustainability, 11(9), 2638. https://doi.org/10.3390/su11092638

Jääskä, E., Aaltonen, K., & Kujala, J. (2021). Game-based learning in project sustainability management education. Sustainability, 13(15), 8204. https://doi.org/10.3390/su13158204

Katika, T., Karaseitanidis, I., Tsiakou, D., Makropoulos, C., & Amditis, A. (2022). Augmented reality (AR) supporting citizen engagement in circular economy. Circular Economy and Sustainability, 2(3), 1077-1104.

Kirchherr, J., Yang, N. H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the circular economy (revisited): An analysis of 221 definitions. Resources, Conservation and Recycling, 194, 107001. https://doi.org/10.1016/j.resconrec.2023.107001

Lange, S., Frick, V., Gossen, M., Pohl, J., Rohde, F., & Santarius, T. (2023). The induction effect: Why the rebound effect is only half the story of technology's failure to achieve sustainability. Frontiers in Sustainability, 4, 1178089. https://doi.org/10.3389/frsus.2023.1178089

Lemon, K. N., & Verhoef, P. C. (2016). Understanding customer experience throughout the customer journey. Journal of Marketing, 80(6), 69-96. https://doi.org/10.1509/jm.15.0420

Murakami, S., Oguchi, M., Tasaki, T., Daigo, I., & Hashimoto, S. (2010). Lifespan of commodities, part I: The creation of a database and its review. Journal of Industrial Ecology, 14(4), 598-612. https://doi.org/10.1111/j.1530-9290.2010.00250.x

Muranko, Z., Andrews, D., Newton, E. J., Chaer, I., & Proudman, P. (2018). The pro-circular change model (P-CCM): Proposing a framework facilitating behavioural change towards a circular economy. Resources, Conservation and Recycling, 135, 132-140. https://doi.org/10.1016/j.resconrec.2017.12.017

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular economy: Measuring innovation in the product chain. Planbureau voor de Leefomgeving.

Van Aken, J. E., & Romme, G. (2009). Reinventing the future: Adding design science to the repertoire of organization and management studies. Organization Management Journal, 6(1), 5-12. https://doi.org/10.1057/omj.2009.1

Whalen, K. A., Berlin, C., Ekberg, J., Barletta, I., & Hammersberg, P. (2018). 'All they do is win': Lessons learned from use of a serious game for circular economy education. Resources, Conservation and Recycling, 135, 335-345. https://doi.org/10.1016/j.resconrec.2017.06.021

Materials and Longevity

Research paper
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Exploring Material Potentials for Product Design: In Pursuit of a Narrative-Based Approach

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Keywords: DIY Materials; Material Driven Design; Materials Narrative; Material Potentials.

Abstract: This research proposes a narrative-based approach and two corresponding strategies as part of an interdisciplinary project. The approach could be an initial step in understanding the user's first impression concerning materials experience and other material potentials, informing designers about translating them into product design decisions. The project combines Material-Driven Design (MDD) and user-centred research methods to develop composite Do-it-Yourself (DIY) materials by upcycling textile and plastic wastes. It aims to transform these materials into seven products designed for office environments that promote sustainability. The project's design brief includes the product's primary function, context, and target group. However, the MDD process follows the material exploration to decide on the product proposals formed towards the end. That calls for an alternative method that adapts MDD to broader product development scenarios, particularly those guided by a predefined design brief, to enhance the value of Materials Experience (MX) in conventional design processes. This research initially implements a design probe study to address this gap and to understand forty-six office worker participants' first impressions of DIY material. Based on the study's findings and initial material tinkering process within the research group, a need for a contextual elaboration of materials to address material potentials holistically, including experience, form, function, and affordance, became apparent. Hence, a narrative-based approach is grounded with materials agency in mind and strengthened with anthropomorphism and material journey mapping strategies to obtain insights for the abovementioned scenarios.

Introduction

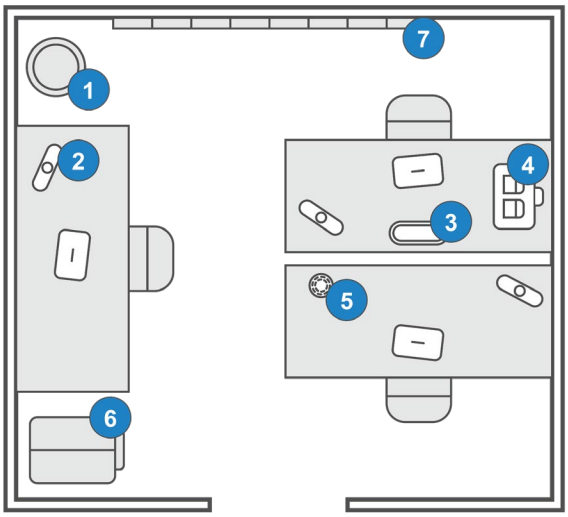
Designers increasingly participate in developing materials by exploring beyond form and function, considering experiential aspects and affordances (Barati & Karana, 2019). This shift enables sustainable alternatives (Vezzoli, 2014) and enhances product experiences within the user-centred design (Pedgley, 2014). Benefiting from the novel perspectives of Materials Experience (MX) (Karana, Pedgley et al., 2015), this research emerges from an interdisciplinary project developing Do-it-Yourself (DIY) composite materials (Rognoli et al., 2015) from polyethene (plastic bottle caps) and textile wastes. Aiming for material circularity (Moreno et al., 2016), the project combines Material Driven Design (MDD) (Karana, Barati et al., 2015) with user-centred research methods (Williams, 2009), involving design, textile engineering, and interior architecture experts (Efilti et al., in press).

During MDD, several user studies with materials are conducted. Accordingly, this paper first reports the findings of a part of a design probe pilot study with forty-six office workers. Based on these results and material explorations, we highlight the need for a narrative-based approach to investigate DIY material potentials—including form, function, and affordance—in scenarios with predefined design briefs, similar to our case. Therefore, this research aims to ground a narrative-based method for investigating material potentials where a predefined design brief is present by integrating strategies of material anthropomorphism and material journey mapping.

Research Context

Office environments were selected due to their potential role in promoting sustainable behaviours through design and product use (Stringer, 2010). The product line-up (Figure 1) addresses daily workspace needs, showcasing composite materials' versatility in function, structure, and usability. Starting with the commonly practised act of collecting bottle caps in Türkiye, the project aims to offer tangible

feedback to users by transforming collected bottle caps into useful products for sustainable behaviour change (Lilley, 2009).



1 Recycling Unit
2 Lighting Unit
3 Desktop Organiser
4 Personal Bag
5 Speaker
6 Cat House
7 Wall Panel

Figure 1. A plan drawing showing the products in an office interior.

Developing Materials

The global rise in plastic production highlights plastic's crucial role in everyday life due to its durable properties and cost-effectiveness. Extensive use and low recycling rates pose significant environmental risks, necessitating sustainable management strategies (Pandey et al., 2023). Recycling plastics presents a viable solution to mitigate pollution (Murat et al., 2020), with polyethene (PE) and polypropylene (PP) prominent in plastic waste streams (Streit et al., 2022). International polymer trade is predominantly influenced by PE, which is widely used in products like bottles and containers (Felgel-Farnholz et al., 2023).

Similarly, substantial cotton fabric waste is generated due to the growing global demand for cotton-based textiles. Challenges in transportation logistics and inefficient sorting and purification technologies hinder recycling, resulting in millions of tons being disposed of in landfills or incinerated globally (Tang et al., 2023).

Design practices can address these issues using innovative approaches such as DIY materials, allowing designers to repurpose waste through sustainable individual or collective initiatives (Rognoli et al., 2015). DIY materials fall into five categories (Ayala-Garcia et al., 2017), and the fourth category, waste-derived materials—including our composite—is notable for reflecting designers' sustainability focus and resource-conscious innovation. These materials promote material longevity by extending waste materials' lifespan and delaying disposal through upcycling (Santulli & Rognoli, 2020; Goldsworthy et al., 2018). From this perspective, plastic and cotton wastes were combined into composites.

For DIY material development, polyethene packaging, such as bottle caps and detergent bottles, was collected, cleaned, ground, or left intact and melted at 160°C under varying pressure using a hydraulic lamination heat press (Figure 2).

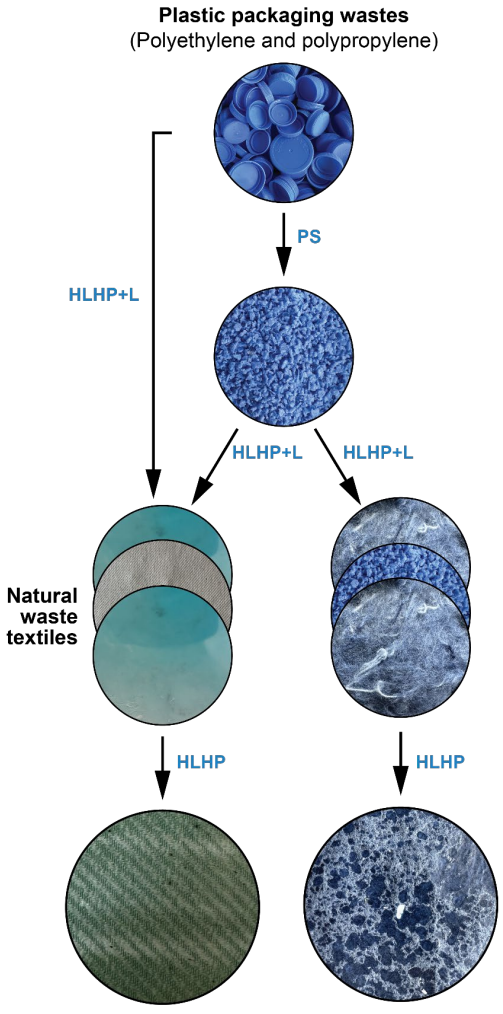


Figure 2. A diagram showing the production process of the materials.

That produced linear PE plates of varying thicknesses and colours, combined with various

fabrics to create composite structures. Using different forms (layers, fibres), materials (cotton, jute, flax), and weavings (twill, basketweave) of textiles, we aimed to develop diverse material proposals. Among explored combinations, the twill-weaved cotton fabric paired with high-density PE sheets arranged in varying layer counts proved most promising for further application (see Figure 2, left end). We proceeded to product development after identifying optimal composite compositions through initial experiments.

Developing Products

MX refers to how users interact with materials experientially and functionally, subjectively involving senses (sensorial level), meanings (interpretive level), emotions (affective level), and actions (performative level), depending on the object, context, and time factors (Giaccardi & Karana, 2015). Seeking meaningful MX, MDD provides designers with a structured method to explore material potentials—form, function, experience, and affordance—through four stages: understanding the material, envisioning experiential potentials, forming experience patterns, and developing product concepts (Karana, Barati, et al., 2015). MDD aligns well with DIY materials, providing an analytical, traceable approach to create meaningful material experiences and uncover new potentials (Karana et al., 2018).

The project's steps were planned to be conducted in two parallel channels: user-centred research and MDD. In the MDD channel, initial material studies began with visits to the material production lab. Then, a digital material chart study was conducted, primarily focusing on the two main components of the composite materials developed in the research. The primary purpose of this study was to inventory the materials expected to be used in the products. The MDD process began with technical characterisation, subjecting the materials to various tests to become familiar with their properties. Through multiple experiments, it was anticipated how the materials behaved under specific effects (e.g., burning, bending, punching, etc.). Then, the subsequent experiential characterisation within the research group members was conducted to have an initial idea of what to expect regarding experiential qualities.

The research group was already familiar with the material, and the design brief was at hand. That made pursuing the usual MDD process, which follows the material exploration to decide on the product proposals, inefficient for our case. Therefore, following the remaining MDD steps intact became less applicable to the project, highlighting the need for a complementary study to feed the remaining process for deeper insights.

Finding the Right Research Method

For our proposal of a narrative-based approach for investigating materials, we primarily benefited from analysing the pilot design probe study to ground our proposal and visited the narratives and materials agency. Also, it is worth noting that the Meanings of Materials (MoM) tool (Karana et al., 2010) and the Materials-to-Experiences at Four Levels (Ma2E4) toolkit were influential throughout the study, as the authors advised for MDD (Camere & Karana, 2018).

Pilot Study: Design Probe

Probing is a research approach that sensitises participants to observation. It leads them to reflect on, verbalise, and visualise their experiences and actions through various descriptive and exploratory tasks (Mattelmäki, 2008). A probe package is designed to comprehend the experiences of recycling, collective working, individual working, leisure time and interaction with non-humans in different office environments (see Efilti et al., in press for the details of the other pages of the probe kit).

Research Design, Data Collection and Analysis

The probe packages were distributed across ten professional office environments (ten separate firms). Five office workers from each office completed the tasks, resulting in 46 participants (n=46).

Besides tasks conducted over the first four days to understand users' perspectives toward predefined experiences, each design probe kit included an identical final-day task explicitly dedicated to material exploration. In this final task, participants interacted freely with a given DIY composite material sample (25×60×3 mm) taped to the page's right side (Figure 3). Participants were then prompted to reflect on their impressions and feelings through structured questions.

The structured task consisted of answering six questions (Table 1). The first question allowed participants to freely associate adjectives with

the material without directives. Questions 2, 3, and 4 were adapted from the Ma2E4 toolkit to gather targeted insights about pleasant, disturbing, and unique qualities. Questions 5 and 6 aimed to reveal participants' associative impressions about possible material resemblances and their potential for products.

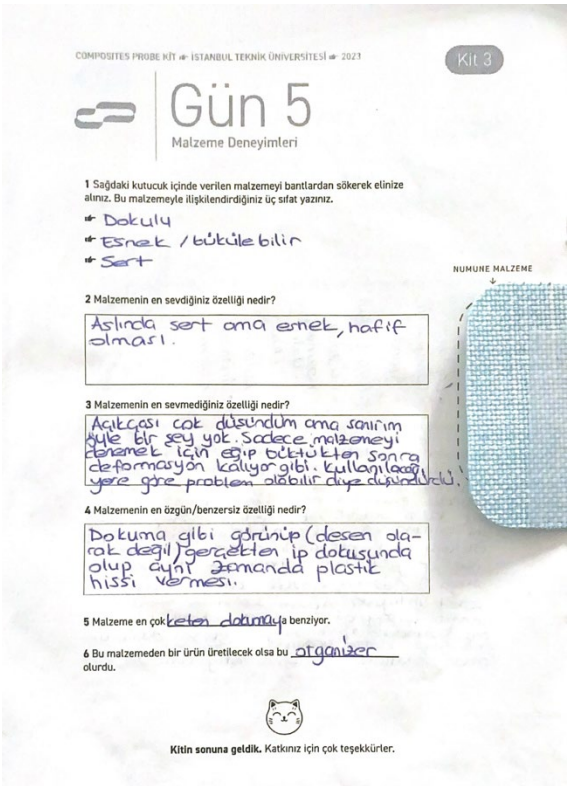


Figure 3. An image showing the last page of the design probe study with a material sample (in Turkish).

Take the material by removing it from the tapes given in the frame on the right.
1. Write three adjectives that you associate with this material.
2. What is the most pleasant quality of the material?
3. What is the most disturbing quality of the material?
4. What is the most unique quality of the material?
5. The material is like …
6. If a product were to be produced with this material, it would be …

Table 1. Tasks and questions on the final page of the design probe study.

Participant responses were qualitatively analysed by coding descriptive keywords, phrases, and comments in two interconnected channels:

- First, guided by the MX framework and its four levels (sensorial, interpretive, affective, and performative), the analysis identified keywords used by participants to describe the material experientially.
- Second, it focused on other material potentials because the data included more than MX-related comments. Participants moved beyond and further commented on the sample's other potentials, thinking of its embodiment as products.

The analysis revealed that participants primarily engaged with the material's visual and tactile qualities (sensorial keywords, 136 codes), with limited references to auditory aspects (1 code). Adjectives describing meanings (interpretive keywords) like *plastic* or *sustainable* appeared in 36 codes, while emotions (affective keywords) like *surprising* or *comforting* were noted in 12 codes (Figure 4). Rather than specific coding of performative level (action-related) insights such as *rubbing*, *scratching*, and *bending*, they were derived from evaluating the probe study concerning senses (e.g., bent because it is found stiff).

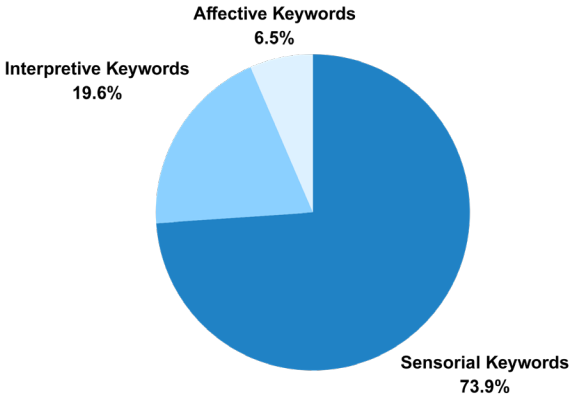


Figure 4. A pie chart showing the distribution of keywords of experiential levels.

Responses to the final two probe questions, designed to explore material potentials, highlighted participants' considerations of function and form. Functional qualities emerged in 68 codes, form-related aspects in 19 codes, and experiential qualities in 15 codes. It contrasted with the earlier probe responses to the first four questions, where experiential qualities (185 codes) were emphasised over functional aspects (13 codes). The study underscores the shift in focus from material qualities to contextual applications when participants are prompted to imagine material embodiment (Figure 5).

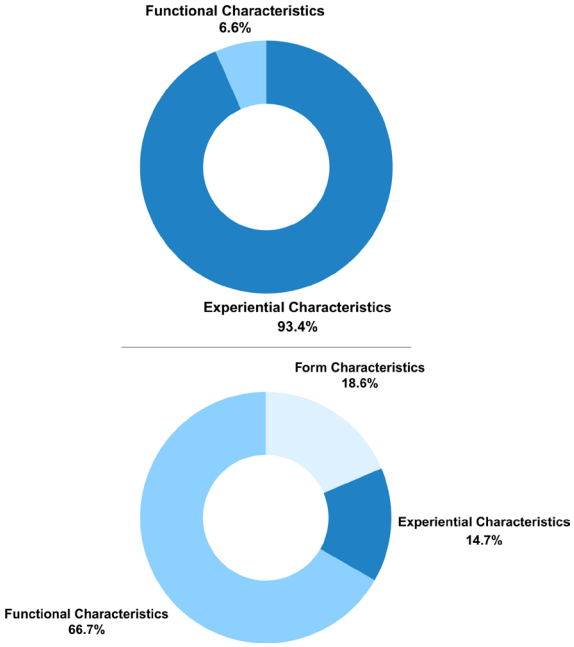


Figure 5. Two charts compare the emergence of material characteristics in the answers (Top: One to four; Bottom: five and six).

Points to Take from Pilot Study

Our exploration confirmed that our materials are primarily perceived through visual and tactile senses, as established by the MoM tool and supported by the design probe study.

Instead of focusing on meaning-driven material selection or altering material development, our research prioritises understanding how meanings and emotions, independent of specific sensorial qualities, can inform design decisions. To achieve this, we aim to assess how the sensorial level influences meanings and emotions instead of directly evaluating them on a scale (like in the Ma2E4 toolkit).

Since we did not give any background information or vocabulary to choose from, the participants were free to answer the questions as they wished. That led to intertwined assessments in terms of experiential levels rather than levelled and separate evaluations, which were more valuable in our case to feed design decisions. Furthermore, concerning all of the answers given on a probe page, the whole experience with the material presents a cohesive story concerning the materials' performative, affective and interpretive levels yet lacked detail due to the probe's scope. Therefore, the intertwined and cohesive assessments of experiential levels (senses, meanings, emotions and actions) could provide a holistic understanding of a material's experience.

On the other hand, although obtained emotion keywords were limited and often implicitly embedded in the answers, not providing them for experiential level participants and guiding participants to think towards such keywords could yield less obtrusive and richer results. For example, attributed meanings (interpretive level) by participants differentiated while analysing the probe study. We found different categories for meanings, going from shallow to deep, such as ambiguous expressions, comparative expressions, sensorial expressions, metaphorical expressions and contextual expressions, which could enrich the method proposal by providing different ways of obtaining meanings towards materials.

Most importantly, experiential qualities do not yield enough knowledge for us since the material is not the only focus and is separated from its context of being a product. Examining other material potentials could enrich these by shifting the focus from materials to products. The probe kit showed that the participants envisioned what materials could become despite not knowing the material's capabilities. The primary consideration has shifted from experiences to include function and form when it comes to the contextualisation of the material. Benefiting from that and our product proposals, including other material potentials, could help us understand the connection between all material potentials. Considering the contextualisation of material without concrete products, participants must be immersed in contextual representations to get context-driven insights regarding materials and their potential. Consequently, the findings from our pilot study underscored participants' holistic engagement with the materials, highlighting the importance of context for exploring material potentials. These insights prompted us to revisit narratives and material agency to develop complementary strategies.

Revisiting Narratives and Material Agency

Narratives and storytelling are subjects studied in depth within design research, and they can immerse people in contextual settings to investigate design possibilities (Coulton et al., 2017; Grimaldi et al., 2013). Regarding the investigation of materials, narratives are addressed in terms of their importance in understanding MX in a timeframe (Pedgley, 2021), enhancing materials knowledge and

materials selection (César Dutra & Schmid Calvão, 2024) and teaching sustainability regarding materials (Hasling & Ræbild, 2021) in design education, as well as communicating material characteristics (Rognoli et al., 2022) and materials visualisation (Alan & Pedgley, 2024). Two research papers used the power of material narratives in understanding material qualities. First, *The Material Connaissance* framework shows how storytelling and metaphor can convey sensory and emotional dimensions while encouraging co-creation and a deeper understanding of material interactions (Bofylatos & Boukouvala, 2023). Second, Landwehr Sydow et al. (2017) emphasise the significance of conceptualising materials as dynamic entities with histories and trajectories. They propose using narratives to integrate the sensory, emotional and functional aspects of material experience.

We reviewed numerous studies during this process to help us adopt a strategy. One of the most prominent and recent is material agency, referring to the capacity of materials to act or influence outcomes within a system (Bennett & Frost, 2010; Haraway, 2003; Ingold, 2012), acknowledging their *identities* and *biographies* (Rognoli et al., 2022) despite such notions being usually attributed to humans. Acknowledging materials as entities with their own agency (Parisi & Rognoli, 2016) that could help in qualitative research (Giaccardi et al., 2016), we identified anthropomorphism and personification (Iovino, 2015; Park & Nam, 2015; Wu et al., 2023) (of materials) as valuable strategies to let participants think in materials agency in a way that is easier to relate to and resonate with for the broader aim of immersing them in contextual narratives. Consequently, participants start thinking about the experiential qualities of materials through personal traits and actions by creating an *anthropomorphised material* that forms a smooth entry to a storyworld. Building upon our initial strategy, we then reinterpreted *material journey mapping* (Aktaş, 2023) to align with personification by positioning materials as actors taking an active role in shaping contexts and having a word on deciding its transformation.

In summary, we identified anthropomorphism and material journey mapping as strategic tools by recognising the importance of material agency and the narrative framing of materials. Based on these strategies, the following section aligns our narrative approach explicitly with the study's findings.

Discussion: In Pursuit of a Materials Narrative

We have yet to shape a detailed research design to decide which narrative method to use or how to implement the strategies. Nevertheless, this section discusses the alignment between the pilot study analysis and 1) a proposal for a narrative-based approach for the overall framework, 2) material anthropomorphism as the first strategy to enter the narrative and 3) material journey mapping as the second strategy to continue the narrative by considering material's becomings (Figure 6). The logic behind each alignment to meet our needs for holistically investigating all material potentials is explained accordingly.

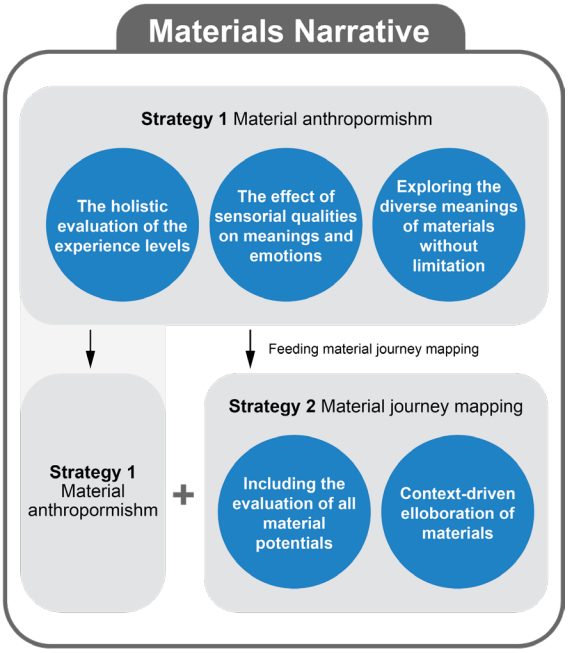


Figure 6. A diagram showing the outcomes of the design probe study and their alignment with the strategies for a narrative-based approach.

First, the research indicates that when the design briefs are predefined, following the MDD method intact remains irrelevant in generating deeper user-centred insights for product design ideas and exploring the interplay between materials, envisioned products, predefined users and the context in this specific case. Furthermore, the design probe study's findings suggest that the sensations, emotions, and actions a material evokes are inseparable and intertwined. Also, it emphasises the importance of considering how a material's other potentials beyond experience contribute to its ontology.

Lastly, it demonstrates that situating materials within realistic contexts is essential for fully comprehending their potential. In that regard, narratives can be helpful research tools for us to address such challenges and potentials by immersing participants in contextual settings, allowing them to think towards materials engagingly and imaginatively. That addresses our need for a deeper exploration of design possibilities with the materials at hand beyond exploring material possibilities.

Our first strategy of anthropomorphism stems from the idea of materials agency but in a more relatable way. Although anthropomorphism might appear reductionist, it facilitates a more relatable connection between the material and evaluators, leveraging metaphorical thinking and human tendencies toward empathy and understanding (Epley et al., 2007). Through this strategy, we address the probe's three findings regarding the experiences of materials. Namely, they are a) the holistic evaluation of the experience levels, b) the effect of sensory qualities on meanings and emotions, and c) exploring the diverse meanings of materials without limitation. When a human perceives material through their senses, it becomes the foundational input for creating meanings, eliciting emotions, and influencing behaviours (Karana et al., 2009). Using the power of metaphors, assigning human traits and behaviours to materials can be an effective tool in obtaining insights regarding meanings, emotions, and actions based on sensory interactions driven by creativity. By personifying materials, people can elaborate on them in a more relatable way, and the richness of experiential vocabulary could be enhanced through appropriate research design and prompts.

Following the first, our second strategy in the narrative is framed as *material journey mapping*, in which we reinterpreted the stages by Aktaş (2023), which investigates the materials' becomings in stages and corresponding systems. By focusing on the *design process* and *use phase*, we aligned it with the insights we took from the design probe study: d) including evaluating all material potentials and e) context-driven elaboration of materials. We employed anthropomorphism as the initial step, allowing us to envision the material as an active participant in office environments. By framing the material as a conversation starter and co-creator of interactions, we could effectively explore context-driven factors such as form, function, and affordance. It also can further enrich our understanding of the material's experiential potential. Mapping each stage of the material journey enables designers to see how materials evolve, respond to contexts, and inform design decisions.

Conclusion

This paper discusses an interdisciplinary project aimed at upcycling textile and plastic packaging waste into DIY materials through Material-Driven Design (MDD) and user-centred research. It emphasises the value of a narrative-based approach supported by anthropomorphism and material journey mapping.

The study has certain limitations: firstly, the narrative method and strategies rely on the researchers' interpretative analysis and need further empirical grounding; secondly, alternative methodological strategies could be derived from the current data; finally, the pilot study's design and analysis influenced the research direction, leaving it open to reinterpretation. Future research should address these limitations through detailed methodological justification and clear demonstrations of practical implementation.

Acknowledgements

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References

Aktaş, B. M. (2023). Following a material's journey to unravel becomings and systems in human-material interaction. In C. May (Ed.), *Proceedings of Relating Systems Thinking and Design (RSD12) Symposium* (pp. 1–26). Systemic Design Association.

Alan, A. C., & Pedgley, O. (2024). Visualising speculative materials: Using text-to-image prompting to elaborate livingness as a designed material quality. In H. Grierson, E. Bohemia, & L. Buck (Eds.), *Proceedings of the International Conference on*

Engineering and Product Design Education, EPDE 2024 (pp. 306–311). The Design Society. https://doi.org/10.35199/EPDE.2024.52

Ayala-Garcia, C., Rognoli, V., & Karana, E. (2017). Five kingdoms of DIY-materials for design. *EKSIG 2017 Alive Active Adaptive: International Conference on Experiential Knowledge and Emerging Materials*, 222–234.

Barati, B., & Karana, E. (2019). Affordances as materials potential: What design can do for materials development. *International Journal of Design*, *13*(3), 105–123.

Bennett, J., & Frost, S. (Eds.). (2010). *New Materialisms: Ontology, Agency, and Politics*. Duke University Press.

Bofylatos, S., & Boukouvala, N. (2023). Material connaissance as a tacit knowledge co-creation method. In D. De Sainz Molestina, L. Galluzzo, F. Rizzo, & D. Spallazzo (Eds.), *IASDR 2023: Life-Changing Design*. Design Research Society. https://doi.org/10.21606/iasdr.2023.427

Camere, S., & Karana, E. (2018). Experiential Characterisation of Materials: toward a toolkit. In C. Storni, K. Leahy, M. McMahon, P. Lloyd, & E. Bohemia (Eds.), *Design as a catalyst for change - DRS International Conference 2018*. DRS. https://doi.org/10.21606/drs.2018.508

César Dutra, J., & Schmid Calvão, P. (2024). Transmedia storytelling in materials selection design: an interdisciplinary experience with undergraduate engineering students. *European Journal of Engineering Education*, *49*(4), 716–733. https://doi.org/10.1080/03043797.2024.2311166

Coulton, P., Lindley, J., Sturdee, M., & Stead, M. (2017). Design fiction as world building. *Proceedings of the 3nd Biennial Research Through Design Conference*, 1–16. DOI: 10.6084/m9.figshare.4746964.

Efilti, P., Gelmez, K., Alan, A. C., Yılmaz, O., Gürel, R., Çelikoğlu, Ö., & Cordan, Ö. (in press). Participatory design research for sustainability: A design probe study from creative collaboration to the design inspiration. *Proceedings of DESIGNA2024 International Conference on Design Research*.

Epley, N., Waytz, A., & Cacioppo, J. T. (2007). On seeing human: A three-factor theory of anthropomorphism. *Psychological Review*, *114*(4), 864–886. https://doi.org/10.1037/0033-295X.114.4.864

Felgel-Farnholz, A., Schweighuber, A., Klampfl, C. W., & Fischer, J. (2023). Comparative study on the degradation of HDPE, LLDPE and LDPE during multiple extrusions. *Polymer Degradation and Stability*, *216*, 110486. https://doi.org/10.1016/j.polymdegradstab.2023.110486

Giaccardi, E., Cila, N., Speed, C., & Caldwell, M. (2016). Thing ethnography: Doing design research with non-humans. *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 377–387. https://doi.org/10.1145/2901790.2901905

Giaccardi, E., & Karana, E. (2015). Foundations of materials experience: An approach for HCI. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2447–2456. https://doi.org/10.1145/2702123.2702337

Goldsworthy, K., Earley, R., & Politowicz, K. (2018). Circular speeds: A review of fast & slow sustainable design approaches for fashion & textile applications. *Journal of Textile Design Research and Practice*, *6*(1), 42–65. https://doi.org/10.1080/20511787.2018.1467197

Grimaldi, S., Fokkinga, S., & Ocnarescu, I. (2013). Narratives in design: A study of the types, applications and functions of narratives in design practice. *Proceedings of the 6th International Conference on Designing Pleasurable Products and Interfaces*, 201–210. https://doi.org/10.1145/2513506.2513528

Haraway, D. (2003). *The Companion Species Manifesto: Dogs, People, and Significant Otherness*. Prickly Paradigm Press.

Hasling, K. M., & Ræbild, U. (2021). Building sustainable material narratives with material pathways. In H. Grierson, E. Bohemia, & L. Buck (Eds.), *Proceedings of the 23rd International Conference on Engineering and Product Design Education (EPDE 2021)* (p. 1105). The Design Society. https://doi.org/10.35199/EPDE.2021.4

Ingold, T. (2012). Toward an ecology of materials. *Annual Review of Anthropology*, *41*(1), 427–442. https://doi.org/10.1146/annurev-anthro-081309-145920

Iovino, S. (2015). The living diffractions of matter and text: Narrative agency, strategic anthropomorphism, and how interpretation works. *Anglia*, *133*(1), 69–86. https://doi.org/10.1515/ang-2015-0006

Karana, E., Barati, B., Rognoli, V., & Zeeuw Van Der Laan, A. (2015). Material driven design (MDD): A method to design for material experiences. *International Journal of Design*, *9*(2), 35–54.

Karana, E., Blauwhoff, D., Hultink, E.-J., & Camere, S. (2018). When the material grows: A case study on designing (with) mycelium-based materials. *International Journal of Design*, *12*(2).

Karana, E., Hekkert, P., & Kandachar, P. (2009). Meanings of materials through sensorial properties and manufacturing processes. *Materials & Design*, *30*(7), 2778–2784. https://doi.org/10.1016/j.matdes.2008.09.028

Karana, E., Hekkert, P., & Kandachar, P. (2010). A tool for meaning driven materials selection. *Materials & Design*, *31*(6), 2932–2941. https://doi.org/10.1016/j.matdes.2009.12.021

Karana, E., Pedgley, O., & Rognoli, V. (2015). On Materials Experience. *Design Issues*, *31*(3), 16–27. https://doi.org/10.1162/DESI_a_00335

Landwehr Sydow, S., Tholander, J., & Jonsson, M. (2017). "It's a bomb!" -- material literacy and narratives of making. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 121–132. https://doi.org/10.1145/3025453.3025529

Lilley, D. (2009). Design for sustainable behaviour: strategies and perceptions. *Design Studies*, *30*(6), 704–720. https://doi.org/10.1016/j.destud.2009.05.001

Mattelmäki, T. (2008). Probing for co-exploring. *CoDesign*, *4*(1), 65–78. https://doi.org/10.1080/15710880701875027

Moreno, M., De los Rios, C., Rowe, Z., & Charnley, F. (2016). A Conceptual Framework for Circular Design. *Sustainability*, *8*(9), 937. https://doi.org/10.3390/su8090937

Murat, B. I. S., Kamalruzaman, M. S., Azman, M. H. N., & Misroh, M. F. (2020). Assessment of mechanical properties of recycled HDPE and LDPE plastic wastes. *IOP Conference Series: Materials Science and Engineering*, *957*(1), 012046. https://doi.org/10.1088/1757-899X/957/1/012046

Pandey, P., Dhiman, M., Kansal, A., & Subudhi, S. P. (2023). Plastic waste management for sustainable environment: techniques and approaches. *Waste Disposal & Sustainable Energy*, *5*(2), 205–222. https://doi.org/10.1007/s42768-023-00134-6

Parisi, S., & Rognoli, V. (2016). Interaction matters. A material agency's perspective on materials experience. In S. Crabu, P. Giardullo, F. Miele, & M. Turrini (Eds.), *6th STS Italia Conference | Sociotechnical Environments* (pp. 675–691). Sts Italia Publishing.

Park, S., & Nam, T.-J. (2015). Product-personification method for generating interaction ideas. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *9*(2), 97–105. https://doi.org/10.1007/s12008-013-0196-x

Pedgley, O. (2014). Materials Selection for Product Experience. In *Materials Experience* (pp. 337–349). Elsevier. https://doi.org/10.1016/B978-0-08-099359-1.00024-2

Pedgley, O. (2021). *ID536 Materials Experience 2021-22 Course Notes (MX Narratives & Frameworks, Week 4)* (pp. 29–33). Middle East Technical University.

Rognoli, V., Bianchini, M., Maffei, S., & Karana, E. (2015). DIY materials. *Materials & Design*, *86*, 692–702. https://doi.org/10.1016/j.matdes.2015.07.020

Rognoli, V., Petreca, B., Pollini, B., & Saito, C. (2022). Materials biography as a tool for designers' exploration of bio-based and bio-fabricated materials for the sustainable fashion industry. *Sustainability: Science, Practice and Policy*, *18*(1), 749–772. https://doi.org/10.1080/15487733.2022.2124740

Santulli, C., & Rognoli, V. (2020). Material tinkering for design education on waste upcycling. *Design and Technology Education: An International Journal*, *25*(2), 50–73.

Streit, A. F. M., de Santana, M. P., de Oliveira Júnior, D. L., Bassaco, M. M., Tanabe, E. H., Dotto, G. L., & Bertuol, D. A. (2022). Development of a pre-treatment process of polymeric wastes (HDPE, LDPE/LLDPE, PP) for application in the qualification of selectors of recyclable materials. *Environment, Development and Sustainability*, *24*(5), 6349–6371. https://doi.org/10.1007/s10668-021-01705-5

Stringer, L. (2010). *The Green Workplace: Sustainable Strategies that Benefit Employees, the Environment, and the Bottom Line*. St. Martin's Press.

Tang, L., Lyu, B., Gao, D., Jia, Z., Zhu, J., & Ma, J. (2023). Waste cotton fabric-derived multimodal heating textile for comfortable and reliable personal thermal management. *Journal of Cleaner Production*, *425*, 138992. https://doi.org/10.1016/j.jclepro.2023.138992

Vezzoli, C. (2014). The "material" side of design for sustainability. In E. Karana, O. Pedgley, & V. Rognoli (Eds.), *Materials experience: Fundamentals of materials and design* (pp. 105–121). Elsevier. https://doi.org/10.1016/B978-0-08-099359-1.00008-4

Williams, A. (2009). User-centered design, activity-centered design, and goal-directed design. *Proceedings of the 27th ACM International Conference on Design of Communication*, 1–8. https://doi.org/10.1145/1621995.1621997

Wu, A. Y., Malter, M. S., & Johar, G. V. (2023). "Recycle me!" Product anthropomorphism can increase recycling behavior. *Journal of the Association for Consumer Research*, *8*(3), 351–363. https://doi.org/10.1086/72499

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Design-ability in the Circular Economy of Textiles

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Keywords: Textile design; Fiber materials; Longevity; Sustainability; Circular Economy.

Abstract: Recent research underscores the importance of longevity, defined as the combination of high and long-term usage frequency and durability, in the textile and fashion industry's shift toward circularity and sustainability. This paper explores and discusses the designer's ability to design for longevity of textiles. Thus, focus is on the potential role of textile designers, examining the extent to which the skills and competencies of the designer may potentially have an actual influence on longevity. Additionally, the paper discusses the systemic context that creates opportunities for design to contribute to the longevity of textiles and garments. Theoretically, the paper draws on Young's framework of levels of context—specifically design in context and designing context—as well as Pineda et al.'s emphasis on the relationship between contexts and the designed object. Empirically, the study is based on data collected from an ongoing research project, [Project X], in which a consortium of academic institutions and industry partners explores opportunities for textile recovery through material-led experiments with recycled textile fibres, further processed in a local R&D factory setup. This paper demonstrates that the challenges of recycling extend beyond design strategies and material experiments, encompassing cultural perceptions and the opportunities available to designers. Furthermore, by highlighting the competencies required to facilitate relationships and collective knowledge building through textile prototypes, the paper supports previous research suggesting that designers play a central role in the transition toward sustainability.

Introduction

The textile and fashion industries consume vast resources and generate significant waste, leading to severe environmental consequences (European Parliament, 2024). Over the past decade, these industries have increasingly relied on material sourcing, including textile recycling, as a solution to their environmental sustainability challenges. However, research indicates that textile recycling represents a 'weak' approach to the circular economy, positioned at the lower end of the 9R framework of circularity (Bauwens et al., 2020; Kirchherr et al., 2023). This aligns with the EU waste hierarchy, which prioritizes reducing new production as the most impactful measure, while considering fibre recycling to have a substantially lower impact in fostering a circular transition (European Union, 2008).

It is widely argued that up to 80% of a product's environmental impact and costs are determined during the design stage (Graedel et al., 1995; Diaz et al., 2021), underscoring the critical role of design in sustainability. The Brundtland Report (1987) and current policies, such as the newly extended Eco Design Directive, emphasize the importance of design in developing durable and sustainable textiles (European Union, 2024). These perspectives position designers as key agents in facilitating a more circular textile industry (Pineda et al., 2024). Yet, despite efforts to embed longevity into materials and products, the industry's environmental and social impacts remain severe (Geneva Environment Network, 2024; Moreira et al., 2022). The ever-increasing volume of textiles produced and consumed continues to offset improvements at the product level (Fletcher, 2017; Beaurain et al., 2023).

Thus, while designers might have the potential to influence up to 80% of a product's environmental impact, research suggests that their sustainability efforts are often limited to material selection and product-level durability. These efforts fail to address broader issues, such as those related to business models (Karell & Niinimäki, 2020; Klepp et al., 2023).

This limitation places significant pressure on individual design teams to drive the transition toward sustainability, while restricting their ability to address larger systemic challenges (Hasling & Ræbild, 2017). A more nuanced understanding of designers' competencies—shaped by company strategies and production systems—is crucial to facilitating design-led change (Riisberg, 2006; Lerberg et al., 2010; Karell & Niinimäki, 2020; Pineda et al., 2024).

This paper explores how designers, when given room for manoeuvre, can contribute to the longevity of textiles, defined as the intersection of technical, functional, aesthetic, and emotional qualities (Hasling & Ræbild, 2017; Jørgensen & Bang, 2024). Focusing on textile designers' explorations with yarns made from recycled fibres, this paper provides a deeper understanding of the challenges and opportunities related to creating durable, high-quality textiles from recycled fibres, for both garments and interiors, as well as a more nuanced understanding of the role that design can play in the transition of the textile and fashion industries toward sustainability.

[Project X]

Empirically, this paper draws on qualitative data from an ongoing research project—referred to as [Project X]—which explores the challenges and opportunities of local textile recycling and production in Denmark. The project aims to generate knowledge on extending the textile lifespan, improving the quality for reuse, and ensuring recyclability without the use of harmful substances. Denmark faces over 30 years of lost infrastructure, expertise, and competencies in textile processing, making it a particularly challenging context for advancing textile practices. The country lacks the necessary infrastructure and expertise to effectively process and recycle locally discarded textiles (Keys et al., 2023). These challenges are both technical and cultural in nature. While imperfections are inherent in recycled yarns and textiles, most design teams and brands are unfamiliar with the aesthetics of imperfection and small-scale production for niche markets—conditions that contrast with the dominant logic of mass production (Larsen, 2025). In response [Project X] has established a local Research and Development (R&D) factory, enabling project partners to experiment with textile production from fibre to fabric. Fibers, yarns, and textile prototypes are developed and tested based on various criteria, including technical, functional, and aesthetic considerations.

The designer's role in sustainability

The traditional understanding of a fashion and textile designer is that of a professional who designs textile products, such as garments and fabrics, and combines them into range plans, lineups, and collections, taking into account the delicate interplay between technical, functional, aesthetic, and emotional factors. In commercial settings, the typical fashion designer operates within an aesthetic space defined by trends, brand strategies, and commercial interests, while the typical textile designer also works with technical and functional materials development. However, despite the fact that designers are often seen as central figures in sustainability fashion literature, their ability to drive environmental and social change is frequently more limited than previously suggested (Larsen, 2025). This limitation is sometimes due to a lack of knowledge about materials, recycling, and best practices. However, research also shows that company strategies often dictate and restrict design work, leaving designers with little room for meaningful influence (Bang & Jørgensen, 2024; Fletcher, 2017; Hornbuckle, 2018; Karell & Niinimäki, 2020).

Exploring the role of design in the transition towards sustainability, Young (2008) suggests that the design of concrete products, configurations, technical details, and components is design in context; designing at the level of system thinking is designing context; and designing at the level of policy formation and ideology is design of context. While design today is seen to operate at all three levels, Pineda et al. (2024) highlight the need to further analyse and unpack the relationship within and between context and the designed object.

Given the textile and fashion industries' reliance on recycled materials, it is essential to explore the challenges and opportunities for sustainability in textile recycling (Keys et al., 2023). This paper aims to contribute to the understanding of the role design plays in the transition toward sustainability by drawing on Young's (2008) framework to examine textile

recycling as a field that presents inherent challenges to promoting longevity. A critical question is to determine under what circumstances designers could assume a more prominent role in the emerging circular economy, where the management of existing resources becomes essential, and traditional production and design models are no longer sustainable (Larsen, 2025; Pineda et al., 2024). Additionally, it is crucial to consider what this role would entail and how it will shape designers' approaches to design, including the models, tools, and processes they employ (Bang & Jørgensen, 2024; Fletcher & Grose 2012; Harsaae & Bang, 2024; Harsaae & Bang, 2023; Ladekarl et al., 2023).

Methodology

In this paper, we analyse and discuss empirical data from [Project X], which runs from 2023 to 2026 and involves 13 partners from academia and industry (see Table 1).

Partner	Organisation
A	Interior textiles
B	Fashion
C	Workwear
D	Knit manufacturer
E	Weave manufacturer
F	Textile recycling
G	Textile recycling
H	National business Cluster
I	Research and Innovation
J	University
K	University College
L	University
M	University

Table 1: Project participants

[Project X] is organised in five cross-sectoral work packages (see Table 2).

Work Package	Title
WP1	New feedstock and fibre spinning
WP2	From yarn to printed fabric
WP3	Material driven design for circularity
WP4	Circular economy framework
WP5	Project management

Table 2: Cross-sectoral work packages

Methodologically, the paper employs a combination of qualitative research (Kvale, 2007; Spradley, 2016), practice-based research (Cross, 1982; Schön, 1983, Lawson, 2004), and material-driven design methods (Karana et al., 2015).

The data consists of a substantial number of textile prototypes/datasheets, worksheets and other physical material, field notes and follow-up interviews from workshops and structured material dialogues between partners.

Physical textile prototypes are core in the project (Ravnløkke et al., 2016; Star, 2010). WPs 1, 2 and 3 explore recycled materials from different perspectives: 1) spinning (from fibre to yarn), 2) technical and aesthetic exploration of new yarns (from yarn to weave, print and knit) and 3) idea development (from yarn to weave, knit and print). The woven, knitted and printed prototypes have been further supported with technical testing, such as rub test. All protypes and processes are registered in datasheets for transparency and further development across work packages.

Biannual workshops are core of the project and includes representatives from all partners across the project. The workshops were also driven by the principle of boundary objects through textile prototypes as a way to create shared understandings (Star, 2010). The workshops have been documented through fieldnotes and worksheets (Spradley, 2016), as well as follow-up interviews (Kvale, 2007). The worksheets and other physical material were inspired by the material driven design method (Karana et al., 2015) and included a series of questions developed to critically examine the textile prototypes' potential for longevity through design and material choice. This included questions relating to the material, design, use and construction perspective.

In analysing the data, we focus on three areas, drawing on Young (2008) and Pineda et al. (2024): first, design in context - the concrete product level; second, the systemic perspective – engaging stakeholders in knowledge exchange; and third, designing relationships - how designers facilitate dialogue between product and system to support longevity

through durability, long-term usage and high use frequency. The final area also considers knowledge building across stakeholders and varying levels of expertise.

Analysis — Prototyping for longevity

Design in context: What happens on the product level.

In [Project X], textile development begins with yarns containing recycled fibres spun in WP1. These yarns are handed over first to WP2 for functional and aesthetic exploration, then to WP3 for idea development. The yarns are explored on looms and knitting machines. Initial tests include basic weave structures such as twill variations and plain weave, and basic knit structures such as single and double jersey, followed by more experimental textures incorporating floats and decorative patterns. (see Figure 1).



Figure 1. Woven samples with recycled yarn [Project X] ©

At the R&D factory, the textile design team and the spinners work side by side in direct collaboration, with the designers actively participating in the spinning process. One textile designer noted: *"... having the opportunity to take part in the process of spinning is an eye opener, both in terms of the process itself, but also in relation to working with recycled fibres."* This hands-on involvement clarified challenges such as ensuring that shredded fibres are long enough to spin and gives value to the yarn. Designing in context (Young, 2008), the textile designer's core challenge lies in balancing the technical strength with visual and tactile appeal. During prototype development, WP2 and WP3 collaborated to adapt handwoven samples for industrial production tools. Drawing on a specific prototype from one of the trial plans we will illustrate how this collaboration unfolded between the product (textile) and the system (designing context).

Kombi.b.13 (Figure 2) is handwoven on an ARM loom. Its weave structure consists of a plain weave structure, supplemented with floating threads crossing up to a maximum of four warp threads to create a diamond-like pattern. The prototype is woven with a standard cotton warp of combed cotton 34/2 and a weft yarn, which is spun in WP1 containing recycled fibres.

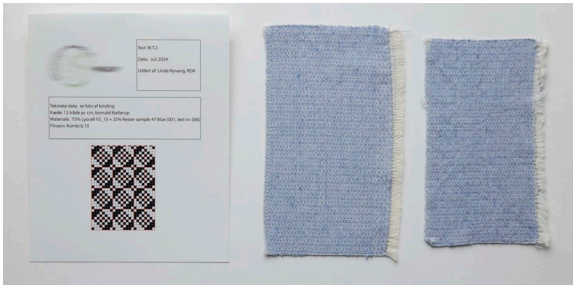


Figure 2. Prototype "Kombi.b.13" [Project X] ©

The prototype, along with many others, was presented and scrutinized at two project workshops, where it played a central role in the project's exploration into local value chains for recycled and more sustainable fibre production. We applied a variation of the material driven design method to guide the dialogue and investigation.

Designing contexts: Knowledge exchange on a systemic level.

[Project X]'s workshop series provides a foundation for evaluating the potential applications and longevity of the developed textiles, as perceived by stakeholders across the consortium. Drawing on a material-driven design approach, the workshops enable a practical, hands-on process for material and product development, as well as dialogue and knowledge exchange.

During a workshop (12.09.2024), the prototype (Figure 2) for instance received the following comments: *"Beautiful weave structure"*; "*Suitable as residential curtain fabric, but not for the contract market"*; *"Considered too thin with too many floats for upholstery"*; *"Good elasticity, especially diagonally"*; *"Even structure and uniform colour"* and *"Slightly nubby texture [visible fibre specs]"* (representatives from C and K).

Based on such feedback, it was decided to further develop the prototype – an iteration aimed at improving it in response to qualitative feedback from the industrial partners. The revised prototype, now featuring three threads per pick, resulted in a firmer and stiffer textile. This also altered its visual expression, making the diamond pattern more pronounced (Figure 3).

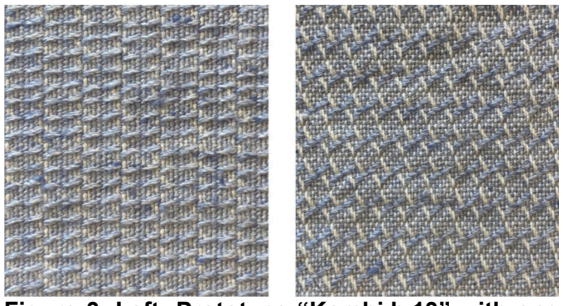


Figure 3. Left: Prototype "Kombi.b.13" with one thread per pick. Right: "Kombi.b.13" with three threads per pick. [Project X] ©

At the next project workshop (31.10.24), the updated prototype was evaluated again. One group remarked: *"Stable, slightly stiff/hard, moderate elasticity"*; *"Dense structure, durable surface, suitable as outer fabric – not for garments worn close to the body"*; *"Unique expression with 3D pattern that may have branding potential and stands out from more basic products"*; "*Stable and durable despite its open and lightweight appearance*" (representatives from B, C, K and M).

Following these workshops, WP2 and WP3 adapted the handwoven prototype to an industrial sample loom to further explore its scalability (Figure 4).

Experiences from both versions showed that a more balanced structure could be achieved by reducing the weft density. It was also noted that the analogue loom's weft density could not be transferred directly to the digital loom, due to space limitations in the warp. As a result, weft density was adjusted from 32 wefts/cm to 16 and 24 wefts/cm respectively. This adjustment also made the diamond pattern appear more balanced, as illustrated in Figure 3 left.



Figure 4. Prototype "Kombi.b.13", transferred to an industrial sample loom. [Project X] ©

The workshop discussions highlight the opportunities for companies to expand their product range through storytelling, potentially enhancing product value and exclusivity. Although recycled fibres are not yet fully sufficient for all applications, stakeholders see them as a step towards meeting new regulations. The work of WP3, particularly the workshop series, demonstrates how designers, when given the necessary space and infrastructure, can add nuances to our understanding of textile applications and questions of sustainability. Thus, through design, we reveal both the possibilities and limitations of textiles and foster dialogue on urgently needed advancements.

Discussion: Material longevity and the role of the designer

With the local R&D factory at the heart of [Project X], the project operates at the level of *design in context* (product) and *designing context* (system) (Young, 2008). Using physical textile prototypes as tools for dialogue, discussions become tangible and actionable among the participants. These prototypes provoke reflection and help reframe what counts as value for both industry and end users. In this setting, the designer takes on a critical and constructive role, challenging norms and exposing overlooked potentials. The designer's role extends to actively articulating and making the dilemmas and constraints associated with the use of recycled fibres in textile design tangible. Moreover, in [Project X] the designer

holds a strong position in facilitating knowledge production and interdisciplinary exchange across the value chain.

This collaborative framework illustrates how designers can play a broader and significantly more impactful role in designing for textile longevity. By actively engaging across the entire development chain—from fibre testing and material dialogues to industry workshops—the designer is strongly positioned to develop knowledge and thereby contribute to systemic change. The framework also highlights the value of bringing stakeholders together, into the spinning lab, textile workshops, and collaborative sessions. This fieldwork underscores the role of design in exploring and developing material qualities, with prototypes functioning as tools for knowledge exchange (Star, 2010; Ravnløkke et al., 2016). By facilitating mutual understanding between designers, manufacturers, and other stakeholders, [Project X] not only fosters knowledge sharing but also positions the designer as a facilitator—bridging technical and creative insights and enabling cross-sectoral and cross-disciplinary collaboration instead of stakeholders working in silos.

Initial findings suggest that no one can develop recycled materials in isolation. To mature how textile recycling is perceived, practised, and implemented, stakeholders must collaborate across the value chain. Only with supportive infrastructure can designers apply their skills fully and significantly advance the longevity of materials and products.

Moreover, the iterative development of more nuanced assessment schemes that incorporate environmental, design, and business aspects should be embedded into this process to fully understand the relevance of the collaborative development work and the designer's role within it. This has been a central topic in the consortium, contributing to a shared language and deeper understanding of barriers and potentials in textile recycling.

These reflections align with previous research showing that design practices must be embedded in diverse knowledge domains—artistic, technical, economic, and production-based—to achieve high-value outcomes (Karell & Niinimäki, 2020). When the design phase is seen as part of a broader system, as in Buchanan's (1998) augmented concept of design, cultural, economic, and political structures function as interlocked components of the process.

Conclusions

As the starting point of this paper, we explore the potential role of designers in promoting textile longevity. If the impact of the designer is viewed as being limited to the materials- and product level, mirroring the actual situation in most of the industry today, it becomes highly questionable whether design truly accounts for 80% of a product's environmental impact and potential for longevity. Design practices are always nested within a web of framing conditions. With the linear business model and fast fashion logic as dominant forces, designers have little to no opportunity to drive meaningful change.

Supporting previous research in the field (Karell & Niinimäki, 2020; Pineda et al., 2024), [Project X] suggests that a designer's potential cannot be realized at the material and product level alone but must be understood within —and critically— between contexts. Within this lies an opportunity to fully utilize the designer's ability to create value from textile resources and gain greater agency over the environmental impact of materials and products.

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References

Bang, A. L. & Jørgensen, P.-E. (2024). Bæredygtig produktion – udvikling af tekstilprodukter i en cirkulær økonomi. In Juel-Jacobsen, L. G. (ed.) *Bæredygtige Business Studier*. Samfundslitteratur.

Bauwens, T., Hekkert, M. & Kirchherr, J. (2020). Circular futures: What will they look like? *Ecological Economics*, 175, 106703. https://doi.org/10.1016/j.ecolecon.2020.106703

Brundtland, G. (1987). Report of the World Commission on Environment and Development: Our Common Future. United Nations General Assembly document A/42/427.

Buchanan, R. (1998). Branzi's dilemma: Design in contemporary culture. *Design Issues*, 14(1), 3-20

Cross, N. (1982). Designerly Ways of Knowing. *Design Studies, Vol 3, no 4, pp. 221-227*

Diaz, A., Schöggl, J.-P., Reyes, T., & Baumgartner, R. J. (2021). Sustainable product development in a circular economy:

Implications for products, actors, decision-making support, and lifecycle information management. *Sustainable Production and Consumption, 26*, 1031–1045. https://doi.org/10.1016/j.spc.2020.12.044

European Parliament (2020/2024). The impact of textile production and waste on the environment. https://www.europarl.europa.eu/topics/en/article/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics.

European Union (2024). REGULATION (EU) 2024/1781 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 June 2024. In: EUR-Lex, Official Journal of the European Union, https://eur-lex.europa.eu/eli/reg/2024/1781/oj

European Union (2008). Directive 2008/98/EC of the European Parliament and of the Council. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098 (accessed November, 2024)

Fletcher, K. (2017) Exploring demand reduction through design, durability and 'usership' of fashion clothes. *Philosophical Transactions of the Royal Society A*, 375, 20160366. http://dx.doi.org/10.1098/rsta.2016.0366

Fletcher, K. & Grose, L. (2012). *Fashion and Sustainability: Design for Change*. London: Laurence King Publishing.

Graedel, T. E., Reaves, C. P. and Sekutowski, J. C. (1995). Green product design. *AT&T Technical Journal*, 74(6), p. 17-25.

Geneva Environment Network (2024). The Environmental Cost of Fashion. https://www.genevaenvironmentnetwork.org/resources/updates/sustainable-fashion/ (accessed November, 2024).

Harsaae, M. & Bang, A. L. (2024). Mode, materialer og materialitet i den antropocæne tidsalder. In: M. P. & Tække, J. (red.). Antropocæn: menneske, samfund og dannelse i en ny tidsalder. Unge Pædagoger, s. 143-162 20 s.

Harsaae, M., Bang, A. L., Ladekarl, I. M., Pedersen, L. K., Nielsen, T. C. B. & Ege, A. (2023). The Matter of Matters. In *Proceedings of Textiles Intersections Conference. Design Research Society,* 10 s. DOI: 10.21606/TI-2023/121

Hasling, K. M. & Ræbild, U. (2017). Sustainability cards: Design for longevity. PLATE 2017 Conference Proceedings. https://adk.elsevierpure.com/ws/portalfiles/portal/61261821/Hasling_R_bild_2017_._Sustainability_Cards_Design_for_Longevity.pdf (accessed December, 2024)

Hornbuckle, R. (2018). What else do we know? Exploring alternative applications of design knowledge and skills in the development of circular textiles. *Journal of Textile Design, Reserch and* Practice, 6(1), 23-41. https://doi.org/10.1080/20511787.2018.1434745

Karana, E., Barati, B., Rognoli, V. and van der Laan, A. Z. (2015). Material Driven Design (MDD): A method to design for material experiences. International Journal of Design, 9(2), 35-54. https://www.ijdesign.org/index.php/IJDesign/article/viewFile/1965/687 (accessed December 2024).

Karell, E. & Niinimäki, K. (2020). A mixed-method study of design practices and designers' roles in sustainability-minded clothing companies. *Sustainability* 2020, 12(11), 4680; https://doi.org/10.3390/su12114680

Keys, A., Sutherland, A. B., Glutting, J. R., Murdie, M. (2023). *The Circularity Gap Report – Denmark*. Netherlands: Circle Economy Foundation.

Kirchherr, J., Yang, N.N., Schulze-Spüntrup, F., Heerink, M.J. & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions. Resources, Conservation and Recycling. 194, 10700. https://doi.org/10.1016/j.resconrec.2023.107001

Kvale, S., (2007). Doing Interviews. Qualitative Research Kit, SAGE Publications, Ltd., London. https://doi.org/10.4135/9781849208963

Ladekarl, I. M., Harsaae, M. P., Bang, A. L., Pedersen, L. K., Nielsen, T. C. B. & Ege, A. (2023). From Craft to Industry. *Form Akademisk - Forskningstidsskriftet for design og designdidaktik.* 16, 4, s. 1-10 10 s.

Larsen, A.T. (2025). From Fiber to Form. Exploring Design Qualities of Mechanically Recycled Textiles. Unpublished PhD thesis © The PhD school of the Royal Danish Academy.

Lawson, B. (2006). How Designers Think. Oxford: Architectural Press.

Leerberg, M., Riisberg, V. & Boutrup, J. (2010). Design Responsibility and Sustainable Design as Reflective Practice: An Educational Challenge. In: Sustainable Development, 18, 306–317. Wiley Online Library. https://doi.org/10.1002/sd.481

Moreira, N., Hodson, E., & Niinimäki, K. (2022). Social Sustainability and the Textile Industry: New Directions in Sustainability Research. Latest Trends in Textile and Fashion Designing, 4(5), 827-831.https://doi.org/10.32474/LTTFD.2022.04.000199

Pineda, A. F. V., Elle, M., & Iuel-Jensen, J. (2024). The Role of design in Sustainable Transitions: The Case of Mobility in Greater Copenhagen. *Environmental Innovation and Societal Transitions*, Vol. 50. https://doi.org/10.1016/j.eist.2023.100807

Ravnløkke, L., Gøttsche, T. H. M. & Bang, A. L. (2016). Tangible dialogue tools - mediating between non-verbal users and everyday experts. Proceedings of Nordcode, Kolding, Denmark

Riisberg, V. (2006). *Design og Produktion af Trykte Tekstiler - fra Analoge til Digitale Processer.* Unpublished PhD thesis ©Aarhus School of Architecture and Design School Kolding.

Schön, D. (1983). The Reflective Practitioner. How Professionals Think in Action. London: Ashgate.

Spradley, J. P. (2016), Participant observation: Waveland Press, USA.

Star, S.L. (2010). This is not a boundary object: Reflections on the origin of a concept. *Science, Technology & Human Values*, 35(5), 601-617.

Young, R. A. (2008) An Integrated Model of Designing to Aid Understanding of the Complexity Paradigm in Design Practice. *Futures*, 40 (6), p. 562-576. https://doi.org/10.1016/j.futures.2007.11.005

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Sense of Order: The Effects of Machine Aesthetic on Biomaterials Favourability

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Keywords: Material Experience; Sustainable Materials; Circular Economy; User Emotive Response.

Abstract: Designers are increasingly creating materials from renewable and recycled sources to support a circular economy, aiming to mitigate the adverse effects of linear production and consumption. These materials are considered sustainable alternatives to non-renewable materials, such as fossil fuel-based plastics. While users may be drawn to the sustainability narrative and "biography" of such materials, the highly natural appearance of biomaterials can sometimes evoke unappealing user responses. This study examines how "machine aesthetics"—visible signs of production like graphical embossment and engraving—impact user perceptions of biomaterials. The research explores how surface alterations influence emotional responses and underlying appraisals by comparing reactions to biomaterial samples with a high degree of naturalness against those with embossed and engraved surfaces. Findings reveal that machine aesthetics evoke a sense of order, contributing to favourable responses and minimising other negative evaluations of the material aspects. Although users value biomaterials for their natural origins, structured human-imposed aesthetics satisfy a desire for aesthetic coherence and control. This finding suggests that people appreciate sustainable materials' natural imperfections when presented within a framework of manageability and familiarity.

Designers' Pursuit of Sustainable Materials

Designers constantly seek ways to improve living standards. Initially, materiality knowledge was limited to specific fields, but the 'democratisation of knowledge' has spread expertise across disciplines (Biccum, 2024), sparking a renewed interest in Do-It-Yourself practices (Ayala-Garcia et al., 2024; Parisi et al., 2017; Rognoli & Parisi, 2016) and sustainable materials and design (Faludi et al., 2020; Rognoli & Parisi, 2016).

The movement signifies a revival of holistic product-making practices, where designers engage deeply with material origins before transforming them into functional products. This reciprocal relationship allows the product maker and the material to influence and guide each other (Spencer, 2021). Such hands-on interaction fosters a meaningful connection with materials, enhancing the ability to create innovative and functional designs (Pedgley et al., 2021).

This approach echoes the fundamentals of traditional craftsmanship, where artisans master materials with finesse (de Groot et al., 2023), carefully transforming them into functional or decorative items imbued with care and affection (Fuchs et al., 2015). Their motivations were often tied to cultural and heritage preservation rather than explicit sustainability goals (Hasanah et al., 2023).

Designers' current pursuit of sustainable materials aligns with the principles of the circular economy, emphasizing resource sustainability and lifecycle efficiency (Djassemi, 2009). The materials explored offer various benefits, including reduced environmental impact, improved aesthetics, and enhanced user experience (Thundathil et al., 2023).

In addition to the traditional, hands-on, and intuitive approaches commonly employed in 'designerly' material development processes, the Material Driven Design (MDD) framework offers a structured methodology to guide designers in creating innovative material applications. It fosters a deeper understanding of a material's characteristics, behaviours, and experiential qualities (Karana et al., 2015). Additionally, frameworks like Material Driven Textile Design (MDTD) help designers explore and understand the scientific aspects of material creation (Ribul et al., 2021).

The explored materials include unconventional sources like agricultural waste fibres and living organisms such as bacteria and fungi (Bahrudin et al., 2017; Garcia et al., 2017). These innovations signal a shift toward integrating biological systems into material design, where organisms become production co-creators. Additionally, materials within this spectrum hold significant potential for biomimicry applications, such as self-cleaning properties and ultra-lightweight structures (Popescu et al., 2024) Designers play a pivotal role in directing and shaping these living systems to achieve desired material characteristics, as seen in the bio fabrication projects by Susanne Lee (Jewell, 2023), Zena Holloway (Mitra, 2023), and Mycotech Lab (Gultom & Welly, 2023). Materials derived from living organisms are still in their early stages, yet they add to the growing diversity of sustainable material innovations (Bahrudin et al., 2017).

User- Sustainable Material Appraisals

New materials entering the market face significant challenges compared to existing ones in user evaluations. Even plastic, now ubiquitous, was initially met with scepticism, requiring a lengthy gestation period before its successful acceptance (Cordier et al., 2024; Newport, 1997; Shashoua, 2012; Suggit, 1997).

Generally, user material appraisal is a complex and multifaceted process heavily influenced by an individual's experiences, cultural background, gender, age, and memories associated with existing materials (Karana et al., 2013). These factors shape users' emotional responses when encountering new sustainable materials, impacting their overall evaluation and perception of material quality(Gifford et al., 2000).

Research into user-material interactions has identified several themes that influence material appraisal, encompassing physical and non-physical properties. Key themes include sensorial, technical, expressive semantic, use, manufacturing, emotional, and associative description (Karana, 2006).Bahrudin & Aurisicchio (2018) introduced the concept of systemic appraisal, emphasising the perceptual evaluation of materials across their entire lifecycle, including origin, production, use, and end-of-life considerations.

Users often depend on sensorial properties to form initial impressions of unfamiliar materials, drawing comparisons to known materials based on past experiences (Ortíz Nicolás, 2014). In the absence of familiarity, easily observable cues—such as visual appearance and tactile feel—serve as key quality indicators, as they are the most accessible and quickly processed forms of information (Vermeir, 2020).

Therefore, designers must understand how materials' visual and tactile characteristics influence user perception and experience (Haug, 2019). For instance, biomaterials may successfully mimic the texture of leather, yet their unfamiliarity can trigger doubts about functionality, potentially affecting user comfort and confidence (Bahrudin & Aurisicchio, 2018; Ram & Sheth, 1989). Historically, early plastics were designed to imitate familiar materials like ivory and wood to ease user acceptance.

User evaluations of sustainable materials become more complex when biographical narratives are introduced, adding layers to the appraisal process. For instance, some users initially rejected plastic due to its association with impurities from beneath the earth (Meikle, 1997). As the material's background becomes more transparent, the evaluation process grows more intricate. For example, "This material is made of used ground coffee powder from cafes in London" highlights key aspects of its lifecycle, including its origin and provenance (Bahrudin, 2019). Users will then evaluate the narratives based on prior knowledge and specific concerns. The cup from coffee waste might seem like an effective repurposing strategy. However, concerns about transporting waste from distant regions could complicate perceptions of sustainability, leading to varied judgments. (Camilleri et al., 2023; Catlin et al., 2017).

Adding complexity to material appraisals, the concept of "sustainable" is culturally nuanced, and the evaluation is context-specific. For instance, in Japan, local terms such as "material for lifecycle design" and "material of higher efficiency" are used to describe specific aspects of sustainability, reflecting variations of sustainable practices (Halada & Yamamoto, 2001). In Malaysia, the formal jargon *lestari* (see Mohd Salleh, 2012) is often employed to denote sustainability, though these terms may lack everyday familiarity and emotional resonance. These linguistic and conceptual variations underscore the influence of cultural and regional contexts, shaping diverse perceptions of sustainable materials.

Despite sustainability assessments, the origin of material can evoke diverse emotional responses and evaluations, influenced by cultural significance and symbolic meaning (Chávez et al., 2015). For instance, a study on products made from coffee waste fibres revealed that Arab respondents associated coffee with heritage and cultural lifestyle, favouring its application in furniture, while Malaysian respondents perceived coffee as an edible plant, preferring its use in food-related products (Ismail, 2024).

To address these challenges, designers must craft narratives that resonate with users' psychological and social contexts, enhancing the desirability of sustainable materials. By understanding the narratives of the materials they work with, designers can make more informed decisions and better communicate the sustainability credentials of their designs to users (Kesteren et al., 2007; Rognoli et al., 2022).

Biophilic Design and Human-Nature Relationship

Sustainable materials often feature distinct surface qualities, such as the unbleached natural brown of recycled tetra-pak packaging (Ma, 2018). By preserving these natural characteristics, designers emphasise authenticity and foster a sense of connection to nature. Research highlights that bio-based and bio-fabricated materials offer unique experiential qualities, adding aesthetic value through new sensory experiences and cultivating empathy for the natural environment (Sayuti & Kristensen, 2020).

The biophilic design principles aim to integrate natural elements into everyday living, enhancing well-being and encouraging environmental stewardship (Salonen et al., 2022). By incorporating natural textures, organic forms, or sustainable materials, designers can evoke feelings of calm, well-being, and harmony (Branca et al., 2024; Wolfs, 2015). It enhances the quality of life for modern society, which faces the adverse effects of urbanisation (Xia et al., 2024). It taps into humans' innate desire to connect with nature, which can be linked to a higher level of Maslow's hierarchy of needs (Maslow, 1954; Yalch & Brunel, 1996).

However, since the early modern era, humans have often sought to control nature. French-style gardens, known as *Jardins à la française*, gained prominence for their meticulous organisation, geometric precision, and symmetry (Yoon, 1994). Ornamental pruning, also known as topiary art, sculpts greenery into precise shapes, creating a structured visual harmony that evokes order and control. A well-maintained lawn, a symbol of aristocratic ownership, demands significant labour (Harris et al., 2013) and establishes a controlled boundary, reinforcing a sense of autonomy (Ignatieva et al., 2020).

Similarly, although the Asian and Japanese gardens embrace more naturalistic forms, shaping nature following its natural tendencies (Saitō, 2017), imperfections, irregularities, and transient qualities of materials are celebrated in the concept of *wabi-sabi* (Kongot & Matz, 2021; Siyi & Ayob, 2024; Venzo, 2019), the aesthetic concept incorporates a balance between natural beauty and the deliberate exertion of human control. The *karesansui*, or Japanese rock gardens, exhibit a deliberate structural pattern (Van Tonder et al., 2003), conforming to human ideals of form and proportion.

In contemporary society, people have become accustomed to the high standards of machine production, which consistently delivers precise, uniform, and high-quality outputs (Liebl & Roy, 2003; Markoff, 2012). As highlighted by Akbar et al. (2020), humans exhibit a strong preference for control and predictability, often opting for controlled environments over the uncertainties of nature. Plastics, with their durability and versatility, offer a sense of

control, allowing individuals to experience the aesthetic qualities of natural materials without their inherent vulnerabilities, such as erosion or decay. Hence, artificial substitutes, such as plastic-wood composite flooring or PVC stone walls, are frequently employed for convenience. (Tabassum & Park, 2024; Zhong et al., 2022).

Advancing the Uptake of Sustainable Materials

When engaging with sustainable materials, users encounter a complex interplay of cognitive and emotional responses. Research indicates that the visual and tactile properties of materials—such as texture, colour, and perceived naturalness—play a crucial role in shaping user perceptions of value, aesthetics, and overall desirability (Dhakal et al., 2017; Thundathil et al., 2023). While emphasising the natural qualities of a material can draw attention to its sustainability, user acceptance is not guaranteed; it is often mediated by perceptions of quality, functionality, and visual appeal (Magnier & Crié, 2015; Magnier & Schoormans, 2015; Overvliet et al., 2014).

Users generally regard naturalness as a desirable attribute, influenced by both practical benefits and personal values (Li & Chapman, 2012). Materials that retain visual cues of their original state are often more readily judged as natural and environmentally friendly (Zhang et al., 2023). Users continue to embrace the natural appearance of building materials, even when they are aware that the materials are artificial (Zhang et al., 2023). Acceptance of material attributes like sensory appeal and perceived naturalness can strengthen emotional attachment, ultimately encouraging longer product usage and extending its lifespan (Haines-Gadd et al., 2018).

However, Karana (2012) highlights the inherent tension in biomaterials, where attributes associated with naturalness and high quality frequently conflict rather than align. A natural material may be made plain-looking to ensure easier acceptance, though this can diminish its perceived sustainability value. Conversely, materials that retain distinctive natural appearances might enhance eco-friendly appeal but face scepticism regarding durability. In such cases, strengthening the material's narrative can improve perceptions of its functional qualities (Bahrudin, 2019). But, such dynamics are rarely straightforward. Material acceptance is also shaped by familiarity with surface qualities and alignment with the material's sustainability narrative. Therefore, thoughtful messaging and intentional design strategies are essential to navigating these nuanced evaluations and fostering greater user acceptance of sustainable products (Houf et al., 2024).

To what extent can sustainable materials retain their natural surface characteristics while still being deemed desirable and practical by users? This critical balance between material authenticity and user preference is fertile for further exploration.

Method

This qualitative research explores users' affective responses and underlying appraisals of three Kombucha bacterial cellulose-based material samples. The study was conducted in two phases. The study's first phase involved fifteen university students (aged 19-20) from six countries recruited through convenience sampling. Their age and educational background likely indicate biospheric and altruistic behaviour (Balundė et al., 2020). The second phase was conducted with ten young adult executives (aged 25-35) from various backgrounds in an urban setting. The participants' diverse backgrounds offered a rich understanding of the material samples. The same data collection procedures were used in both phases.

Participants examined three 10cm x 10cm Kombucha-based bio-composite samples. The three samples, A, B, and C, varied in surface texture: A was highly natural, B had laser-hatched patterns, and C had an embossed texture (See Figure 1). Samples A and B are kombucha-based materials reinforced with plant fibres. However, Sample B features engraved geometric patterns, intentionally contrasting with the highly natural appearance of the material. Sample C, without plant fibres, had a moulded surface with small, uniform embossments. All three samples were unbleached and undyed, retaining a natural brown colour.

A list of emotion cards was given to induce participants' affective responses, aiming for explicit, accurate appraisals and expressions (Table 1). The material samples were accompanied by a brief description: "This

sustainable material is made from natural fibres and microorganisms. It's a biodegradable, eco-friendly alternative to single-use plastics, suitable for packaging and leather goods". This description provides basic information without explicitly mentioning bacterial cellulose, which could potentially bias participants' perceptions.

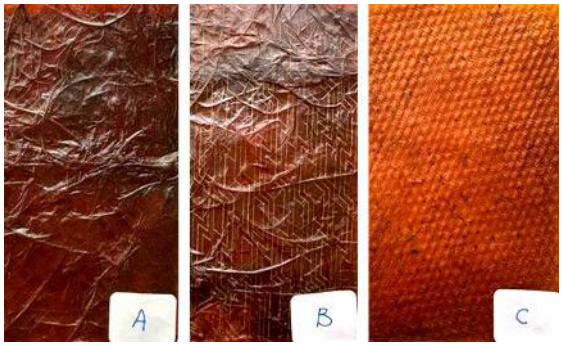


Figure 1. Close-up pictures of the material samples.

Positive Emotion	Negative Emotion
Joy	Irritation
Pleasant	Unpleasant
Satisfaction	Dissatisfaction
Pride	Shame
Admiration	Anger
Curious	Anxiety
Hope	Fear
Impressed	Unimpressed
Love	Dislike
Admire	Disgust
Enthusiastic	Disinterested
Peaceful	Uneasy
Happy	Discomfort
Easy	Doubt
Contentment	Reserved
Respect	Insecure
Surprise	Confused

Table 1 List of Emotions (synthesised from Desmet, 2003; Ebe & Umemuro, 2015).

Each participant was individually presented with the three material samples. They were encouraged to closely examine each sample and express their feelings using the emotion list. Participants were asked open-ended questions to trigger free expression of their thoughts. Each session lasted about thirty minutes.

The interview data—consisting of audio recordings and field notes, including notable non-verbal expressions—were coded and analysed using NVivo software (Figure 2). Each participant's responses were examined as a network of interconnected emotions and underlying reasons. Emotions were often expressed before or after the accompanying rationale, with some instances showing multiple reasons linked to a single emotional response.



Figure 2. Data coding and analysis using Nvivo.

Appraisal Theme	Terms and phrases used in the interview
Sensorial	Color, hair texture, bumpy texture, herbal tea smell, dry longan smell, smooth surface, transparent, translucency, fiber texture, geometry texture
Associative	Like-leaves, like-dry leaves, like-leather, like-fabric, like cool fever patch, like-plastic, like-dry longan
Manufacturing Process	Hatching process, engraving pattern, pattern making process
Expressive Semantic	Natural, luxury, futuristic, beautiful
Use	For bag, for recycled paper wrapper, for craft usage, for lighting design
Systemic	Natural material, environmentally friendly, eco material
Technical	Durable, strong, flexible

Table 2 Material appraisal themes (Bahrudin, 2019b; Karana, 2009) and examples of phrases in the appraisals.

The analysis aims to determine whether the appraisals for material Samples B and C are more favourable than Sample A, particularly concerning sensory experience, as influenced by the 'machine aesthetic'. The data were analysed using thematic analysis to identify recurring patterns. Specifically, the process

involved three steps: first, all emotions were classified into positive and negative categories (Table 1). Second, the underlying reasons for each emotion were categorised based on material appraisal themes (Bahrudin, 2019b; Karana, 2009) (Table 2). Third, to gain deeper insights into the appraisals, participants' expressions were further examined to identify key issues or encapsulated appraisal components (Demir et al., 2009) (Table 3). The emotional-reasoning networks were visually mapped, with black lines indicating connections from Phase 1 and red lines representing those from Phase 2 (Figures 4, 5, and 7).

Appraisal components	Descriptions	Examples of positive and negative emotions
Motive consistency	The fundamental question is: 'To what extent does this situation correspond with my motivations?'	**Joy (Irritation)** - elicited when a the situation is appraised as consistent (conflicting) with one want.
Intrinsic pleasantness	The intrinsic pleasantness component pertains to the sensory appeal of an object. The corresponding question is: 'To what degree does this object possess sensory appeal?'	**Pleasant (Unpleasant)** - expressed due to affection (disliking) towards particular sensorial properties.
Expectation confirmation	This is about whether things turned out the way we thought they would. Our expectations can be anything from guessing how a new gadget will work to knowing what a button does on our phone.	**Satisfaction (Dissatisfaction)** - expressed when the outcomes of an event confirms (violates) one's expectations.
Agency	This component explores the issue of responsibility for a given situation. Potential attributions include self, others, and situational factors.	**Pride (Shame)** - elicited when one believes that he or she caused a pleasing (disturbing) event. Thus, he or she attributes the outcome to his effort and skill.
Standard conformance	This component asks, 'Does this situation align with social norms and expectations?' A situation can be seen as breaking, meeting, or exceeding these standards.	**Admiration (Anger)** - evoked when a situation is appraised as surpassing (violating) a standard.
Coping potential	This component examines one's perceived capacity to address and mitigate harmful elements of a situation. A sense of agency can lead to overt attempts to influence the situation.	**Anger** - involves high coping potential, manifested in the form of aggressive behaviour towards the person or the object that is responsible for the unpleasant situation, in an attempt to change the unpleasant aspects of the situation or restore social respect. **Anxiety** - involves low coping potential, meaning that one appraises oneself as having little control or power to change the situation, which results in moving away from the situation.
Certainty	This component pertains to the degree of confidence associated with an event. The question is: 'To what extent am I certain about this event?'	**Hope (Fear)** - evoked when one thinks that something pleasing (disturbing) may happen in the future but is unsure about it.

Table 3 The seven appraisal components, descriptions, and emotions (Demir et al., 2009).

Results

Participants in Phase 1 and Phase 2 generally showed consistent and coherent responses. Although some minor differences were noted, these seemed to result from random individual expression rather than any dominant divergence in perception. They demonstrated an active interest in participating in the study, as it involved the evaluation of novel materials. Their feedback initially focused on assessing the sensorial properties of the samples and associated them with familiar materials (Figure 3). Therefore, the predominant material appraisal themes identified for the three samples are "sensorial" and "associative". As participants interacted with the materials and experienced their flexibility, many remarked that "it is like leather."



Figure 3. The participants held the material samples up to the light to observe their translucency attributes.

As illustrated in Figures 4 and 5, Samples A and B elicited predominantly negative appraisals. In contrast, Sample C received more positive feedback than Samples A and B. Sample A, with its high naturalness, elicited more negative responses. This might be due to the tension between the material's natural qualities and industry standards for product finishes. Only for Sample B did participants express positive appraisals of its sustainability, suggesting a general acceptance of the material as a plastic alternative.

Across all sample appraisals, interesting relationships exist between the various appraisal components and emotional responses. For example, the "sensorial" and "associative" themes consistently appear to underpin positive emotions like "pleasant" and "curious". Meanwhile, "motive consistency" and "manufacturing process" seem to contribute to more negative responses like "confused" and "unimpressed." Additionally, the "coping potential" component, which represents the user's perceived ability to handle or manipulate the material, appears to be a key driver in the negative responses for sample A and B.

For Sample A, most participants primarily evaluated the colour and texture of the samples (sensorial) and expressed adverse reactions

(intrinsic pleasantness) to their surface qualities. Participants also criticised the material's appearance by associating it with mundane materials (associative) and highlighting its perceived lack of a high-quality finish, as expected by conventional standards (standard conformance). For example, a participant expressed, "The material is coarse, the fibrous texture is uncomfortable to the touch, ….unlike the smooth feel of plastic or leather. ".

Some participants expressed apprehension about using the material, driven by concerns about its aesthetic appeal and functionality, which are closely linked to their perceived ability to manage such situations (coping potential). Other less prominent appraisal components are 'motive consistency', 'agency' and 'expectation confirmation'.

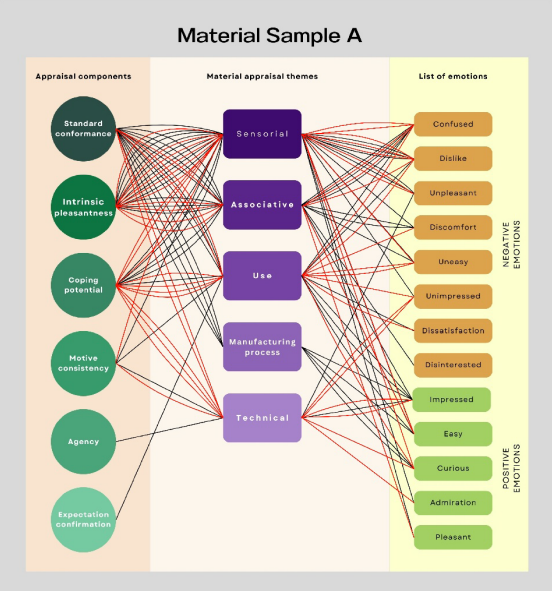


Figure 4. Network of Appraisals for Material A

Figure 5 shows the participants' responses to Sample B. The sample elicited slightly fewer negative emotional reactions than Sample A. Like Sample A; the central appraisal theme is on the material 'sensorial' properties and linked to 'intrinsic pleasantness' and 'coping potential'. For example, a participant said, "The material feels smoother and less textured,…I like the softness, … can use it as a leather bag".

The issue of 'Standard Conformance' did not emerge in the appraisal of Sample B, likely because participants recognised it as having characteristics similar to those of Sample A. Instead of reiterating the same appraisals, participants raised new concerns such as 'Expressive Semantic' and 'Systemic.'

The subtle surface treatment appeared to have an impact on the overall perception. Some participants preferred the more controlled texture of Sample B. One participant commented, "Sample B looks cleaner, with a less random texture and a futuristic, geometric pattern." Nevertheless, several negative appraisals emerged as participants expressed discomfort and confusion with the combination of the structured geometric pattern overlaying the natural, organic fibre arrangement on the sample surfaces (see Figure 6).

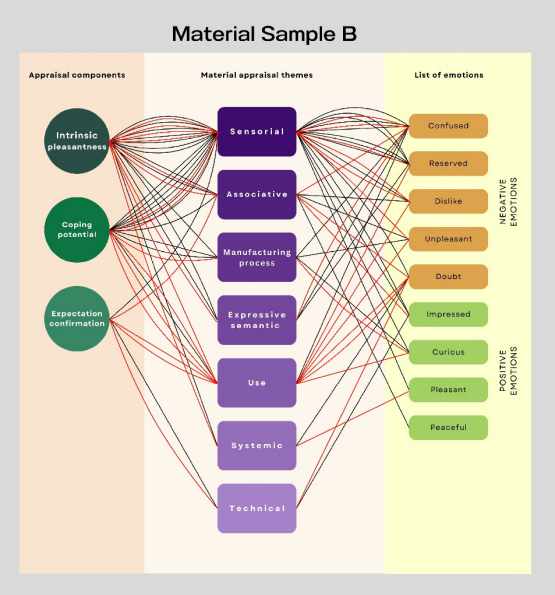


Figure 5. Network of Appraisals for Material B

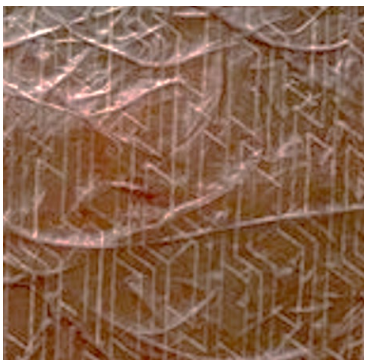


Figure 6. Subtle geometric pattern engraving on material sample B.

For Sample C, positive emotions dominated the participants' appraisals (Figure 7). The positively evaluated themes included

'Sensorial', 'Technical', 'Associative', 'Use', and 'Manufacturing Process'. Some participants associate it with luxury packaging materials and appreciate its symmetrical geometric texture. One participant noted, "The textured pattern on the material C gives it a leather-like and plastic-like feel, making it seem durable'. Other participants associated the translucency attribute of the sample with potential applications such as curtains and lampshades.

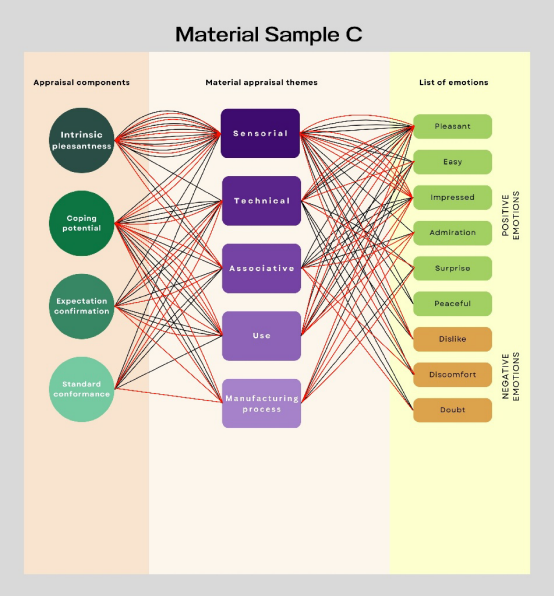


Figure 7. Network of Appraisals for Material C

Only the materials 'Sensorial', 'Technical' and 'Associative' properties minorly trigger negative emotions. Despite their overall positive reception, some participants expressed dislike or discomfort with the subtle, random freckle pattern on Sample C (Figure 8). A participant described, "The material's random dots, scattered across its surface, may be visually distracting and detract from its overall appearance."



Figure 8. Subtle natural random black freckles in material sample C.

Findings and Discussions

Sample C was generally preferred over Samples A and B. This finding suggests that a material's surface qualities strongly influence users' perception of sustainable materials from unconventional origins. When a material's surface appears natural, users often associate it with familiar materials, impacting their overall impression.

Over the high level of naturalness surface qualities, participants preferred a more plain with uniform surface treatment (machine aesthetics). Even within a design characterised by a high degree of order, unexpected natural elements can disrupt the appraisals and evoke mixed emotional responses. It is important to note that the participants in this study consist of tertiary-level students and young adult executives from urban settings. Their diverse experiences with natural materials may lead to findings that differ from those of suburban residents, who are likely more familiar with materials exhibiting natural characteristics.

The findings of this study emphasize the need for careful design consideration when working with natural fibre composites and biomaterials to balance their inherent natural qualities with user expectations. Drawing attention to a material's origin, such as incorporating visible coconut fibres, can spark curiosity and foster emotional attachment by highlighting its unique tactile and visual properties. However, focusing solely on raw naturalness may lead to perceptions of inferiority or reduced durability.

To counter this, enhancing biomaterials with machine aesthetics—such as embossed patterns or structured surface treatments—can signal intentional craftsmanship and processing. Perhaps mimicking existing, established materials may be a good strategy for easing user acceptance. For example, recycled plastics with colourful specks and irregular textures are often well-received, as users associate these features with familiar materials like terrazzo.

Furthermore, designers can apply machine-trace elements at the product level—through details like moulding marks, stitching, or architectural construction—to introduce structured accents that reinforce durability, quality, and reliability. These design choices, much like decisions about product form or

colour, combine creative intuition with strategic reasoning, considering aesthetics, functionality, target users, and material narratives.

These findings provide valuable theoretical insights into how designers can enhance the sensorial experience of sustainable materials from unconventional sources. They build upon frameworks like the Material Driven Design (MDD) framework (Karana et al., 2015), with particular emphasis on the tinkering phase to explore the material's technical and sensorial properties and expand the understanding of its experiential potential. Materials that exhibit distinct natural characteristics can be further enhanced through careful surface manipulation, tailored specifically to their intended use. While the technical properties of these materials are best analysed using engineering methods and procedures, their aesthetic appeal and visual elements can be significantly elevated through the expertise of fine artists and graphic designers (Alahira et al., 2024).

By adopting an interdisciplinary approach, it is possible to develop innovative and sustainable materials and products that connect with consumers on both practical and emotional levels. This approach helps bridge the gap between the material's origin and user expectations, ensuring that natural aesthetics are balanced with perceptions of durability and quality. By applying these strategies, designers improve material appraisal, foster emotional connection, and elevate the overall material experience, supporting product longevity and encouraging more sustainable consumption.

Conclusions

Shaping materials to meet user preferences is essential in craftsmanship and product design. Sustainable biomaterials pose unique challenges due to their natural origins and surface qualities. While storytelling about a material's origin is important, balancing natural appeal with user aesthetic ideals is crucial. This study shows that while high naturalness can be perceived negatively, materials with lower naturalness and more visual coherence are often preferred. This preference likely reflects modern users' familiarity with machine-made precision.

The relationship between a material's biography and its sensory qualities is crucial and warrants further research. Understanding how users from different cultural background perceive and interact with these elements will help designers create functional and emotionally engaging materials. By balancing natural appeal with user preferences, sustainable materials can be developed into functional solutions that meet practical needs and instil user confidence in their durability. This, in turn, fosters product longevity, helping to reduce waste and support more sustainable consumption practices.

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References

Akbar, N., Abubakar, I. R., & Bouregh, A. S. (2020). Fostering Urban Sustainability through the Ecological Wisdom of Traditional Settlements. *Sustainability*, *12*(23), 10033. https://doi.org/10.3390/su122310033

Alahira, J., Olu-lawal, K. A., Ejibe, I., & Ninduwezuor-Ehiobu, N. (2024). Sustainable materials and methods in industrial design: Bridging the gap with fine arts and graphic design for environmental innovation. *Engineering Science & Technology Journal, 5*(3), 774–782. https://doi.org/10.51594/estj.v5i3.901

Ayala-Garcia, C., Scalabrini, M., & Cohen, N. (2024). DIYR: The Do-It- Yourself-Revolution. *Diid*, *1*(82). https://doi.org/10.30682/diid8224i

Bahrudin, F. I. (2019). *The Experiential Dimension of Sustainable Material*. Imperial College London.

Bahrudin, F. I., & Aurisicchio, M. (2018). The appraisal of sustainable materials. *Proceedings of International Design Conference, DESIGN*, *6*. https://doi.org/10.21278/idc.2018.0455

Biccum, A. R. (2024). What do you need to know to live in the world? Global educational reform and the democratisation of knowledge. *Globalisation, Societies and Education*, 1–20. https://doi.org/10.1080/14767724.2024.2312834

Branca, G., Resciniti, R., & Babin, B. J. (2024). Sustainable packaging design and the consumer perspective: a systematic literature review. *Italian Journal of Marketing*, *2024*(1), 77–111. https://doi.org/10.1007/s43039-023-00084-1

Cordier, M., Uehara, T., Jorgensen, B., & Baztan, J. (2024). Reducing plastic production: Economic loss or environmental gain?

Cambridge Prisms: Plastics, *2*, e2. https://doi.org/10.1017/plc.2024.3

de Groot, B. G., Badreshany, K., Torres-Martínez, J. F., & Fernández-Götz, M. (2023). Capturing technological crossovers between clay crafts: An archaeometric perspective on the emergence of workshop production in Late Iron Age northern Spain. *PLOS ONE*, *18*(5), e0283343. https://doi.org/10.1371/journal.pone.0283343

Demir, E., Desmet, P. M. a, & Hekkert, P. (2009). Appraisal patterns of emotions in human-product interaction. *International Journal of Design*, *3*(2), 41–51.

Desmet, P. (2003). Designing emotions. *The Design Journal*, 60–62.

Dhakal, U., Berardi, U., Gorgolewski, M., & Richman, R. (2017). Hygrothermal performance of hempcrete for Ontario (Canada) buildings. *Journal of Cleaner Production*, *142*, 3655–3664. https://doi.org/10.1016/j.jclepro.2016.10.102

Ebe, Y., & Umemuro, H. (2015). Emotion evoked by texture and application to emotional communication. *Extended Abstracts of the ACM CHI'15 Conference on Human Factors in Computing Systems*, *2*, 1995–2000. https://doi.org/10.1145/2702613.2732768

Fuchs, C., Schreier, M., & Van Osselaer, S. M. J. (2015). The Handmade Effect: What's Love Got to Do with It? *Journal of Marketing*, *79*(2), 98–110. https://doi.org/10.1509/jm.14.0018

Gifford, R., Hine, D. W., Muller-Clemm, W., Reynolds, D. J., & Shaw, K. T. (2000). Decoding Modern Architecture. *Environment and Behavior*, *32*(2), 163–187. https://doi.org/10.1177/00139160021972487

Haines-Gadd, M., Chapman, J., Lloyd, P., Mason, J., & Aliakseyeu, D. (2018). Emotional Durability Design Nine—A Tool for Product Longevity. *Sustainability*, *10*(6), 1948. https://doi.org/10.3390/su10061948

Halada, K., & Yamamoto, R. (2001). The current status of research and development on ecomaterials around the world. *MRS Bulletin*, *26*(11), 871–879.

Harris, E. M., Martin, D. G., Polsky, C., Denhardt, L., & Nehring, A. (2013). Beyond "Lawn People": The Role of Emotions in Suburban Yard Management Practices. *The Professional Geographer*, *65*(2), 345–361. https://doi.org/10.1080/00330124.2012.681586

Hasanah, U., Sukoco, B. M., Supriharyanti, E., & Wu, W.-Y. (2023). Fifty years of artisan entrepreneurship: a systematic literature review. *Journal of Innovation and Entrepreneurship*, *12*(1), 46. https://doi.org/10.1186/s13731-023-00308-w

Haug, A. (2019). Acquiring materials knowledge in design education. *International Journal of Technology and Design Education*, *29*(2), 405–420. https://doi.org/10.1007/s10798-018-9445-4

Houf, L., Szymkowiak, A., & Shepherd, L. A. (2024). Promotion of Sustainable Products: Can Sustainability Labels Promote User Selection of Environmentally Friendly Products? *Sustainability*, *16*(13), 5390. https://doi.org/10.3390/su16135390

Ignatieva, M., Haase, D., Dushkova, D., & Haase, A. (2020). Lawns in Cities: From a Globalised Urban Green Space Phenomenon to Sustainable Nature-Based Solutions. *Land*, *9*(3), 73. https://doi.org/10.3390/land9030073

Ismail, Z. H. (2024). *Product Application Map for Emerging Sustainable Materials with Smell-Perceived Associations*. Universiti Teknologi Malaysia.

Karana, E. (2006). Intangible characteristics of materials in industrial design. *Proceedings of the Design and Emotion Conference, 27-29th September*.

Karana, E. (2009). *Meanings of materials*.

Karana, E. (2012). Characterization of "natural" and "high-quality" materials to improve perception of bio-plastics. *Journal of Cleaner Production*, *37*, 316–325. https://doi.org/10.1016/j.jclepro.2012.07.034

Karana, E., Barati, B., Rognoli, V., & Laan, A. Z. Van Der. (2015). *Material Driven Design (MDD): A Method to Design for Material Experiences*. *9*(2), 35–54.

Karana, E., Pedgley, O., & Rognoli, V. (2013). Materials Experience: Fundamentals of Materials and Design. In *Materials Experience: Fundamentals of Materials and Design*. https://doi.org/10.1016/C2012-0-02198-9

Kesteren, I. E. H. van, Stappers, P. J., & Bruijin, J. C. M. de. (2007). Materials in Product Selection: Tools for Including User-Interaction in Materials Selection. *International Journal of Design*, *1*(3), 41–55.

Kongot, A., & Matz, A. (2021). Perfectly Imperfect: A Speculation about Wabi-Sabi Inspired User Experience Design: Wabi-Sabi Inspired UX Design. *Conference on Human Factors in Computing Systems - Proceedings*. https://doi.org/10.1145/3411763.3450370

Li, M., & Chapman, G. B. (2012). Why Do People Like Natural? Instrumental and Ideational Bases for the Naturalness Preference. *Journal of Applied Social Psychology*, *42*(12), 2859–2878.

https://doi.org/10.1111/j.1559-1816.2012.00964.x

Liebl, M., & Roy, T. (2003). Handmade in India Preliminary Analysis of Crafts Producers and Crafts Production. *Economic and Political Weekly*, *38*(51/52).

Magnier, L., & Crié, D. (2015). Communicating packaging eco-friendliness. *International Journal of Retail & Distribution Management*, *43*(4/5), 350–366. https://doi.org/10.1108/IJRDM-04-2014-0048

Magnier, L., & Schoormans, J. (2015). Consumer reactions to sustainable packaging: The interplay of visual appearance, verbal claim and environmental concern. *Journal of Environmental Psychology*, *44*, 53–62. https://doi.org/10.1016/j.jenvp.2015.09.005

Markoff, J. (2012, August 18). Skilled Work, Without the Worker. *The New York Times*.

Maslow, A. (1954). *Motivation and personality*. Harper & Row.

Meikle, J. L. (1997). Material doubts: the consequences of plastic. *Environmental History*, *2*(3), 278–300. https://doi.org/10.2307/3985351

Mohd Salleh, M. N. (2012). Gerakan Baru dalam Senibina Lestari: Buluh Sebagai Sumber dan Bahan Binaan untuk Bangunan Hijau. *Habitat Magazine*.

Newport, R. (1997). Plastics and design. In S. Mossman (Ed.), *Early plastics: perspectives 1850-1950* (p. 102). Leicester University Press.

Ortíz Nicolás, J. C. (2014). *Understanding and designing pleasant experiences with products* [Doctoral dissertation, Imperial College London]. https://doi.org/10.1017/CBO9781107415324.004

Overvliet, K. E., Karana, E., & Soto-Faraco, S. (2014). Perception of naturalness in textiles. *Materials and Design*, *90*, 1192–1199. https://doi.org/10.1016/j.matdes.2015.05.039

Parisi, S., Rognoli, V., & Sonneveld, M. (2017). Material Tinkering. An inspirational approach for experiential learning and envisioning in product design education. *The Design Journal*, *20*(sup1), S1167–S1184. https://doi.org/10.1080/14606925.2017.1353059

Pedgley, O., Rognoli, V., & Karana, E. (2021). *Materials experience 2: expanding territories of materials and design*. Matthew Deans.

Popescu, C., Dissanayake, H., Mansi, E., & Stancu, A. (2024). Eco Breakthroughs: Sustainable Materials Transforming the Future of Our Planet. *Sustainability*, *16*(23), 10790. https://doi.org/10.3390/su162310790

Ram, S., & Sheth, J. N. (1989). Consumer Resistance to Innovation: The Role of Product Knowledge by Ram and Sheth: *The Journal of Consumer Marketing*, *6*, 1–12.

Rognoli, V., & Parisi, S. (2016). *The material experiences as DIY-Materials : self The material experiences as DIY-Materials : June*.

Rognoli, V., Petreca, B., Pollini, B., & Saito, C. (2022). Materials biography as a tool for designers' exploration of bio-based and bio-fabricated materials for the sustainable fashion industry. *Sustainability: Science, Practice and Policy*, *18*(1), 749–772. https://doi.org/10.1080/15487733.2022.2124740

Saitō, Y. (2017). *Japanese Gardens* (Vol. 1). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780190456320.003.0009

Shashoua, Y. (2012). *Conservation of plastics*. Routledge.

Siyi, D., & Ayob, S. (2024). From Aesthetics to Design: Sustainability of Wabi-sabi in Ceramic Product Design in the Contemporary Context. *Idealogy Journal*, *9*(1). https://doi.org/10.24191/idealogy.v9i1.530

Spencer, C. (2021). *Situationships: Creating Situations And Relationships For And With Material*. Syracuse University.

Suggit, M. (1997). Living with plastics. In S. Mossman (Ed.), *Early plastics: perspectives 1850-1950* (p. 125). Leicester University Press.

Tabassum, R. R., & Park, J. (2024). Development of a Building Evaluation Framework for Biophilic Design in Architecture. *Buildings*, *14*(10), 3254. https://doi.org/10.3390/buildings14103254

Thundathil, M., Nazmi, A. R., Shahri, B., Emerson, N., Müssig, J., & Huber, T. (2023). Visual–Tactile Perception of Biobased Composites. *Materials*, *16*(5), 1844. https://doi.org/10.3390/ma16051844

Treviranus, J. (2010). The Value of Imperfection: the Wabi-Sabi Principle in Aesthetics and Learning. *Open ED 2010 Proceedings*, *2010*, 1–10. http://openaccess.uoc.edu/webapps/o2/handle/10609/4869

Van Tonder, Lyons, M. J., & Gert, J. (2003). Structural order in Japanese "Karesansui" gardens. *South African Journal of Art History*, *18*.

Venzo, P. (2019). Wabi Sabi: Intermediated Textures of Impermanence and Imperfection. *Belas Infiéis*, *8*(3), 217–225. https://doi.org/10.26512/belasinfieis.v8.n3.2019.26340

Vermeir, I. (2020). How Visuals Affect Food Choice. *Foods*, *9*(12), 1835. https://doi.org/10.3390/foods9121835

Wolfs, E. L. M. (2015). Biophilic Design and Bio-Collaboration. *Archives of Design Research*, *113*(1), 71. https://doi.org/10.15187/adr.2015.02.113.1.71

Xia, Y., Shao, Y., Zheng, Y., Yan, X., & Lyu, H. (2024). Bridging Nature and Urbanization: A Comprehensive Study of Biophilic Design in the Knowledge Economy Era. *Journal of the Knowledge Economy*. https://doi.org/10.1007/s13132-024-02023-7

Yalch, R., & Brunel, F. (1996). Need hierarchies in consumer judgments of product designs: is it time to reconsider Maslow's theory? *Advances in Consumer Research*, *23*, 405–410.

Yoon, H. (1994). Two Different Geomentalities, Two Different Gardens: the French and the Japanese Cases. *GeoJournal*, *33*(4), 471–477.

Zhang, Y., Song, Y., & Luo, J. (2023). The Effect of Sustainable and Natural Looking on Perceived Aesthetics and Eco-Friendliness in Building Material Evaluation. *Buildings*, *13*(2), 483. https://doi.org/10.3390/buildings13020483

Zhong, W., Schröder, T., & Bekkering, J. (2022). Biophilic design in architecture and its contributions to health, well-being, and sustainability: A critical review. *Frontiers of Architectural Research*, *11*(1), 114–141. https://doi.org/10.1016/j.foar.2021.07.006

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Can Circular Economy Strategies Limit the Prospective Dysprosium Demand in the European Union?

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Keywords: Dysprosium; rare earths; demand; climate targets; circular economy.

Abstract: Dysprosium (Dy) is a high critical rare earth element, which is basically used for improving the thermo-magnetic properties in various low carbon products. This research provides a detailed examination on the evolution of Dy demand, in-use stock, and end-of-life (EoL) under ambitious climate targets and demand shrinkages that can be expected due to the implementation of two circular economy strategies: material efficiency and end-of-life recycling in 13 product sectors in the European Union from 2022 to 2050. Our results indicate that future Dy demand, in-use stock accumulation, and EoL generation are likely to be exacerbated by High-APS (Announced Pledges Scenario) and High-NZE (Net Zero Emissions by 2050 Scenario). Moreover, the circular economy strategies used in this study will contribute to significant decreases in the future Dy demand when such strategies are combined and applied in a high magnitude under High-APS and High-NZE scenarios. Recent efforts in the partial and full elimination of Dy mainly in high-tech products such as wind turbines and electrical vehicles are admirable, however, it is necessary to more focus on improving the implementation of circular economy strategies in manufacturing processes to mitigate future Dy supply uncertainties in the European Union.

Introduction

Rare earth elements (REEs) are critical materials for almost all regions due to the growing demand for low-carbon technologies (Eheliyagoda et al., 2023; Liu et al., 2022). The European Union (EU) is having a greater concern to become the global leader of manufacturing low-carbon emitting products that thrives the demand for REEs. Neodymium-iron-boron permanent magnets (NdFeBs) are the characteristic semi-products used to manufacture numerous low-carbon products in which a REE called dysprosium (Dy) is added to sharpen their high magnetic properties (Dai et al., 2023). However, Dy has already been identified as one of the most critical rare earths to the EU in meeting the future demand for clean energy products (European Commission, 2023).

Several factors can be highlighted regarding the high-risk status of Dy in the EU. First, Dy primary production is highly concentrated to outside the EU region, fundamentally to the Southern China (Seo and Morimoto, 2014). Dy belongs to the heavy rare earths group, but any of such minable reserves are not discovered within the EU to the authors knowledge. Due to this geological limitation, the EU should totally rely on imports of Dy materials to fulfill their demand that is expected to be even more in the future as a response to the European climate targets on reaching net-zero emissions. This eventually creates a competition for the Dy demand in the global market, so that, an uncertainty can be aggregated on the stability of affordable price ranges, which may directly affect to the EU clean high-tech manufacturing sector. Second, almost 100% of the heavy rare earth supply to the EU highly depends on China's exports. The limited consideration in the source diversification may increase future uncertainties in the supply chain. Last but not least, the promotion of the use of secondary REE materials in the products is under the least prioritized concern in the EU, which continues the demand for more virgin minerals. For instance, the recycling of REEs still maintains under a much lower rate, which has been denoted as less than 1% by some studies (Wang et al., 2022; Xiao et al., 2022).

Circular economy strategies play a vital role in decoupling the primary resource demand and increasing the longevity of products. Due to the geological unavailability for economically viable heavy rare earth reserves, focusing on circular economy principles can have a promising impact in addressing future Dy supply gaps for the EU. Therefore, this study aims to, (1) forecast the Dy demand, in-use stock accumulation, and end-of-life generation until 2050 considering three climate scenarios (i.e., the stated policies scenario (STEPS), the announced pledges scenario (APS), and the net zero emissions by 2050 scenario (NZE)) and, (2) model the impact of 2 circular economy strategies: material efficiency and end-of-life recycling in the future Dy demand decrease in the European Union.

Materials and Methods

System boundary and definition

This study used the EU (i.e., 27 countries) as the spatial boundary and the period between 2022 and 2050 as the temporal boundary. Accordingly, Dy flows, stocks, and end-of-life (EoL) from 2022 to 2050 were projected for the EU. Mining and beneficiation, refining and separation, fabrication, manufacturing, consumption, and end-of-life (EoL) management are the six life stages that make up the EU Dy cycle (Rasmussen et al., 2019). The historical figure of the EU Dy flows and stocks (i.e., from 1988 to 2021) was directly taken from a recent study published by Eheliyagoda et al. (2023) to construct future scenarios. Based on our earlier research, 13 product categories: computers, mobile phones, wind turbines, refrigerators, air conditioners, washing machines, e-bikes, electric vehicles, high-speed trains, ICE vehicles, industrial robots, MRI machines, and elevators were chosen to estimate the future Dy demand, in-use stock accumulation, and EoL generation under climate targets of the EU.

Dysprosium demand, in-use stock, and end-of-life forecasts

The application demand between 2022 and 2050 was calculated using several methods such as particular annual growth rates and logistic regression. A three-scenario strategy has been proposed by the International Energy Agency (IEA) to examine patterns in future global energy demand. They are Stated Policies Scenario (STEPS), Announced Pledges Scenario (APS), and Net Zero Emissions by 2050 Scenario (NZE). Accordingly, we used global level IEA consumption data on electric vehicles and wind turbines to derive their future European Dy demand scenarios. By observing the patterns of variations in the Dy consumption under these three ambitious climate targets, we nominated the STEPS as a low scenario, and the APS and NZE as high scenarios in the present study. Except for electric vehicles and wind turbines, the other product demand predictions for these three scenarios were based a variety of approaches. The EU future demands of the other products (excluding electric vehicles and wind turbines) were estimated under Low-STEPS, High-APS, and High-NZE scenarios, taking parameters such as changes in the number of households, device ownership, and regional population. The logistic growth model was appropriately used to project future scenarios. After forecasting demands of products, the stock-driven method was applied to estimate the in-use stock accumulation and EoL generation of each product. The in-use stock and EoL projections were based on the lifetime distribution function of commodities including Weibull and Normal distributions.

Demand reduction projections due to the application of circular economy strategies

This study used two circular economy strategies: material efficiency and end-of-life (EoL) recycling to measure the possible impact in the Dy demand decrease from 2022 to 2050 in the EU. These strategies were evaluated via five scenarios under each demand-side scenario (e.g., Low-STEPS, High-APS, and High-NZE). The forecasts were based on anticipated technological and strategical transformations from 2022 to 2050, with some assumptions supported by previous literature and industrial/technical reports (Dai et al., 2023; European Commission, 2023). In preparing material efficiency scenarios, we undertook a gradual decrease of 10%, 50%, and 50% in Dy amounts across various products by 2050 under Low-STEPS, High-APS, and High-NZE scenarios respectively based on technological advancements. In this case, a low technological modification is associated with Low-STEPS, whereas high technological modifications are associated with High-APS and High-NZE scenarios. It was assumed that the Dy amount per product would decrease annually according to the polynomial regression. End-of-life (EoL)

recycling scenarios were developed with the aim of facilitating sustainable resource use in the future through industrial, technological, and strategic transitions. We used two criteria in evaluating the situation: one based on a likely scenario (e.g., rational recycling), and the other on a speculative scenario (e.g., hypothetical recycling) to determine the optimal action. We assigned 1%, 25%, and 25% annual recycling rates until 2050 to Low-STEPS, High-APS, and High-NZE scenarios respectively to capture results under the rational EoL recycling condition. Furthermore, 30%, 90%, and 90% annual recycling rates until 2050 were assigned to Low-STEPS, High-APS, and High-NZE scenarios respectively to capture results under the hypothetical EoL recycling condition. Scenarios to represent the combined effect of these two circular strategies were also processed for identifying the best course of action.

Results

Dysprosium demand, in-use stock, and end-of-life projections under ambitious climate targets in the European Union

Figure 1 shows Dy application demand, in-use stock accumulation, and EoL generation of different product categories under Low-STEPS, High-APS, and High-NZE scenarios in the EU. The EU Dy demand will increase from 119 t to 235 t under Low-STEPS scenario, from 128 t to 445 t under High-APS scenario, and 128 t to 399 t under High-NZE scenario between 2022 and 2050. Furthermore, the in-use stock accumulation will rise from 0.86 kt to 3.48 kt under Low-STEPS scenario, from 0.87 kt to 6.19 kt under High-APS scenario, and from 0.87 kt to 6.59 kt under High-NZE scenario from 2022 to 2050. Moreover, total EoL generation will grow from 37 t to 174 t under Low-STEPS scenario, from 37 t to 277 t under High-APS scenario, and from 37 t to 309 t under High-NZE scenario between 2022 and 2050. Overall, wind turbines, electric vehicles, high-speed trains, and industrial robots will play the pivotal role in enhancing the future Dy demand and in-use stock. On the other hand, wind turbines, electric vehicles, and industrial robots will more contribute to increase the Dy EoL generation in the EU.

Impact of circular economy strategies in the dysprosium demand prospects in the European Union

Circular economy strategies can play an immense role to complement primary resource consumption in terms of critical materials (Wang et al., 2024). As shown in Figure 2, Dy demand can be decreased to a considerable extent from the implementation of circular strategies in higher proportions under High-APS and High-NZE scenarios in the future. Due to the implementation of the material efficiency strategy, the estimated Dy demands will decline to 188 t, 212 t, and 223 t under the High-APS climate scenario and to 274 t, 214 t, and 200 t under the High-NZE climate scenario by 2030, 2040, and 2050 respectively. Even though rational EoL recycling itself will not contribute to sufficient Dy demand reductions under all demand-side scenarios, hypothetical EoL recycling itself will alter the Dy demand to over a half of amount out of the estimated Dy demand accounting for 196 t and 121 t in High-APS and High-NZE scenarios by 2050. The combination of material efficiency and rational EoL recycling brings an excellent complement for the primary consumption showing up to 177 t and 146 t Dy demand shrinkages under High-APS and High-NZE scenarios by 2050 respectively. Moreover, the combination of material efficiency and hypothetical EoL recycling depicts up to 57 t and 7 t Dy demand reductions under High-APS and High-NZE scenarios by 2050 respectively. However, the Low-STEPS scenario will not adequately provide Dy demand decreases under the concerned circular economy strategies, which can be attributed to its status in the less technological transition. Overall, the combined effect and high magnitude in the substitution of circular economy strategies can make significance demand reductions in High-APS and High-NZE scenarios in upcoming decades.

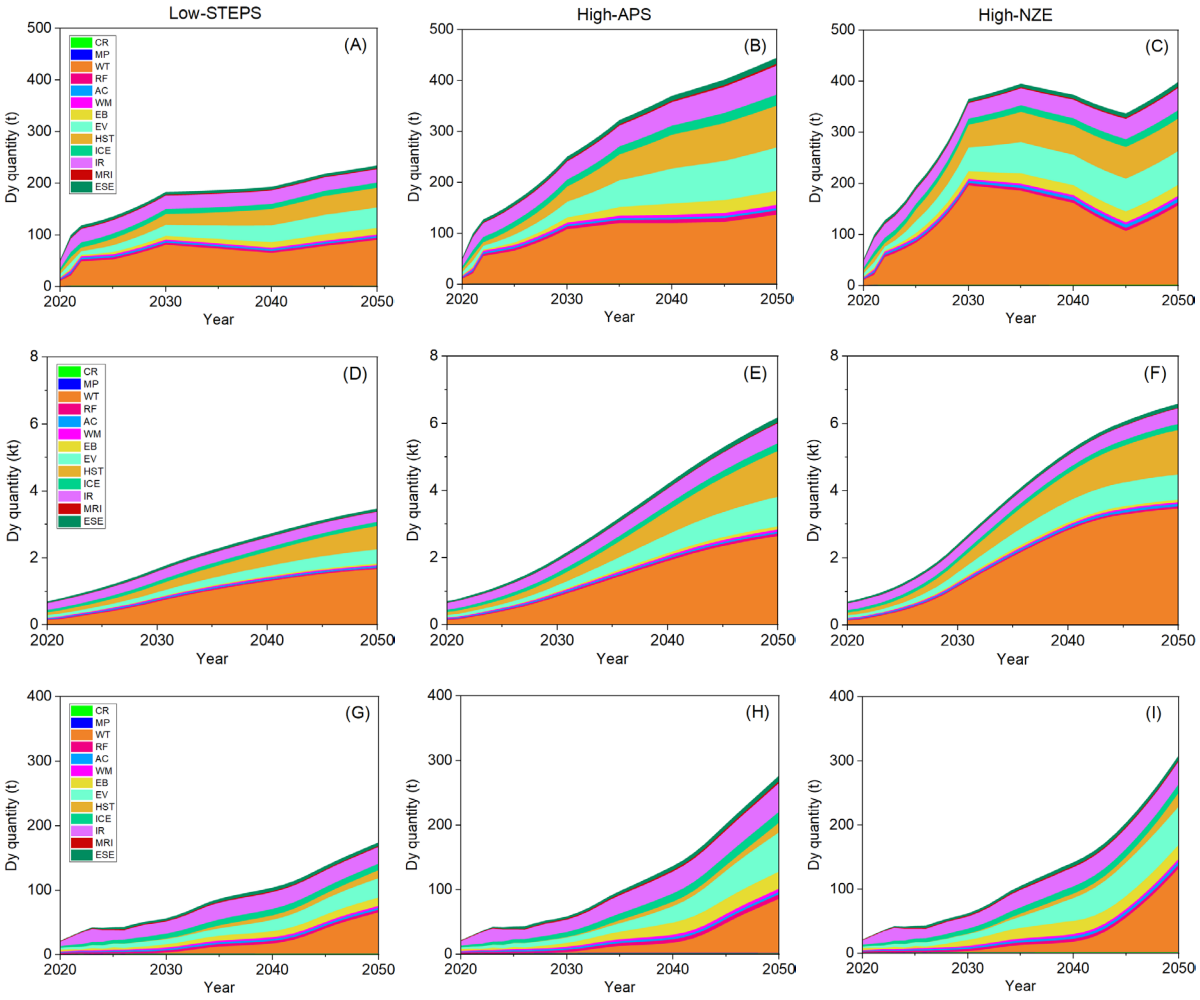


Figure 1 Dysprosium consumption, accumulation, and waste generation patterns under climate scenarios from 2020 to 2050 in the European Union. (A-C) Demand, (D-F) In-use stock, (G-I) End-of-life. Note: STEPS: Stated Policies Scenario, APS: Announced Pledges Scenario, NZE: Net Zero Emissions by 2050 Scenario, CR: computer, MP: mobile phone, WT: wind turbine, RF: refrigerator, AC: air conditioner, WM: washing machine, EB: e-bike, EV: electric vehicle, HST: high-speed train, ICE: internal combustion engine vehicle; IR: industrial robot, MRI: magnetic resonance imaging machine, and ESE: elevator.

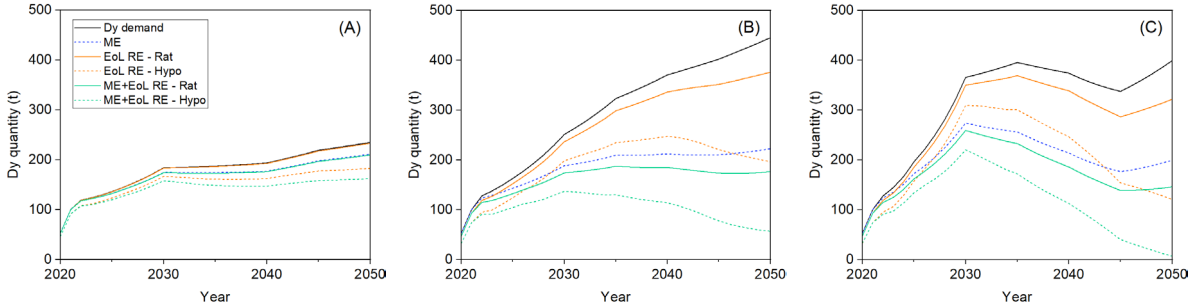


Figure 2 Effect of implementing circular economy strategies for dysprosium decoupling in the European Union. (A) Low-STEPS scenario, (B) High-APS scenario, (C) High-NZE scenario. Note: ME: material efficiency, EoL RE – Rat: end-of-life recycling – rational, EoL RE – Hypo: end-of-life recycling – hypothetical, ME+EoL RE – Rat: material efficiency + end-of-life recycling – rational, and ME+EoL RE – Hypo: material efficiency + end-of-life recycling – hypothetical.

Discussion

Regulatory and economic barriers on rare earth permanent magnet end-of-life applications in the European Union

A major policy-related challenge within the EU legislative framework is the lack of specific regulations requiring the provision of information about the magnets used in various EoL applications. Without standardized labeling or markings, magnet scrap must be manually extracted, sorted, and analyzed to identify the type of magnet and its material composition when EoL products are collected. This lack of clear information leads to significant uncertainty, making the recycling process both economically inefficient and more complex. The difficulty in accurately identifying magnet materials increases the time and costs associated with recycling, impeding the scalability of such processes. Implementing clear labeling requirements could significantly improve recycling efficiency, simplify sorting procedures, and support the sustainable recovery of valuable materials like rare-earth magnets, contributing to both economic and environmental goals. Another obstacle is the lack of sufficient financial incentives in the EU to support the secondary market for rare-earth magnets. Despite technological progress in rare earth recycling, secondary production remains at a considerable competitive disadvantage compared to primary production. This disparity makes it difficult for recycled rare-earth magnets to compete in terms of cost and scale, restricting the growth of a sustainable secondary market. Without stronger financial support or incentives, advancing toward a circular economy for rare earth materials becomes more challenging, limiting the potential for more sustainable and economically viable recycling solutions (Rizos et al., 2024).

The high cost involved in the recycling of magnets, especially during the extraction phase creates challenges in competing with the production of primary magnets. Furthermore, the price volatility of rare earths presents another obstacle as these fluctuations hinder the creation of sustainable business models for magnet recycling. Such instability makes it difficult to establish profitable recycling operations, slowing the development of a stable and sustainable secondary market for rare-earth magnets (Rizos et al., 2024).

Challenges and technical implications to meet future dysprosium constraints in the European Union

The EU high-tech manufacturing industry is expected to have a key role in shaping the future Dy demand. Based on foreseeable trends in the Dy demand, companies are moving to largely reduce or eliminate the usage of Dy from high-tech products such as electric vehicles and wind turbines. The unavailability of heavy rare-earth reserves, full import dependency, and the high cost incurred in the primary Dy importation can be denoted as main reasons that the EU should address to mitigate future supply uncertainties. To cope with uncertainties in the primary Dy supply, the EU is transforming to improve circular economy strategies in their production processes. Even though these strategies may not contribute to fully accommodate the primary supply issue, a considerable transition can be expected in the use reduction of Dy along with increasing the secondary supply. New varieties of NdFeB magnets with no or very little Dy have already been developed by a number of original equipment manufacturers (OEMs) (Dai et al., 2023). Furthermore, producers of NdFeB motors, which constitute significant amounts of Dy have begun manufacturing less REE or Dy products through various methods to lower costs and streamline supply chains (Sepehri-Amin et al., 2018). Moreover, Western nations have initiated research and development efforts to manufacture REE-free synchronous motors (e.g., the EU, France, and Slovenia), REE-free asynchronous motors (e.g., the EU), and magnet-free electric traction motors (e.g., Germany) (Dai et al., 2023). In order to fulfill the EU's future Dy demand, such techniques would be worth considering.

Longevity strategies to extend the lifetime of dysprosium-containing products

As the demand for dysprosium-containing products, particularly in electronics, electric vehicles, and renewable energy technologies, continues to rise, it becomes imperative to focus on strategies that extend their life cycle. Design approaches that prioritize durability, modularity, and energy efficiency can significantly enhance the longevity of products, ensuring that dysprosium-based components, such as magnets, remain functional over

extended periods. Moreover, regular maintenance, including monitoring for wear and implementing preventive upkeep, is essential in prolonging the operational lifespan of these products. Consumer education on proper usage and maintenance further contributes to preserving the integrity of dysprosium-containing systems. In addition, remanufacturing and recycling offer sustainable alternatives by reducing the need for new dysprosium extraction. Through the disassembly and refurbishment of products with recycled components, these practices minimize waste and conserve critical resources. By integrating these strategies, it is possible to mitigate the environmental impact associated with dysprosium, fostering a circular economy where valuable materials are reused and kept in circulation, thereby reducing reliance on mining efforts.

Conclusions

This study projected the evolution of the EU Dy demand, in-use stock, and end-of-life (EoL) based on the anticipated climate targets and the effect of two circular economy strategies (i.e., material efficiency and end-of-life recycling) in altering the demand between 2022 and 2050. Our findings show that High-APS and High-NZE scenarios are likely intensify the future Dy demand, in-use stock accumulation, and EoL generation. Industrial sectors such as wind turbines, electric vehicles, and industrial robots are more inclined to require Dy in the EU. Furthermore, the combination and the high scale of substitution of circular economy strategies can lead to significant demand reductions in the coming decades under High-APS and High-NZE scenarios. The EU efforts in recent technological advancements to minimize the Dy consumption are admirable, but they may not be able to fully address future Dy supply uncertainties. Therefore, it is important to more focus on the implementation of multiple circular economy strategies in their production processes to cope up future challenges in the Dy supply shortage and to improve the sustainable resource use in the EU manufacturing sector.

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References

Dai, T., Liu, Y. F., Wang, P., Qiu, Y., Mancheri, N., Chen, W., Liu, J. X., Chen, W. Q., Wang, H. & Wang, A. J. (2023). Unlocking Dysprosium Constraints for China's 1.5 degrees C Climate Target. Environmental Science & Technology, 57, 14113-14126. https://doi.org/10.1021/acs.est.3c01327

Eheliyagoda, D., Ramanujan, D., Veluri, B., Liu, Q. & Liu, G. (2023). Tracing the multiregional evolution of the global dysprosium demand-supply chain. Resources, Conservation and Recycling, 199, 107245. https://doi.org/10.1016/j.resconrec.2023.107245

European Commission (2023). Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU - a foresight study. https://data.europa.eu/doi/10.2760/386650

Liu, Q., Sun, K., Ouyang, X., Sen, B., Liu, L., Dai, T. & Liu, G. (2022). Tracking Three Decades of Global Neodymium Stocks and Flows with a Trade-Linked Multiregional Material Flow Analysis. Environmental Science & Technology, 56, 11807-11817. https://doi.org/10.1021/acs.est.2c02247

Rasmussen, K. D., Wenzel, H., Bangs, C., Petavratzi, E. & Liu, G. (2019). Platinum demand and potential bottlenecks in the global green transition: a dynamic material flow analysis. Environmental Science & Technology, 53, 11541-11551. https://doi.org/10.1021/acs. est.9b01912

Rizos, V., Righetti, E. & Kassab, A. (2024). Understanding the barriers to recycling critical raw materials for the energy transition: The case of rare earth permanent magnets. Energy Reports, 12, 1673-1682. http://doi.org/10.1016/j.egyr.2024.07.022

Seo, Y. & Morimoto, S. (2014). Comparison of dysprosium security strategies in Japan for 2010-2030. Resources Policy, 39, 15-20. https://doi.org/10.1016/j.resourpol.2013.10.007

Sepehri-Amin, H., Hirosawa, S. & Hono, K. (2018). Chapter 4 - Advances in Nd-Fe-B Based Permanent Magnets. Handbook of magnetic Materials, 27, 269-372. https://doi.org/10.1016/bs.hmm.2018.08.003

Wang, P., Yang, Y. -Y., Heidrich, O., Chen, L. -Y., Chen, L. -H., Fishman, T. & Chen, W. -Q., (2024). Regional rare-earth element supply and demand balanced with circular economy strategies. Nature Geoscience,

17, 94-102. https://doi.org/10.1038/s41561-023-01350-9

Wang, Q. -C., Chen, W. -Q., Wang, P. & Dai, T. (2022). Illustrating the supply chain of dysprosium in China through material flow analysis. Resources, Conservation and Recycling, 184, 106417. https://doi.org/10.1016/j.resconrec.2022.106417

Xiao, S., Geng, Y., Pan, H., Gao, Z. & Yao, T. (2022). Uncovering the key features of dysprosium flows and stocks in China. Environmental Science & Technology, 56, 8682-8690. https://doi.org/10.1021/acs.est.1c07724

Research paper
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Towards an integrative approach for ecodesign principles and sustainable material selection. A systematic literature review to explore scholarly contributions at the intersection of materials, sustainable design and household appliances

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Keywords: Ecodesign; Design for Sustainability; Sustainable Materials; Materials selection; Household Appliances

Abstract: Through a systematic literature review the scholarly contributions at the intersection of ecodesign, sustainable material selection, and the household appliance sector are explored. A comprehensive search was conducted on the Scopus database, yielding 181 initial results, which were narrowed down to 52 relevant documents for in-depth analysis. Notably, the review revealed a growing research interest in these areas, particularly since 2015, reflecting broader industry trends towards circular and sustainable production models. Key findings include the identification of eco-innovation drivers, approaches for sustainable product design and assessment, and the importance of validating research outcomes through real-world case studies. The analysis also pointed out an evolution in sustainable design strategies and material selection focus, shifting from sole materials recycling towards durability, repair and life-extension. Some overarching themes emerged across the reviewed documents, including the application of Life-Cycle-Thinking approaches together with LCA-based methods and a general push to foster the implementation of ecodesign strategies in early design phases to maximize their effectiveness. The review also allowed to identify and visualize a network of scholars focused on appliance-related research works. A significant finding is the relative scarcity of research that effectively aim at integrating ecodesign and material selection specifically for the appliance industry.

Introduction

Sustainable development and transition towards circular economy require a synergistic action of multiple actors such as governments, local authorities, companies, practitioners and consumers. For this reason, bridging academic knowledge and business realities can be a win-win opportunity: on one hand, it allows companies to gain innovative and long-termed insights from privileged observers into research issues; on the other hand, allows universities to become aware of real-world challenges that industries must face. To foster the creation of such bridges, the Italian Ministry of University and Research (MUR) has co-financed – together with Italian companies – innovative PhD scholarships framed within the National Recovery and Resilience Plan initiative "From research to business" to relaunch the Italian economy after the COVID-19 pandemic (MUR, 2023). One of these doctoral scholarships in Design entitled "*Towards a New Approach for a Holistic Integration of Sustainable Material Selection and Ecodesign in an Appliances Company*" was initiated by Politecnico di Milano together with the Italian cooking and washing appliances manufacturer Smeg S.p.A.

The rationale in which the research is rooted is the will to define a comprehensive approach to holistically integrate sustainable use of materials with Design for Sustainability-related strategies for household appliances projects to be applied within the Italian context. The proposed approach will address design innovation across multiple scales, ranging from the product and material lifecycle (ecodesign) to more comprehensive approaches (systemic design). This multi-tiered innovation strategy is guided by two key elements: design strategies that promote sustainability and circularity, and established material selection methods and tools, with a particular focus on environmental

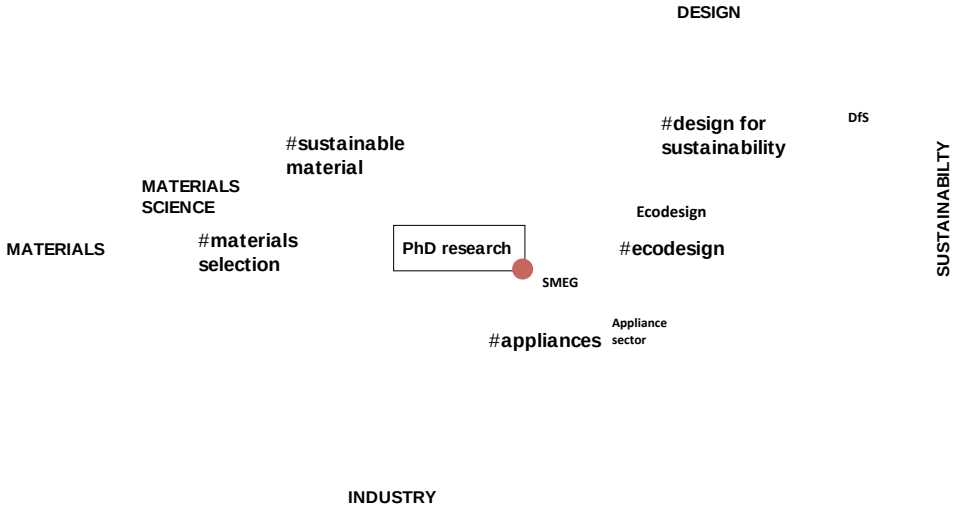


Figure 1. PhD research areas.

materials characteristics. Furthermore, the household appliance sector, with its regulatory landscape and industry-specific features, is taken into account to ensure the practical applicability and transferability of the research outcomes. Figure 1 depicts the three overlapping areas and disciplines involved in the PhD research: product design, materials and the household appliances industry with sustainability that runs across them all. Thus, the final aim of the doctoral research will be the harmonic integration of ecodesign principles into material selection for household appliances companies. Referring to broader sustainability theories, the PhD research primarily focuses on the "Product and Material" dimensions of the organizational circular economy (Uhrenholt, J. N. et al., 2022). Dialogue with companies in the development of doctoral theses in Design has been common practice at Politecnico di Milano for some years now and has always proven to foster better grounding of research results and to inform research based on concrete case studies (Italia, M., 2024; Papile, F., 2022; Piselli, A., 2018).

The content of this contribution concerns a systematic literature review in which the areas of design for sustainability (especially focused on the ecodesign approach) and material selection have been correlated with the appliance sector to map the existing network of scholars and types of contributions, useful to inform the abovementioned PhD research. This was done to identify possible convergences between sustainable and circular design strategies (Bakker, C. A. et al., 2014; Bhamra, T., & Lofthouse, V., 2016; Bocken, N. M. et al., 2016; Clark, G. et al., 2009; Vezzoli, C. & Manzini, E., 2008) and material selection (Ashby, M. F., 2022; Ashby, M. F., 2012; Ashby, M. F., & Johnson, K., 2013), as both these very broad fields individually show a vast corpus of specific literature.

A final introductory clarification is necessary: although in recent years Design for Sustainability (DfS) approaches have evolved both in scope (form the sole product to socio-technical system) and in the breadth of design problem framing (from technocentric to human-centric) (Ceschin, F., & Gaziulusoy, İ., 2019), ‘ecodesign’ was selected as keyword for two main reasons: sustainability in the household appliances sector in Italy is still strongly related to product and material lifecycles addressed by ecodesign; secondly, selecting keywords related to other DfS approaches, no relevant results were returned.
However, the approach resulting from the doctoral research will reflect the holistic evolution that has characterized ‘Design for X’ – where ‘X’ stands for several design approaches – in recent years (Moreno, M. et al.,

Query string	Limits	Records
TITLE-ABS-KEY (("design for sustainability") AND (appliance OR "domestic appliance" OR "home appliance" OR "household appliance"))	Years: 2004-2024 Langauage: English, Italian	2
TITLE-ABS-KEY ((ecodesign OR eco-design) AND (appliance OR "domestic appliance" OR "home appliance" OR "household appliance"))	Years: 2004-2024 Langauage: English, Italian	142
TITLE-ABS-KEY (("material selection") AND (appliance OR "domestic appliance" OR "home appliance" OR "household appliance"))	Years: 2004-2024 Langauage: English, Italian	32
TITLE-ABS-KEY (("sustainable material") AND (appliance OR "domestic appliance" OR "home appliance" OR "household appliance"))	Years: 2004-2024 Langauage: English, Italian	13

TITLE-ABS-KEY ((Appliance OR "domestic appliance" OR "home appliance" OR "household appliance") AND ("design for sustainability" OR ecodesign OR eco-design OR "material selection" OR "sustainable material"))

Figure 2. Scopus query string.

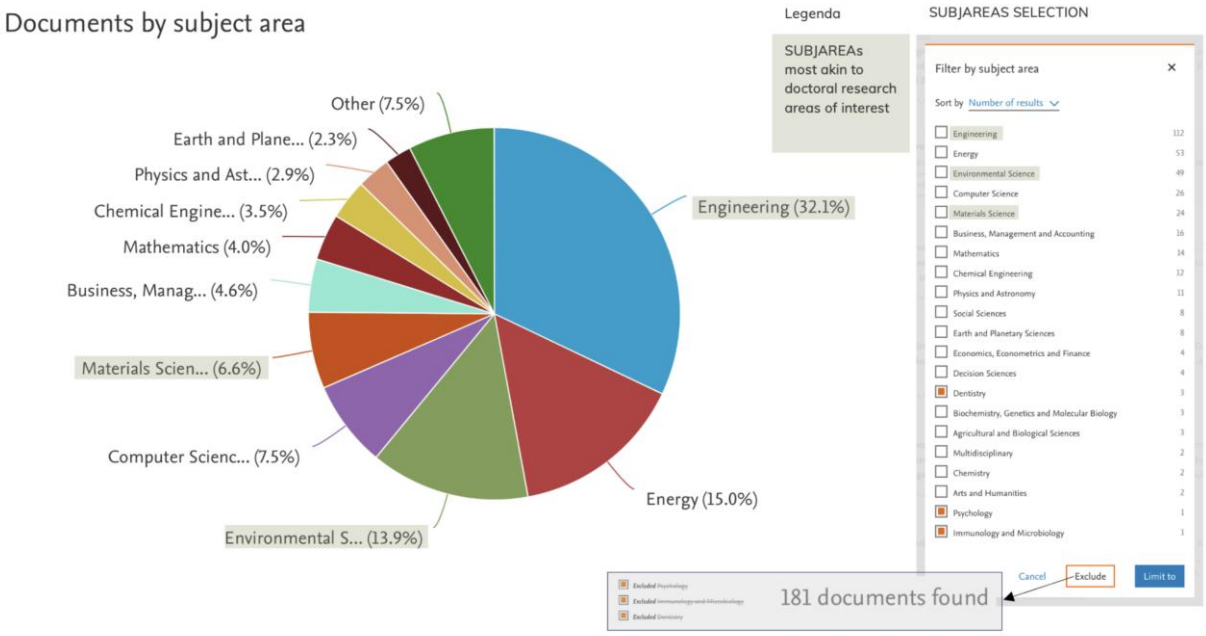


Figure 3. Subject areas exclusion limits and documents distribution.

2016), considering the relevance and importance of the further implications that go beyond the sole product level. In fact, holistic approaches seems to have the potential to pave the way to a wiser and more efficient use of materials (Allwood, J., 2011) for product design and for the implementation of circular economy principles (Bompan, E. & Brambilla, I., 2016).

Methods

Since the protocol adopted for conducting the literature review uses some items from PRISMA statement (Page, M. J. et al., 2021), but doesn't adopt it in full, the various steps followed will be described in detail to ensure maximum methodological transparency.

The review was conducted on Scopus database and the results are updated to June 2024.

To define the search string, four keywords were selected, two related to the design discipline (i.e. design for sustainability, ecodesign) and two related to the materials field (i.e. material selection, sustainable material). In order not to miss results, when necessary, keywords were associated with their synonyms through the Boolean logic operator 'OR'. The four keywords were then associated with the household appliances domain through the logical conjunction operator 'AND'. A search was then launched on the Scopus database to retrieve documents containing the required keywords combination within the article title, abstract or keywords; two further limits were also applied to the research results regarding the year of publication (2004-2024) and the language of the documents (English and Italian). Figure 2 summarizes the steps described above to shape the query string used to launch the advanced search on Scopus; in addition, the number of records for each keywords combination is also provided in the figure.

In order to narrow down the search results, an exclusion limit was applied to subject areas: dentistry, psychology, immunology and microbiology were thus excluded (Fig. 3). After some iterative verifications, based on records titles and keywords, it has been decided not to exclude certain disciplinary areas – such as computer science – distant from the main topics of interest of the doctoral research (Fig. 1) since they output relevant results (based on a preliminary screening carried out on the contribution titles).

The search, with these filters set, yielded 181 resulting documents. Figure 3 illustrates the distribution of records in the various subject areas: even if Scopus doesn't have subject area dedicated to design, others that returned the highest number of records are related to the areas of interest of the doctoral research: engineering (112), environmental science (49) and material science (24).

Afterwards, the 181 records were screened by title and abstract reading. Downstream this skimming process 52 documents were assessed for eligibility, 29 were left apart for further future information due to their minor relevance and 100 were discarded.

The following tools were used for data processing: OpenRefine for data extraction and refinement; Microsoft Excel for data systematisation; and RawGraphs for results visualization.

Findings and discussion

Table 1 in the Appendix provides key information on the 52 documents selected for analysis: contained search keyword(s); author(s); document title; publication year; author(s)'s keywords.

A first notable aspect to highlight is the substantial disparity between the results derived from the different keywords: in fact, 43 out of 52 of the eligible documents were retrieved since they contained the keyword 'ecodesign'; this is due to the fact that ecodesign is widespread in almost any project-based discipline (e.g. product design, packaging design, interior design, fashion and textile design, graphic design and visual communication, architecture and construction, urban planning and landscape architecture, industrial and manufacturing engineering, electronics and technology) to indicate design strategies that take sustainability-related criteria into account. At the same time, 'ecodesign' is a widely used term in standards and legislative acts, such as the Ecodesign for Sustainable Products Regulation (ESPR), which entered into force in July 2024 and will be

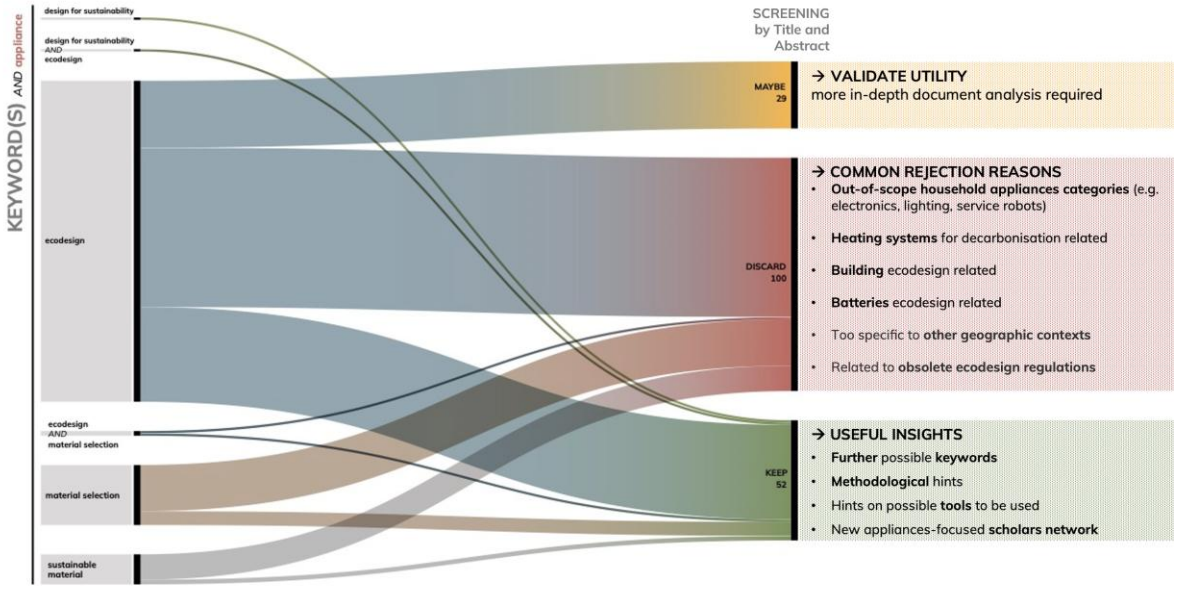


Figure 4. Rejection reasons and useful insights

the cornerstone of the European Commission's approach to more environmentally sustainable and circular products (European Commission, 2023). This interdisciplinary nature and the wide-ranging applications of the term 'ecodesign' make it an excellent umbrella term but, at the same time, it may produce many results outside the scope of a specific research. In contrast, the term 'material selection', is much more vertical and mainly used in the field of engineering and product design (Ashby, M. F., 2005) and it output fewer research results (7).

In this regard, an interesting exercise has been to analyze the reasons that led to the exclusion of several documents in the screening phase, many of which are precisely related to the broadness of the term ecodesign (Fig. 4).

Firstly, some papers were excluded because they focused on the ecodesign of artefacts not relevant to the doctoral research (e.g. building, batteries, heating systems); others, although more focused on industrial product design, involved appliances outside the cooking and washing scope. A further reason for exclusion concerned a geographical issue: some papers in fact concerned issues closely related to specific contexts (e.g. Asian) that are not consistent for the Italian one on which the doctoral research is focused. Finally, given the use of the term 'ecodesign' in legislative acts, several excluded documents addressed design issues aimed at ensuring compliance with regulations or standards that are now obsolete or replaced by updated versions.

In Figure 5, the distribution of documents over time is plotted. This timeline clearly visualizes and increasing research interest on topics related to ecodesign and sustainable material selection for appliances. In particular, the growth is more pronounced from 2015 onwards, and this is consistent with the results of other reviews on adjacent topics (Rotondo, B., & Arquilla, V., 2024). This result also reflect a more general trend towards the uptake of more circular and sustainable models in various industries (Bocken, N. M. et al., 2016; Ellen MacArthur Foundation, 2015; Pigosso, D .C. A. et al., 2013) and a materials landscape increasingly rich in new sustainability-oriented solutions and attentive to eco-informed selection (Genovesi, E., & Pellizzari A., 2021; Italia, M. et al., 2023; Papile, F. et al., 2020; Poblete, S. S. D. et al., 2024).

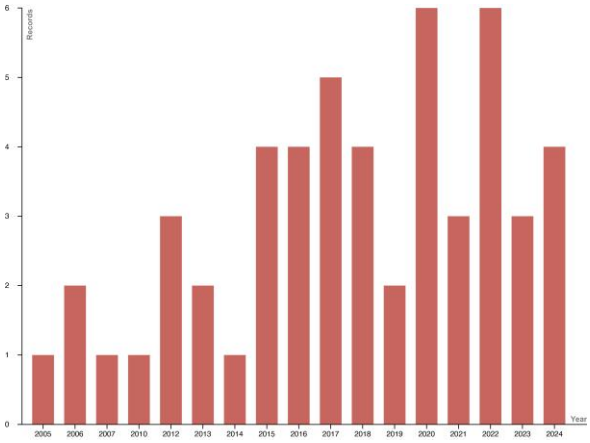


Figure 5. Distribution of documents by publication year

Insights from selected documents review

The documents selected for analysis offered several useful insights including further possible search keywords, hints on ecodesign methods and tools and material selection strategies.

Below, the main insights derived from the in-depth analysis of the documents are reported and discussed.

• *Eco innovation drivers*
Many authors have pointed out which drivers in the appliances sector give momentum to the sustainable transition. There are mainly two forces, one from the top down, and one from the bottom up: the first is connected to regulations imposing requirements for sustainable design, circular use of resources and proper end-of-life management; the second one is the ever-increasing consumers demand for responsibly designed products (Papetti, A. et al., 2017; Ardente, F. et al., 2015; Dostatni, E. et. al., 2015b; Karagiannopoulos, P.S. et al., 2024; Landi, D. et al., 2016; Kara, S. et al., 2006).

• *Approaches and tools for (re)design and assessment*
Common outcomes of appliance-related applied research consist in approaches or tools aimed at enabling more circular or sustainable (re)design of existing and/or new products; or tools aimed at obtaining environmental assessment of such products. Often, these research works make use of digital tools (e.g. virtual prototyping) and aim – whenever possible – to be interoperable with the design tools used in industry (e.g. CAD, CAE, CFD, FEM, etc.) (Germani, M. et al., 2015; Dudkowiak, A. et al., 2021; Favi, C. et al., 2018; Peters, H. A., et al., 2012; Kara, S. et al., 2006; Germani, M. et al., 2013).

• *Validation on real cases*
A recurring aspect is that the abovementioned approaches or tools that are developed in research undergo a validation process through applicability tests in firms or pilot projects (Germani, M. et al., 2015; Papetti, A. et al., 2017; Landi, D., & Cicconi, P., 2022; Favi, C. et al., 2018; Piselli, A. et al., 2016).

• *Guidelines extraction*
Furthermore, it is often the case that the main takeaways derived from applied research activities, case study tests and literature reviews are then translated into guidelines or other forms knowledge base to foster eco-informed design and materials choices (Favi, C., et al., 2024; Zong, J. et al., 2019; Rodríguez, N. B., & Favi, C., 2022; Rodríguez, N. B., et al., 2023; Favi, C., et al., 2016; Peters, H. A., et al., 2012).

• *Household appliances and packaging*
The analyzed papers, in most cases, focus on large or small cooking or washing appliances (dishwashers, extractor hoods, hobs, electric kettles, etc.). However, in some cases, packaging becomes the subject of research, since acting on the materials that constitute the packaging systems and ensuring their proper management, it is possible to reduce the overall impacts associated with the household appliance itself (Landi, D., & Cicconi, P., 2022; Postacchini, L., et al., 2021; Landi, D., et al., 2020)

• *Consumers behavior*
An assumption underlying some of the documents analyzed concerns the recognition of the key influence of consumer behavior on sustainability and the importance of working on it through Design for Sustainable Behaviour-related interventions (Withanage, C., et al., 2016). Household appliance usage patterns, as well as food habits and diets (Favi, C., et al., 2020), can greatly influence the related impacts. Therefore, if design takes the user into

consideration, it is possible to reduce the impacts related to the use phase by increasing energy efficiency (Boyano, A., et al., 2020) and to evaluate different end-of-life options (Pérez-Belis, V. et al., 2017).

• *Design for X*
In recent years, we witnessed a product development process with an increasingly holistic approach, able to consider multiple aspects of the product in design decisions and capable of integrating circularity and sustainability issues. This resulted in the development of several 'Design for X' (DfX) techniques (Holt, R., & Barnes, C., 2010), each one with a specific focus and many aimed at fostering more sustainable design choices (e.g. Design for Remanufacturing, etc.). As evidence of this trend, several DfX strategies are implicitly or explicitly referred to in the reviewed documents. The most cited are Design for Assembly, Design for Energy Efficiency, Design for Disassembly and Design for Repair (Rodríguez, N. B., & Favi, C., 2022; Bracquené, E., et al., 2021; Favi, C. et al., 2018; Postacchini, L., et al., 2021; Wichniarek, R. et. al., 2018; Favi, C., & Germani, M., 2012; Collado-Ruiz, D., et al., 2007). In particular, with respect to the last mentioned strategy, some papers (Rodríguez, N. B., et al., 2023; Boix Rodríguez, N., & Favi, C., 2022) also refer to possible metrics to measure repairability – the so-called 'repairabilty index' – a very topical issue given the recent European debate around the 'Right to Repair' legislation aimed at making repair easier and more appealing to consumers (European Parliament, 2024). In general, especially in more recent documents, the trend is towards strategies to favor reuse, upgrading, repair and product life extension.

• *Material selection*
Analyzing material selection-focused documents, it can be observed that in older records reference is made mainly to materials recycling (Peters, H. A., et al., 2012; Luttropp, C. et al., 2010; Johansson, J., & Luttropp, C., 2006). In more recent papers, the focus shifts to durability and longevity (Bakırlıoğlu, Y., & Doğan, Ç., 2020) which are recognized as preferable solutions to recycling. Other issues related to sustainability in the use of materials for appliances are the following: importance of incorporating eco-properties in material selection (Guo, A. H., 2014); crucial role of material selection to ensure durability, considering requirements such as heat (Kaushik, D., et al., 2024) and chemical resistance (Basso, M. et al., 2017); and evaluating alternative material solutions to those already in use ('material replacement') (Piselli, A. et al., 2018; Anjumol, K. S. et al., 2022). Finally, Skorup, D. (2022) study demonstrates the impact that material selection can have on environmental impact through Life-Cycle-Assesment (LCA) studies.

As a concluding remark of this section, two aspects appear in most of the documents: the widespread application of Life-Cycle-Thinking (LCT) approach supported by Life Cycle Assessment method; and the will to implement ecodesign strategies since the early design phases to maximize the impact reduction.

Appliances-focused scholars

By extrapolating data on authors and co-authors of the selected articles, it was also possible to map a network of appliances-focused scholars.

Figure 6 offers a comprehensive view of authors and co-authors of the documents that passed the screening phase. Based on the results, it is possible to highlight scholars who authored or co-authored more contributions. In ecodesign-related publications the most prolific are Germani M. (15 records), Favi C. (14), Dostatni E. (9), Landi D. (8), Cicconi P. (7), Grajewski D. (7). Notably, can be noticed a co-authorship on multiple contribution (Tab. 1) by Germani, Favi, Landi and Cicconi, affiliated to different Italian research institutions (respectively UNIVPM, UniPr, UniBg and UNIVPM).

Regarding material selection, the main authors identified are Simonato M. (3 records), Del Curto B. (2) and Piselli A. (2) who co-authored of publications focused on the approach to materials selection in the professional appliances industry (Piselli, A. et al., 2018; Piselli, A. et al., 2016).

A further aspect of interest to highlight is that only two scholars – namely Ng C.Y. and Chuah K.B. – co-authored a contribution which

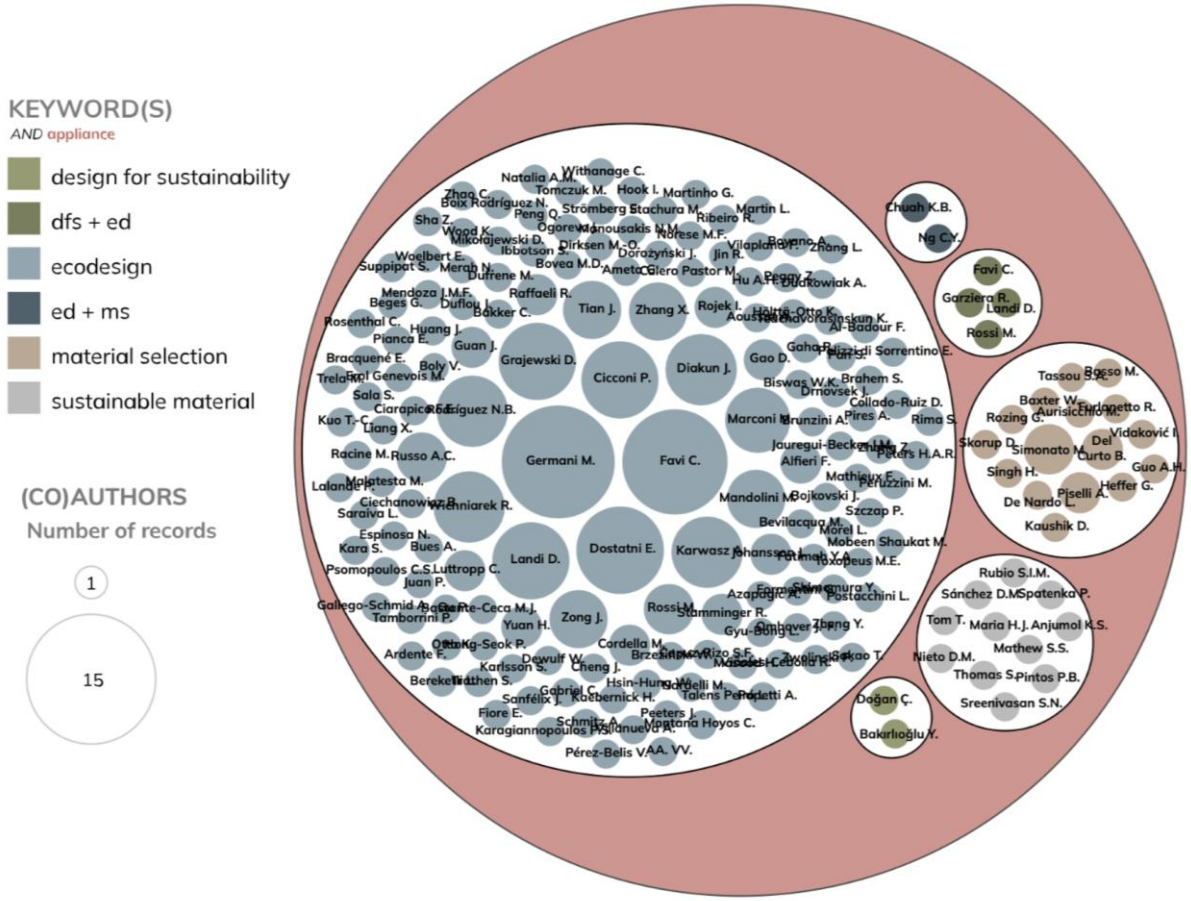


Figure 6. Appliances-focused scholars

combines the keywords ecodesign, material selection and appliance (Ng, C. Y., & Chuah, K. B., 2012). This evidence confirms that – at least limited to Scopus database – a substantial body of literature aiming at an effective integration of ecodesign and material selection for the appliances sector is still lacking.

Conclusions, perspectives and limitations

The systematic review has revealed several insights at the intersection of ecodesign, sustainable material selection, and household appliance sector. The analysis of 52 selected documents highlights a growing research interest in these areas, particularly since 2015, reflecting broader industry trends towards circular and sustainable production models. Through this in-depth analysis, common themes were identified such as eco-innovation drivers, approaches for sustainable (re)design and assessment, and the importance of validating research outcomes through real-world case studies. The review also highlighted the evolution of sustainable design strategies and material selection focus from recycling to durability and longevity, aligning with current sustainability paradigms. A notable remark is the relative scarcity of research products aimed at holistically integrating ecodesign and material selection tailored for the appliance industry, and this indicates a research gap that wants to be filled through the doctoral research described in the introduction.

A general suggestion for future Scopus searches using ‘ecodesign’ as a keyword is to narrow the search to the categories of artefacts in the scope of the research using the appropriate logical operators in the query string. Furthermore, if the research deals with topics

related to legal acts on ecodesign, it may be useful to limit the search to the last 10 years.

Finally, it is important to remark that the search is limited to publications indexed on Scopus database, thus contributions available on other databases have been excluded.

References

Anjumol, K. S., Sreenivasan, S. N., Tom, T., Mathew, S. S., Maria, H. J., Spatenka, P., & Thomas, S. (2022). Development of natural fiber-reinforced flame-retardant polymer composites. In Bio-Based Flame-Retardant Technology for Polymeric Materials(pp. 369-389). Elsevier https://doi.org/10.1016/B978-0-323-90771-2.00010-9

Ardente, F., Pastor, M. C., Mathieux, F., & Peiró, L. T. (2015). Analysis of end-of-life treatments of commercial refrigerating appliances: Bridging product and waste policies. Resources, Conservation and Recycling, 101, 42-52 https://doi.org/10.1016/j.resconrec.2015.05.005

Ashby, M. F. (2022). Materials and sustainable development. Butterworth-Heinemann

Ashby, M. F. (2012). Materials and the environment: eco-informed material choice. Elsevier

Ashby, M. F., & Johnson, K. (2013). Materials and design: the art and science of material selection in product design. Butterworth-Heinemann. pp. 133-139

Ashby, M. F. (2005). Materials Selection in Mechanical Design. Elsevier Science

Allwood, J. M., Ashby, M. F., Gutowski, T. G., & Worrell, E. (2011). Material efficiency: A white paper. Resources, conservation and recycling, 55(3), 362-381 https://doi.org/10.1016/j.resconrec.2010.11.002

Bakirlioğlu, Y., & Doğan, Ç. (2020). Exploring product/part longevity in open design of small kitchen appliances. The Design Journal, 23(6), 885-905 https://doi.org/10.1080/14606925.2020.1826635

Bakker, C. A., Den Hollander, M. C., Van Hinte, E., & Zijlstra, Y. (2014). Products that last: Product design for circular business models. TU Delft Library

Basso, M., Simonato, M., Furlanetto, R., & De Nardo, L. (2017). Study of chemical environments for washing and descaling of food processing appliances: An insight in commercial cleaning products. Journal of Industrial and Engineering Chemistry, 53, 23-36 https://doi.org/10.1016/j.jiec.2017.03.041

Bhamra, T., & Lofthouse, V. (2016). Design for sustainability: a practical approach. Routledge

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy, Journal of Industrial and Production Engineering, 33(5), 308– 320. doi:10.1080/21681015.2016.1172124

Boix Rodríguez, N., & Favi, C. (2022). Disassembly analysis of gas cooktops: towards eco-design rules for product repairability. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 86250). American Society of Mechanical Engineers https://doi.org/10.1115/DETC2022-89860

Boix Rodríguez, N., & Favi, C. (2023). De-manufacturing Analysis for Product Repairability and Serviceability in Cooking Systems. In Proceedings of the Changeable, Agile, Reconfigurable and Virtual Production Conference and the World Mass Customization & Personalization Conference (pp. 452-460). Springer International Publishing https://doi.org/10.1007/978-3-031-34821-1_49

Bompan, E., Brambilla, I. (2016). Che cosa è l'economia circolare. Milano: Edizioni Ambiente

Boyano, A., Espinosa, N., & Villanueva, A. (2020). Rescaling the energy label for washing machines: an opportunity to bring technology development and consumer behaviour closer together. Energy Efficiency, 13, 51-67 https://doi.org/10.1007/s12053-019-09829-4

Bracquené, E., Peeters, J., Alfieri, F., Sanfelix, J., Duflou, J., Dewulf, W., & Cordella, M. (2021). Analysis of evaluation systems for product repairability: A case study for washing machines. Journal of Cleaner Production, 281, 125122 https://doi.org/10.1016/j.jclepro.2020.125122

Ceschin, F., & Gaziulusoy, İ. (2019). Design for sustainability: A multi-level framework from products to socio-technical systems. Routledge. pp. 12-22 https://doi.org/10.4324/9780429456510

Clark, G., Kosoris, J., Hong, L. N., & Crul, M. (2009). Design for sustainability: current trends in sustainable product design and development. Sustainability, 1(3), 409-424 https://doi.org/10.3390/su1030409

Collado-Ruiz, D., Bastante-Ceca, M. J., Viñoles-Cebolla, R., & Capuz-Rizo, S. F. (2007). Identification of Common Strategies for Different Electric and Electronic Equipment in Order to Optimize their End-of-Life. In DS 42: Proceedings of ICED 2007, the 16th International Conference on Engineering Design, Paris, France, 28.-31.07. 2007 (pp. 147-148)

Dostatni, E., Diakun, J., Grajewski, D., Wichniarek, R., & Karwasz, A. (2015a). Functionality assessment of ecodesign support system. Management and Production Engineering Review, 6(1), 10-15 DOI: 10.1515/mper-2015-0002

Dostatni, E., Diakun, J., Grajewski, D., Wichniarek, R., & Karwasz, A. (2015b). Multi-agent system to support decision-making process in ecodesign. In 10th international conference on soft computing models in industrial and environmental applications (pp. 463-474). Springer International Publishing https://doi.org/10.1007/s00500-016-2302-z

Dostatni, E., Diakun, J., Wichniarek, R., Karwasz, A., & Grajewski, D. (2018). Product variants recycling cost estimation with the use of multi-agent support system. In Advances in Manufacturing (pp. 311-320). Springer International Publishing DOI: 10.1007/978-3-319-68619-6_30

Dostatni, E., Mikołajewski, D., Dorożyński, J., & Rojek, I. (2022). Ecological design with the use of selected inventive methods including AI-based. Applied Sciences, 12(19), 9577 https://doi.org/10.3390/app12199577

Dostatni, E., Rojek, I., Szczap, P., & Tomczuk, M. (2019). Inventive Methods in Designing an Environmentally Friendly Household Appliance. In Innovation, Engineering and Entrepreneurship (pp. 347-353). Springer International Publishing https://doi.org/10.1007/978-3-319-91334-6_47

Dudkowiak, A., Grajewski, D., & Dostatni, E. (2021). Analysis of selected IT tools supporting eco-design in the 3D CAD environment. IEEE Access, 9, 134945-134956 DOI: 10.1109/ACCESS.2021.3116469

Ellen MacArthur Foundation. (2015). Towards a circular economy: Business rationale for an accelerated transition. https://www.ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition

European Commission. (2023). Ecodesign for Sustainable Products Regulation. European Commission. https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en

European Parliament. (2024, April 23). Right to repair: Making repair easier and more appealing to consumers | News | European Parliament. www.europarl.europa.eu. https://www.europarl.europa.eu/news/en/press-room/20240419IPR20590/right-to-repair-making-repair-easier-and-more-appealing-to-consumers

Favi, C., & Germani, M. (2012). A method to optimize assemblability of industrial product in early design phase: from product architecture to assembly sequence. International Journal on Interactive Design and Manufacturing (IJIDeM), 6, 155-169 DOI: 10.1007/s12008-012-0147-y

Favi, C., Formentini, G., & Rodríguez, N. B. (2020). Eco-design of cooking appliances based on food habits and diets. Procedia CIRP, 90, 372-376 DOI: 10.1016/j.procir.2020.02.054

Favi, C., Germani, M., Mandolini, M., & Marconi, M. (2016). Includes knowledge of dismantling centers in the early design phase: a knowledge-based design for disassembly approach. Procedia Cirp, 48, 401-406 https://doi.org/10.1016/j.procir.2016.03.242

Favi, C., Germani, M., Mandolini, M., & Marconi, M. (2018). Implementation of a software platform to support an eco-design methodology within a manufacturing firm. International Journal of Sustainable Engineering, 11(2), 79-96 DOI: 10.1080/19397038.2018.1439121

Favi, C., Landi, D., Garziera, R., & Rossi, M. (2024). Fostering Design for Sustainability through the Adoption of Computer-Aided Engineering Tools in the Development of Energy-Related Products. Sustainability, 16(9), 3516 DOI: 10.3390/su16093516

Fiore, E., Tamborrini, P., & Norese, M. F. (2016, September). Designing major appliances: A decision support model. In 2016 Electronics Goes Green 2016 (EGG) (pp. 1-8). IEEE DOI: 10.1109/EGG.2016.7829816

Germani, M., Dufrene, M., Mandolini, M., Marconi, M., & Zwolinski, P. (2013). Integrated software platform for green engineering design and product sustainability. In Re-engineering Manufacturing for Sustainability: Proceedings of the 20th CIRP International Conference on Life Cycle Engineering, Singapore 17-19 April, 2013 (pp. 87-92). Springer Singapore DOI: 10.1007/978-981-4451-48-2_14

Germani, M., Mandolini, M., Marconi, M., & Rossi, M. (2015). Usability demonstration of the G. EN. ESI eco-design platform: the cooker hood case study. In International Design

Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 57113). American Society of Mechanical Engineers DOI: 10.1115/DETC2015-46361

Guo, A. H. (2014). Research and Exploration on Green Design of Household Electrical Appliances. Advanced Materials Research, 945, 531-534 DOI: 10.4028/www.scientific.net/AMR.945-949.531

Genovesi, E., Pellizzari A. (a cura di) (2021). Neomateriali nell'economia circolar e 2.0. Milano: EdizioniAmbiente

Holt, R., & Barnes, C. (2010). Towards an integrated approach to "Design for X": an agenda for decision-based DFX research. Research in engineering design, 21, 123-136 DOI: 10.1007/s00163-009-0081-6

Italia, M. (2024). Guiding sustainable transition in organisation through design : a framework to promote solutions that foster transition and transform corporate culture towards sustainability [Doctoral dissertation, Politecnico di Milano]. https://hdl.handle.net/10589/221492

Italia, M., Papile, F., Santi, R., & Del Curto, B. (2023). Sustainable Material Selection Framework: Taxonomy and Systematisation of Design Approaches to Sustainable Material Selection. Sustainability, 15(24), 16689 DOI: 10.3390/su152416689

Johansson, J., & Luttropp, C. (2006). Material Hygiene, An EcoDesign Mindset for Optimized Material Use. Proceedings of 13th CIRP Life Cycle Engineering 2006 volume 2, 389-392

Kara, S., Kaebernick, H., & Ibbotson, S. (2006). Using design for environment for redesigning a household appliance. In Innovation in Life Cycle Engineering and Sustainable Development (pp. 293-302). Springer Netherlands DOI: 10.1007/1-4020-4617-0_20

Karagiannopoulos, P. S., Manousakis, N. M., & Psomopoulos, C. S. (2023). "3R" practices focused on home appliances sector in terms of green consumerism: principles, technical dimensions and future challenges. IEEE Transactions on Consumer Electronics https://doi.org/10.1109/TCE.2023.3318874

Kaushik, D., Singh, H., & Tassou, S. A. (2024). Vacuum insulation panels for high-temperature applications–Design principles, challenges and pathways. Thermal Science and Engineering Progress, 102415 DOI: 10.1016/j.tsep.2024.102415

Kuo, T. C., & Hsin-Hung, W. (2005). Fuzzy eco-design product development by using quality function deployment. In 2005 4th International Symposium on Environmentally Conscious Design and Inverse Manufacturing(pp. 422-429). IEEE DOI: 10.1109/ECODIM.2005.1619260

Landi, D., & Cicconi, P. (2022). An approach for the responsible design of the packaging employed in household appliances. In International Conference on Design, Simulation, Manufacturing: The Innovation Exchange (pp. 381-389). Cham: Springer International Publishing DOI: 10.1007/978-3-030-91234-5_39

Landi, D., Cicconi, P., & Germani, M. (2020a). Analyzing the environmental sustainability of packaging for household appliances: A test case. Procedia CIRP, 90, 355-360 https://doi.org/10.1016/j.procir.2020.01.106

Landi, D., Cicconi, P., Germani, M., & Russo, A. C. (2016). A methodological approach to support the design of induction hobs. In ASME International Mechanical Engineering Congress and Exposition (Vol. 50657). American Society of Mechanical Engineers DOI: 10.1115/IMECE2016-65661

Landi, D., Rossi, M., Favi, C., Brunzini, A., & Germani, M. (2020b). A virtual design approach to simulate the hob energy performance. Computer-Aided Design and Applications, 17(5) DOI: 10.14733/cadconfP.2019.127-131

Luttropp, C., Johansson, J., Vilaplana, F., Strömberg, E., & Karlsson, S. (2010). Design for material hygiene-An ecodesign strategy for improved recycling of polymers. In 8th International Symposium on Tools and Methods of Competitive Engineering, TMCE 2010; Ancona; 12 April 2010 through 16 April 2010 (pp. 1223-1231)

Ministero dell'Università e della Ricerca. (2023). Investimento 3.3 - Introduzione di dott. innovativi che rispondono ai fabbisogni di innovazione delle imprese e promuovono l'assunzione dei ric. da parte delle imprese. Retrieved November 2, 2024, from https://www.mur.gov.it/it/pnrr/misure-e-componenti/m4c2/investimento-33-introduzione-di-dott-innovativi-che

Moreno, M., De los Rios, C., Rowe, Z., & Charnley, F. (2016). A conceptual framework for circular design. Sustainability, 8(9), 937 DOI: 10.3390/su8090937

Ng, C. Y., & Chuah, K. B. (2012). Effect of material selection on the life cycle assessment of environmental impact. Advanced Materials Research, 383, 3387-3394 DOI: 10.4028/www.scientific.net/AMR.383-390.3387

Nieto, D. M., Pintos, P. B., Sánchez, D. M., & Rubio, S. I. M. (2022). Large Format Additive Manufacturing in Furniture Design with Novel Cork Based Polymeric Materials. In International conference on The Digital Transformation in the Graphic Engineering (pp. 477-489). Cham: Springer International Publishing https://doi.org/10.1007/978-3-031-20325-1_38

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. bmj, 372

Papetti, A., Germani, M., Marconi, M., & Favi, C. (2017). Lifecycle tools as a support for the eco-design innovation of domestic appliances. In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (Vol. 58165). American Society of Mechanical Engineers https://doi.org/10.1115/DETC2017-68141

Papile, F. (2022). O.S.M.O.S.I.S. Methods and tools to reframe material selection. A cooperative approach for industrial companies towards sustainable transition [Doctoral dissertation, Politecnico di Milano]. https://hdl.handle.net/10589/188693

Papile, F., Del Curto, B., Coccia, A. (2020). System thinking & synthesis mapping to manage product material selection process. Proceedings of Relating Systems Thinking and Design RSD9 Symposium, NID Ahmedabad. In: Systemic Design for Well-Being: From human to humane. Peter Jones

Pérez-Belis, V., Bakker, C., Juan, P., & Bovea, M. D. (2017). Environmental performance of alternative end-of-life scenarios for electrical and electronic equipment: a case study for vacuum cleaners. Journal of Cleaner Production, 159, 158-170 https://doi.org/10.1016/j.jclepro.2017.05.032

Peruzzini, M., Raffaeli, R., Malatesta, M., & Germani, M. (2017). Toward a function-based IT platform for variants redesign of household appliances. AI EDAM, 31(4), 512-534 DOI: 10.1017/S089006041700042

Peters, H. A., Toxopeus, M. E., Jauregui-Becker, J. M., & Dirksen, M. O. (2012). Prioritizing 'Design for Recyclability'guidelines, bridging the gap between recyclers and product developers. In Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, University of California at Berkeley, Berkeley, USA, May 23-25, 2012 (pp. 203-208). Springer Berlin Heidelberg DOI: 10.1007/978-3-642-29069-5_35

Pigosso, D .C. A., Rozenfeld, H., & McAloone, T. C. (2013). Ecodesign maturity model: A management framework to support ecodesign implementation into manufacturing companies. Journal of Cleaner Production, 59, 160– 173 https://doi.org/10.1016/j.jclepro.2013.06.040

Piselli, A. (2018). Material selection in the professional appliances industry. Methods and tools for evaluating sensory criteria and aesthetic obsolescence of materials [Doctoral dissertation, Politecnico di Milano]. https://hdl.handle.net/10589/137861

Piselli, A., Baxter, W., Simonato, M., Del Curto, B., & Aurisicchio, M. (2018). Development and evaluation of a methodology to integrate technical and sensorial properties in materials selection. Materials & Design, 153, 259-272 https://doi.org/10.1016/j.matdes.2018.04.081

Piselli, A., Simonato, M., & Del Curto, B. (2016). Holistic approach to materials selection in professional appliances industry. In DS 84: Proceedings of the DESIGN 2016 14th International design conference (pp. 865-874)

Postacchini, L., Cicconi, P., Ciarapica, F. E., Germani, M., & Bevilacqua, M. (2021). A design method for improving assembly and environmental sustainability in packaging solutions: A case study in household appliances. International Journal of Sustainable Engineering, 14(4), 574-589 https://doi.org/10.1080/19397038.2021.1920644

Poblete, S. S. D., Romani, A., & Rognoli, V. (2024). Emerging materials for transition: A taxonomy proposal from a design perspective. Sustainable Futures, 7, 100155 DOI: 10.1016/j.sftr.2024.100155

Rodríguez, N. B., & Favi, C. (2022). Eco-design guidelines takeaways from the analysis of product repairability and ease of disassembly: a case study for electric ovens. Procedia CIRP, 105, 595-600 DOI: 10.1016/j.procir.2022.02.099

Rodríguez, N. B., & Favi, C. (2023). Life Cycle Impact Assessment of Mechatronic Products: Towards Engineering Eco-Design for Hobs Technologies. In International Conference of the Italian Association of Design Methods and Tools for Industrial Engineering (pp. 100-107). Cham: Springer Nature Switzerland DOI: 10.1007/978-3-031-58094-9_12

Rodríguez, N. B., Gabriel, C., Gaha, R., & Favi, C. (2023). Analysis of disassembly parameters in repairability scores: limitations for engineering design and suggestions for improvement. Procedia CIRP, 116, 738-743 DOI: 10.1016/j.procir.2023.02.124

Rotondo, B., & Arquilla, V. (2024). Exploring the role of design in the new product development process towards circular business innovation: Systematic literature review and future directions https://doi.org/10.21606/drs.2024.492

Skorup, D., Rozing, G., Heffer, G., & Vidaković, I. (2022). Product life cycle analysis on the example of a home appliance. In 30th International Conference on Organization and Technology of Maintenance (OTO 2021) Proceedings of 30th International Conference on Organization and Technology of Maintenance (OTO 2021) (pp. 217-227). Springer International Publishing DOI: 10.1007/978-3-030-92851-3_16

Uhrenholt, J. N., Kristensen, J. H., Rincón, M. C., Adamsen, S., Jensen, S. F., & Waehrens, B. V. (2022). Maturity model as a driver for circular economy transformation. Sustainability, 14(12), 7483 https://doi.org/10.3390/su14127483

Vezzoli, C.; Manzini, E. Design for Environmental Sustainability; Springer: London, UK, 2008

Wichniarek, R., Grajewski, D., Diakun, J., Dostatni, E., & Karwasz, A. (2018). Automatization of the ecodesign process of small household appliances based on CAD 3D system. Tehnički vjesnik, 25(1), 18-25 DOI: 10.17559/TV-20160602135201

Withanage, C., Hölttä-Otto, K., Otto, K., & Wood, K. (2016). Design for sustainable use of appliances: A framework based on user behavior observations. Journal of Mechanical Design, 138(10), 101102 https://doi.org/10.1115/1.4034084

Zhao, C., Peng, Q., Gu, P., & Zhang, Z. Y. (2013). Module development method for Open architecture product using extended QFD. CIE43 proceedings, 16-18

Zong, J., Tian, J., Gao, D., & Zhang, X. (2019). Guidelines for green design of cooking appliances. In E3S Web of Conferences (Vol. 118, p. 02003). EDP Science https://doi.org/10.1051/e3sconf/201911802003

Appendix

Table 1. Reviewed documents.

Contained keyword (s)	Authors	Title	Year	Author Keywords
design for sustainability	Bakırlıoğlu Y.; Doğan Ç.	Exploring Product/Part Longevity in Open Design of Small Kitchen Appliances	2020	co-design; design considerations; design for sustainability; open design; research through designing; small kitchen appliances
design for sustainability; ecodesign	Favi C.; Landi D.; Garziera R.; Rossi M.	Fostering Design for Sustainability through the Adoption of Computer-Aided Engineering Tools in the Development of Energy-Related Products	2024	ecodesign; life cycle engineering; virtual prototyping
ecodesign	Dostatni E.; Diakun J.; Grajewski D.; Wichniarek R.; Karwasz A.	Functionality assessment of ecodesign support system	2015	Agent technology; CAD; Eco-design; PLM; Product modeling
ecodesign	Martin L.; Morel L.; Boly V.	Integration of eco-products' criteria in project management	2020	EcoDesign; Green products; Sustainability
ecodesign	Peruzzini M.; Raffaeli R.; Malatesta M.; Germani M.	Toward a function-based IT platform for variants redesign of household appliances	2017	Computer-Aided Design; Design Methods; Function Modeling; Product Family and Platform; Product Modeling
ecodesign	Germani M.; Mandolini M.; Marconi M.; Rossi M.	Usability demonstration of the g.en.esi eco-design platform: The cooker hood case study	2015	n.a.

ecodesign	Dostatni E.; Mikołajewski D.; Dorożyński J.; Rojek I.	Ecological Design with the Use of Selected Inventive Methods including AI-Based	2022	automatic method—neural networks; eco-product; refrigerator; traditional method
ecodesign	Dudkowiak A.; Grajewski D.; Dostatni E.	Analysis of selected it tools supporting eco-design in the 3d cad environment	2021	3D CAD systems; Eco-design; Product design; Recycling
ecodesign	Dostatni E.; Rojek I.; Szczap P.; Tomczuk M.	Inventive methods in designing an environmentally friendly household appliance	2019	Eco-design; Eco-innovation; Household appliance; Inventive creation method
ecodesign	Zong J.; Tian J.; Gao D.; Zhang X.	Guidelines for green design of cooking appliances	2019	n.a.
ecodesign	Papetti A.; Germani M.; Marconi M.; Favi C.	Lifecycle tools as a support for the eco-design innovation of domestic appliances	2017	n.a.
ecodesign	Withanage C.; Hölttä-Otto K.; Otto K.; Wood K.	Design for sustainable use of appliances: A framework based on user behavior observations	2016	behavioral analysis; design for the environment; design methodology; living laboratory study; sustainable design; user behavior categorization
ecodesign	Rodríguez N.B.; Favi C.	Eco-design guidelines takeaways from the analysis of product repairability and ease of disassembly: A case study for electric ovens	2022	circular economy; cooking appliances; design for disassembly; design for repairability; disassemblability index; disassembly; eco-design; oven; repairability
ecodesign	Landi D.; Cicconi P.	An Approach for the Responsible Design of the Packaging Employed in Household Appliances	2022	Corrugated cardboard; Eco-design; EPS; Packaging
ecodesign	Bracquené E.; Peeters J.; Alfieri F.; Sanfélix J.; Duflou J.; Dewulf W.; Cordella M.	Analysis of evaluation systems for product repairability: A case study for washing machines	2021	Circular economy; Eco-design; Repairability; Scoring; Waste of electric and electronic equipment
ecodesign	Favi C.; Germani M.; Mandolini M.; Marconi M.	Implementation of a software platform to support an eco-design methodology within a manufacturing firm	2018	BoM; CAD; CAE; DfD: Design for Disassembly; DfEE: Design for Energy Efficiency; Eco-design methodology; eco-design software platform; EDIMS: EcoDesign Integration Method for SMEs; LCA; LCC; LCT
ecodesign	Pérez-Belis V.; Bakker C.; Juan P.; Bovea M.D.	Environmental performance of alternative end-of-life scenarios for electrical and electronic equipment: A case study for vacuum cleaners	2017	Ecodesign; Electrical and electronic equipment; Energy efficiency; INLA; LCA; Vacuum cleaner
ecodesign	Boyano A.; Espinosa N.; Villanueva A.	Rescaling the energy label for washing machines: an opportunity to bring technology development and consumer behaviour closer together	2020	Ecodesign; Energy Labelling; Washing machines
ecodesign	Favi C.; Formentini G.; Rodríguez N.B.	Eco-design of cooking appliances based on food habits and diets	2020	Cooking appliances; Ecodesign; Food habits; Product development; Sustainability
ecodesign	Postacchini L.; Cicconi P.; Ciarapica F.E.; Germani M.; Bevilacqua M.	A design method for improving assembly and environmental sustainability in packaging solutions: a case study in household appliances	2021	corrugated fibreboard; design for environment; design for manufacture and assembly; expanded polystyrene; Industrial packaging; life cycle assessment

ecodesign	Fiore E.; Tamborrini P.; Norese M.F.	Designing major appliances: A decision support model	2017	n.a.
ecodesign	Rodríguez N.B.; Gabriel C.; Gaha R.; Favi C.	Analysis of disassembly parameters in repairability scores: limitations for engineering design and suggestions for improvement	2023	Circular Economy; Cooking appliances; Design for Disassembly; Design for Repairability; Ease of repair; Repairability Index
ecodesign	Ardente F.; Calero Pastor M.; Mathieux F.; Talens Peiró L.	Analysis of end-of-life treatments of commercial refrigerating appliances: Bridging product and waste policies	2015	Ecodesign; Energy using products (EuP); Recyclability; Waste of electric and electronic equipment (WEEE)
ecodesign	Dostatni E.; Diakun J.; Grajewski D.; Wichniarek R.; Karwasz A.	Multi-agent system to support decision-making process in ecodesign	2015	Agent technology; Ecodesign; Product design; Product modelling
ecodesign	Rodríguez N.B.; Favi C.	Life Cycle Impact Assessment of Mechatronic Products: Towards Engineering Eco-Design for Hobs Technologies	2024	Cooking Appliances; Cooktops; Eco-Design; LCA; Sustainability
ecodesign	Dostatni E.; Diakun J.; Wichniarek R.; Karwasz A.; Grajewski D.	Product Variants Recycling Cost Estimation with the Use of Multi-agent Support System	2018	CAD 3D; Ecodesign; Recycling; Recycling cost
ecodesign	Boix Rodríguez N.; Favi C.	De-manufacturing Analysis for Product Repairability and Serviceability in Cooking Systems	2023	Cooking appliances; Design for repairability; Disassembly; Eco-design; Sustainable design
ecodesign	Landi D.; Rossi M.; Favi C.; Brunzini A.; Germani M.	A virtual design approach to simulate the hob energy performance	2020	Design methodology; Eco-design strategies; Virtual Prototyping
ecodesign	Landi D.; Cicconi P.; Germani M.	Analyzing the environmental sustainability of packaging for household appliances: A test case	2020	Molded pulp; Sustainable design; Sustainable packaging
ecodesign	Karagiannopoulos P.S.; Manousakis N.M.; Psomopoulos C.S.	"3R" Practices Focused on Home Appliances Sector in Terms of Green Consumerism: Principles, Technical Dimensions, and Future Challenges	2024	"3R" initiative; Green consumer; home appliances industry; technical dimensions
ecodesign	Rodríguez N.B.; Favi C.	Disassembly analysis of gas cooktops: towards eco-design rules for product repairability	2022	Cooking appliances; Design for Repairability; Disassembly; Eco-design; Sustainable design
ecodesign	Favi C.; Germani M.; Mandolini M.; Marconi M.	Includes Knowledge of Dismantling Centers in the Early Design Phase: A Knowledge-based Design for Disassembly Approach	2016	Design for disassembly; Disassembly Knowledge; Dismantling center
ecodesign	Wichniarek R.; Grajewski D.; Diakun J.; Dostatni E.; Karwasz A.	Automatization of the ecodesign process of small household appliances based on CAD 3D system	2018	Automatization; CAD 3D; Design for recycling; Ecodesign
ecodesign	Landi D.; Cicconi P.; Germani M.; Russo A.C.	A methodological approach to support the design of induction hobs	2016	n.a.
ecodesign	Favi C.; Germani M.	A method to optimize assemblability of industrial product in early design phase: From product architecture to assembly sequence	2012	Conceptual design for assembly; Interface connection; Product architecture
ecodesign	Kuo T.-C.; Hsin-Hung W.	Fuzzy eco-design product development by using quality function deployment	2005	Eco design; Green design; Life cycle analysis; Multi-objective analyses; Quality function deployment

ecodesign	Zhao C.; Peng Q.; Gu P.; Zhang Z.	Module development method for open-architecture product using extended QFD	2013	Design for product life cycle; Modular design; Open-architecture product (OAP); Quality Function Deployment (QFD)
ecodesign	Peters H.A.R.; Toxopeus M.E.; Jauregui-Becker J.M.; Dirksen M.-O.	Prioritizing 'design for recyclability' guidelines, bridging the gap between recyclers and product developers	2012	Design; Recyclability; Tool
ecodesign	Collado-Ruiz D.; Bastante-Ceca M.J.; Viñoles-Cebolla R.; Capuz-Rizo S.F.	Identification of common strategies for different electric and electronic equipment in order to optimize their end-of-life	2007	Design for Disassembly and Recycling; Ecodesign; End of life strategies; Waste electric and electronic equipment
ecodesign	Kara S.; Kaebernick H.; Ibbotson S.	Using Design for Environment for redesigning a household appliance	2006	Cost impact; Design for environment; Environmental impact; Redesign
ecodesign	Luttropp C.; Johansson J.; Vilaplana F.; Strömberg E.; Karlsson S.	Design for material hygiene - An ecodesign strategy for improved recycling of polymers	2010	Polymer recycling; Recyling process; Technological innovation for material recycling
ecodesign	Johansson J.; Luttropp C.	Material hygiene, an ecodesign mindset for optimized material use	2006	Disassembly; Material hygiene; Recycling
ecodesign	Germani M.; Dufrene M.; Mandolini M.; Marconi M.; Zwolinski P.	Integrated software platform for green engineering design and product sustainability	2013	Design for environment; Eco-design; Product development process
ecodesign; material selection	Ng C.Y.; Chuah K.B.	Effect of material selection on the Life Cycle Assessment of environmental impact	2012	Eco Design; Electrical Appliances; Life Cycle Assessment
material selection	Kaushik D.; Singh H.; Tassou S.A.	Vacuum insulation panels for high-temperature applications – Design principles, challenges and pathways	2024	Appliances; Core material; Energy efficiency; High temperature; Thermal conductivity; Vacuum Insulation Panels (VIPs)
material selection	Skorup D.; Rozing G.; Heffer G.; Vidaković I.	Product Life Cycle Analysis on the Example of a Home Appliance	2022	Industrial production; Life cycle analysis; Reduction of environmental impact
material selection	Piselli A.; Baxter W.; Simonato M.; Del Curto B.; Aurisicchio M.	Development and evaluation of a methodology to integrate technical and sensorial properties in materials selection	2018	Aesthetics; Human factors; Materials selection; Metal replacement; Product design; Sensory perception
material selection	Basso M.; Simonato M.; Furlanetto R.; De Nardo L.	Study of chemical environments for washing and descaling of food processing appliances: An insight in commercial cleaning products	2017	Chemical environments; Commercial cleaning products; Detergents; Durability; Food processing
material selection	Guo A.H.	Research and exploration on green design of household electrical appliances	2014	Green design; Household electrical appliances; Material; Recycling; Structure

material selection	Piselli A.; Simonato M.; Del Curto B.	Holistic approach to materials selection in professional appliances industry	2016	Design process; Design tools; Interdisciplinary collaboration; Product development; Research methodologies and methods
sustainable material	Nieto D.M.; Pintos P.B.; Sánchez D.M.; Rubio S.I.M.	Large Format Additive Manufacturing in Furniture Design with Novel Cork Based Polymeric Materials	2023	Additive manufacturing; Design for additive manufacturing; Furniture design; Product design; Sustainable materials
sustainable material	Anjumol K.S.; Sreenivasan S.N.; Tom T.; Mathew S.S.; Maria H.J.; Spatenka P.; Thomas S.	Development of natural fiber-reinforced flame-retardant polymer composites	2022	Fire retardancy; Fire retardants; Flammability; Natural fiber polymer composites; Polymer combustion

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Design for longevity in industrial products: a pedagogical case study on steel moulds for injection mould manufacturing

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Keywords: Remanufacturing; Product Longevity; Slowing Resources; Steel Moulds; Manufacturing.

Abstract: This paper aims to demonstrate the life cycle costing and environmental impacts of different R-strategy scenarios, with a focus on steel moulds. Reuse primarily focuses on remanufacturing steel moulds and exploring the most environmentally optimal strategy, serving as a supplier in a circular economy. The scope of this case study does not include recycling scenarios. The study uses a pedagogical case study in collaboration with The LEGO Group. One approach is to map the CO_2-eq footprint of steel mould consumption to prepare for a digital architecture based on material consumption and circular strategies.

Introduction

The application of repair technologies for metalwork, such as welding, laser cladding, and powder metallurgy, is well-known. The literature on lifetime extension is sparse. Hatcher et al. (2011) and Govindan et al. (2017) highlight a lack of research on remanufacturing and closed-loop supply chains outside established industries, such as automotive and electronics, noting a shortage of quantitative methods for optimising operations.

This paper explores opportunities for mould manufacturers to extend the lifetime of steel injection moulds to optimise material efficiency. The study is a collaboration within the MADE FAST project, motivated by the exploration of optimal strategies for science-based targets and data-driven emissions reduction. It focuses on the circular opportunities in mould manufacturing, as an area where the moulding industry holds control over what and how much material is used in mould fabrication. The objective is to demonstrate the life cycle costing and environmental impacts in different R-strategy scenarios focusing on steel moulds. One approach is to map the CO_2-eq footprint of steel mould consumption to prepare for a digital architecture based on material consumption and circular potential data. Concurrent with the case, the partner conducted a pilot study to explore the reuse of mould components, selecting those based on cost and weight. This study builds on the pilot project to provide the company with a data basis, including CO_2. The analysis builds on real-life issues and serves as a pedagogical case study conducted at the LEGO Group manufacturing facility, with an injection mould as the research context. Injection moulds are designed and ordered in various configurations and purposes, ranging from high-volume to low-volume production, and from standard to unique designs, with differing shapes, complexities, and sizes. The object of the case study is the mould box design platform used in the company's internal manufacturing operations, which produces 70% of the injection-moulded goods for the case company. From a cost perspective, an estimated benefit is that when a steel mould foundation is reused one to two times, it results in a 12% savings in mould manufacturing costs, and the new mould cost is reduced due to the reuse of components with depreciated value.

Method and data

Data collection methods include gathering product-specific data using a Bill of Materials, conducting interviews with company employees at both operational and strategic levels, providing guided tours led by company experts who demonstrate the sustainable lifetime extension initiative, and documenting these activities with video and photographs. Additionally, informal meeting summaries were collected from February to November 2024.

Developing a CO_2 tool

A collection of the parts and components that constitute an injection mould, typically used for procurement, order, and assembly, is known as the Bill of Materials (BOM). Each part or component, along with its accompanying data, is available in the BOM, typically including material, weight, quantity, part ID, and part name or description. In this case, the BOM's extension includes volume and generic data on CO_2-equivalents embodied in the material weight. The BOM must expand on data points for all subassemblies and components of a single material. This is necessary to gather generic data on embodied CO_2-eq for the mould parts. The CO_2 tool is set up in Microsoft Excel, providing a basis for exploring and comparing reuse scenarios for injection steel moulds. Generic environmental data is applied as part of building a tool for CO_2-based scenarios. The partner company does not have detailed data points to describe different steel materials used for moulds. Therefore, the next best course of action is to integrate proxy data on CO_2-eq from Ansys Granta Edupack, as detailed in Table 1, "Data basis on mould components applied for the CO_2 tool development".

Volume	[mm^3]	Extracted from the CAD software.
Density	[kg/mm^3]	Collected from the material datasheet from the supplier.
		When the supplier is unknown, a similar material is looked up in the Ansys® Granta material library. Density is collected from the material library for the representative material.
Embedded CO_2	[kg/kg]	The material library chooses a material corresponding to the one listed in the BOM. The CO_2-eq data accounts for potential emissions from mining, material refining, transport, and material processing until the block is delivered as a raw block.
Weight	[kg]	Density is multiplied by the volume.

Table 1. Data based on mould components applied for the CO_2 tool development.

Material Assessment

Material identifiers refer to a specific steel alloy from a particular supplier, purchased based on its quality and the insurance provided for the exact constituents in the alloy, as specified by the supplier. Considering the EU List of Critical Raw Materials, the material assessment of the injection mould visualises material content distribution with Microsoft Excel charts.

Interview to extend data collection

Interviews are used to verify the gathered and structured data, both to extract data from internal company databases for design and procurement, and to agree on the material selection approach for substituting generic data from Ansys Granta EduPack. Interviewees from the company partner include a material specialist, mould designers, supply chain management, and the sustainability team.

User test for the CO_2 tool

A test of the developed tool is performed with the intended users, including the mould design platform owner, mould developer, and the data specialist responsible for developing and converting it into a software platform. The users were shown a demonstration of the tool layout and its features and were provided with test versions of the tool. The company project responsible was facilitating user test input and discussion, and a co-facilitator and researcher kept notes. The duration was 25 minutes. A second test was performed a month later for the intended users in a revised tool version, followed up on key points from the first test.

Lifetime of a mould - state of the art

During the manufacturing stage, which utilizes an injection mould for object production, production stops if a mould component fails prematurely, thereby reducing the mould's lifetime expectancy. The stopped mould box is handled by expert service personnel for maintenance, repair, or replacement of the faulty component with a spare. When the expected lifetime of injection cycles is reached or if the quality of the objects declines, the mould box is worn out and removed from production. In this case example, the mould box order was approved to run 9 million injection cycles. The lifetime expectancy of the mould components is subordinate. The production time of a mould box lasts from a few months to several years, depending on the market demand for the object design and the concomitant mould wear. Wear affecting object quality is prevalent in tool cavities and cores.

Mould components with remaining service life are dismissed when the mould is ordinarily scrapped.

Opportunities for lifetime extensions

The mould box is designed to support the form-giving inserts for exactly the volume of objects in demand, ensuring a match between production volume and cavities, as well as the number of injection cycles. While the form-giving inserts must be remelted and cannot be reused as it is a worn part, simply replacing it and reusing the remaining mould components is not sufficient.

The product - a steel mould

The case injection mould box is a collection of metal components designed to produce plastic objects with tight surface tolerances and stress resistance.

The main categories of mould components include the essential form-giving insert, cavity and core, large plates, and function-specific subassemblies. The lifetime-determining component for the mould box is the form-giving insert, which shapes the object and is essential for defining shape, tolerances, and surface quality. The form-giving insert is the component most marked by wear and tear during cycles, as it is repeatedly closed, filled with hot plastic, opened, and released from the produced plastic object. Once worn out, the mould box is typically welded using a CO_2 burner and sent for mixed-grade metal recycling, as it is the lowest-value option for capturing metal. Figure 1 illustrates the circular scenarios explored.

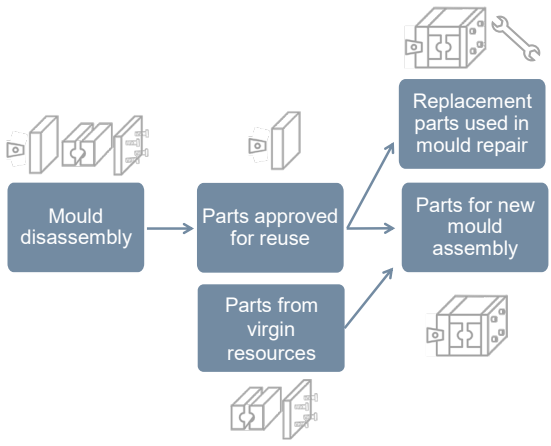


Figure 1. The exploration of longevity strategies.

According to the interviews conducted, it is evident that the remaining mould components have a longer life expectancy due to the precautionary principle of not wasting the engineering effort invested in the form-giving insert. It is worse not to meet manufacturing demand for objects due to a mould malfunction resulting from component design with too low requirements and a form-giving insert with a remaining service life than to have the mould designed to the above-required specification.

Through interviews with the reuse team, it was found that less-worn-out parts and plates are fit to run up to an expected 20-50 million cycles. The mould box, as a case product, is a medium-sized mould containing 755 components, weighing between 270 and 282 kg, depending on the design configuration of the particular mould box type. The partner company manufactures a significant number of moulds worldwide annually, of which 55% are platform-designed for internal standardisation. It reflects the expected volume of worn-out moulds that theoretically enter disassembly as a potential contributor to harvesting for reuse. A mould design platform includes a product portfolio of normally 11 mould designs. An exemplary mould box is drawn by the authors based on supplier sales material and patent figures and was revised by an injection mould expert with the case company. It is illustrated in Figure 2.

Figure 3 shows the material opportunities for the case mould on a weight distribution chart. The main component categories are associated with a material identifier; the largest is from the case mould, marked as tool steel grades 1.2085 and 1.2344. From the product case, the repair team identified 19 reusable components. The mould designers identified more than 59 components that hold sufficient design commonality to be reusable, including the spacers in black and small parts in dark blue and grey.

The assessment using the CO_2 tool identified reusable components based on CO_2 data in comparison to known target lists for reuse. Component categories that include parts not yet recognised by either design or disassembly teams encompass ejector base plates. Increasing the longevity of the mould box is facilitated through repair and replacement, which are simplified by the mould design, allowing for disassembly for specific purposes. Sufficiently exploiting the remaining service life of components from mould boxes taken out of production as worn out allows the manufacturing company to become its own supplier of plates and parts for new mould box assemblies and mould maintenance, facilitating

component replacement. The mould is disassembled to reuse parts and then cleaned. Skilled repair personnel visually inspect each component individually to assess its potential for extended service in production. The parts are sent through the production line as if they are new parts entering quality inspection, and sometimes they are also reworked through machining. All reused parts receive the highest quality inspection of surface and shape tolerances. All reused parts that have passed quality inspection meet the same standards as new parts.

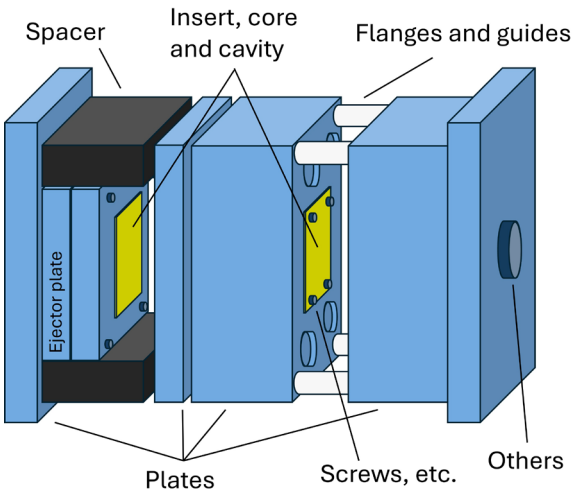


Figure 2. A representation of the main component categories of a mould box.

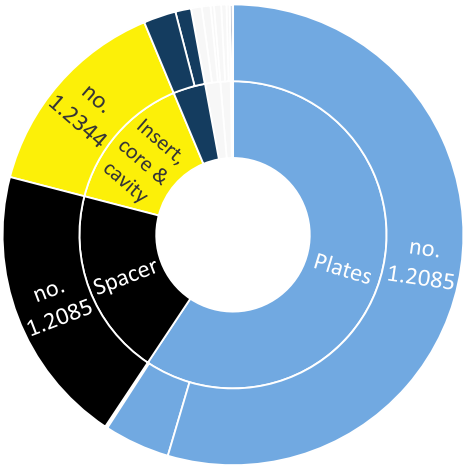


Figure 3. The weight distribution [%] and material codes of the case mould.

Results and Discussion

Expensive components include steel mould plates, which are costly to manufacture, as well as mould parts and subassemblies, which are also expensive to purchase. The interest lies primarily in the reuse of the steel mould plates, as they are the most extensive and heaviest components (Figure 3), accounting for 59% of the total expense. They are typically made from tool steel and are expected to make the most considerable contribution to the overall CO_2-eq emissions. Figure 4 shows the case result of CO_2-eq emissions on component categories, identifying potential targets for reuse, indicated by dots.

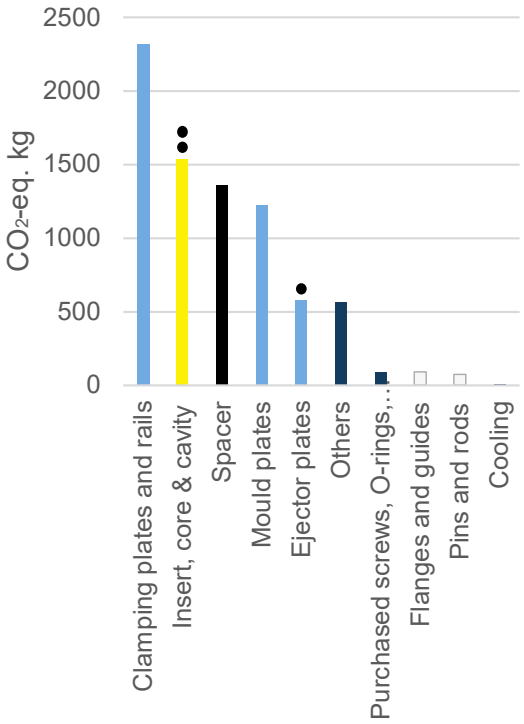


Figure 4. Categories of components in the case mould and their CO_2-eq contribution.

Disassembly is a central process for the circular economy, particularly in terms of resource utilisation and waste reduction (Vanegas et al., 2018; Cappelletti et al., 2022), which emphasises the importance of selecting a relevant End-of-Life strategy and mapping the barriers to circular reuse initiatives. Providing that the mould plate design of the case mould box is the driver of reuse, the design of mould plates varies from generation to generation due to version updates, and the plates must be forward-compatible or reworked to become compatible. Likewise, mould box designers must enable backwards compatibility for mould

boxes to reuse older versions of mould plates. Generational commonality is associated with reduced manufacturing costs (Kim & Kim, 2020), a relevant point for original equipment manufacturers that utilise remanufactured components in their production. Ma et al. (2023) focus on modular design and its benefits for remanufacturing, which is used to upgrade products. In contrast, Mesa (2023) focuses on material choices in the design process. These are themes for future research.

Limitations of the study

CO_2 data is based on generic data and is not intended to provide definitive results; instead, it is indicative of emissions reductions and material choices that consider emissions as a strategic direction.

Conclusion

Few practical case examples exist, although the literature is rich in theoretical circular strategies. This study presents a real-life, yet pedagogical, case study, resulting in the case partner establishing a pilot project to test whether recovering components enables resource utilisation through reuse and remanufacturing, thereby achieving a longevity strategy in mould design and consumption (as shown in Figure 1). Following the pilot and this research project on CO_2 footprint, mould disassembly for reuse recovery has become an integrated part of manufacturing operations. Data on cost, weight, and CO_2 support it.

The lifetime extension business model targets are outlined in the newly released European standard EN 45560, which states that the reuse of products or parts retains the value of virgin resources, including materials, energy, labour, and financial capital, and avoids additional contributions to environmental impacts. The standard provides several examples, though not explicitly, to mould manufacturing and systematic data handling.

While injection moulding machinery adheres to the EU Machinery Directive 2006/42/EC, which focuses on safety, there are no specific standards in place for a greener manufacturing transition. The EU Green Deal contrasts the lack of guidelines with the Eco-design directive for energy-related products to injection mould manufacturing (EN45550-60). The directive includes reducing the use of virgin materials by extending product lifetimes (EN 45552:2020) and reusing components through remanufacturing (EN 45553), which in turn reduces the demand for new materials. In conclusion, the study demonstrated the application of data-driven environmental data to support deliberate sustainable efforts by highlighting targets for reuse and prolonged lifetime of steel mould parts based on weight, material, and CO_2-eq footprint.

Acknowledgements

This study is a collaboration among the industrial partner, the LEGO Group, SDU Innovation and Design Engineering at the University of Southern Denmark, and the Manufacturing Academy Denmark. It is part of a project within the MADE FAST partnership, funded by the Innovation Fund Denmark.

References

Cappelletti, F., & Germani, M. (2023). Carbon reduction engineering through value chains intersection, product and process re-design, industrial processes' scraps de-manufacturing. *International Journal of Production Research.* https://doi.org/10.1080/00207543.2023.2243527

Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products. (2009). *Official Journal of the European Union*, L285,10-35.

Govindan, K., Soleimani, H., & Kannan, D. (2017). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *Journal of Cleaner Production*, 142, 371-384. https://doi.org/10.1016/j.jclepro.2016.03.126

Hatcher, G. D., Ijomah, W. L., & Windmill, J. F. C. (2011). Design for remanufacture: A literature review and future research needs. *Journal of Cleaner Production*, 19(17-18), 2004-2014. https://doi.org/10.1016/j.jclepro.2011.06.019

Kim, J., & Kim, H. M. (2020). Impact of Generational Commonality of Short Life Cycle Products in Manufacturing and Remanufacturing Processes. *Journal of Mechanical Design*, 142(12). https://doi.org/10.1115/1.4047092

Ma, Y. J., Du, G., & Jiao, R. J. (2024). Design for product upgradability considering remanufacturing outsourcing: A three-level joint optimisation approach. *Journal of Cleaner Production.* https://doi.org/10.1016/j.jclepro.2024.104567

Mesa, J. A. (2023). Developing a material selection index based on circularity: A multiple

lifecycle approach. *Resources, Conservation and Recycling.* https://doi.org/10.1016/j.resconrec.2023.104439

Vanegas, P., Peeters, J. R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., Dewulf, W., & Duflou, J. R. (2018). Ease of disassembly of products to support circular economy strategies. *Resources, Conservation and Recycling*, 135, 323-334. https://doi.org/10.1016/j.resconrec.2018.02.020

Research paper
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Compatible blending for circular textiles with next-gen materials

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Keywords: Next-Gen materials; blended textiles; circular textile design; recycling; guidelines.

Abstract: Emerging next-gen materials such as recycled, renewable, or regenerative fibres promise lower impacts in resource extraction and transformation processes than their conventional fibre counterparts. These materials can be instrumental in a shift to a more sustainable fashion and textiles industry. A key contribution to this transition relies on reducing impacts and waste through circular design measures such as increasing lifespans and recycling at end of life. However, as these next-gen materials tend to have properties and costs that deviate from optimised industry norms, they are often used in incompatible blends, thus negating their circularity potential. This paper puts forward a framework to understand material flows and lifecycles as a relation between fibre type and recycling route for designers to operate within the principles of circularity. The research results in a guidebook to support designer's choices of material combinations in line with recycling trajectories, and in a series of samples produced by industry project partners and students demonstrating the application of the framework. The samples use a selection of five example next-gen materials, which are integrated to each practitioners' applications and aesthetics. The underlying aim of the research is to foster a systemic approach to textile design with an increased understanding of material properties and their relation to current and emerging recycling technologies.

Introduction

The fashion and textiles industry is reckoning with its large, negative impact on the social and climate crises of our time and attempting a shift in the right direction (Fashion for Good & Accenture Strategy, 2019; Global Fashion Agenda, 2017). Next-gen materials (Sustainabelle, 2024) or 'preferred materials' (Textile Exchange, 2020) are seen as a promising category of materials with lower impacts than conventional fibres. As defined by (Duarte Poblete et al., 2024) these emerging materials which respond to sustainable and circular design expectations include materials from waste, renewable, and biofabricated materials. These materials can contain recycled textiles or food and agricultural sources to name but a few.

As part of a decarbonisation agenda, they have potential to reduce our dependence on virgin resources and intensive agriculture (Canopy, 2018) and could contribute to a greater diversity and sovereignty of materials (Coléchi, 2023). The benefits of these materials' overall environmental impacts are beginning to be quantified, with WRAP assigning a potential 12% carbon reduction and 18.2% water use reduction to the use of recycled fibres such as mechanically recycled polyester and cotton in fashion (WRAP, 2023).

Designers and innovators are increasingly expressing interest in using these materials, as demonstrated by the growing communities brought together under initiatives such as the Future Fabric Expo (Sustainable Angle, 2024) or the Biofabricate events (Biofabricate, 2024) and they are being supported by the investment community to develop at pace (Sustainable Ventures, 2024). The exciting innovations involved in fibres from mushrooms or algae and the sustainability credentials connected to the use of recycled fibres are seen as great assets to designers hoping to do the right thing. However, there are a range of barriers to their use in textile products. These materials often differ in their technical performance to widely used conventional resources and can pose challenges when incorporating them into established production lines or when considering the technical performance or durability of textiles. They also tend to come at a price premium compared to optimised and large-scale fibres. This results in them regularly being blended with other less novel fibres to compensate for performance or price deviations. However, if the materials in these blends belong to different recycling processes,

then the textile is no longer recyclable and will be destined for downcycling, landfill or incineration.

In a circular textiles economy, multiple strategies to increase the lifespan of materials coexist. Blending different resources may extend their use by decreasing their propensity to wear and tear (Hardingham, 1978). The use of next gen materials may increase emotional durability through a connection to the materiality of a product (Earley & Forst, 2023). Ultimately, products and materials will reach the end of their useful life, and, as a last resort, this is where textile to textile recycling must remain an option for the resources to be recirculated as new fibres.

The aim of this work is therefore to help increase the uptake of these next-gen materials with great potential for reduced impacts, while recommending their use in textiles that are designed for longevity and recycling at end of life, therefore balancing blending for longevity with design for recycling. This paper lays out the work carried out to provide designers with a guidebook and illustrative textile samples that can increase their awareness of materials lifecycles.

Methods

This work was carried out as a one-year collaborative project between researchers at a higher education institute and a range of non-academic partners representing key stakeholders in sustainable fashion such as community activators, textile designers, and recyclers. It was funded as part of the Future Observatory Design Exchange Partnership, an exciting new programme fostering collaboration between design research and businesses.

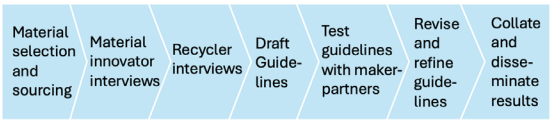


Figure1. Project workflow

The brief presented to the project maker-partners asks them to interpret the circular textile design guidelines in their own practice, using the selection of next-gen materials provided. The makers were provided with the draft guidelines and the selected materials in sufficient quantities to produce examples, and were supported with regular meetings throughout the project.

The project is rooted in design practice research. As described by Kaszynska and Kimbell (2024) this approach responds to three conditions, the three S's: that it should be *sited* in a real world situation, here the textile production system, it is *situated* in relation to a body of academic knowledge, here the theoretical explorations of a circular economy for textiles, and *situating*, producing objects and knowledge that effect a transformation. As also defined in *The Routledge International Handbook of Practice-Based Research (Vear, 2022),* one of the distinguishing characteristics of practice research is the role of the artefact and the forms of knowledge that arise from it. In this sense, the making of textile samples and their contextualisation within the developing frameworks for circular design are key contributions of the work.

The *site*, or context, for the research is understood as the rules and parameters set by the supply chain for textiles from production to recycling. The guidebook that constitutes a key output of the work is a visual summary and representation of the elements and interconnections in the textile recycling lifecycle. To gather the knowledge relative to this fluctuating field and test the assumptions described in the guidebook, a series of interview with material innovators, designers, and recyclers was carried out. The interviews took place online, first in the early stages of the work to define the parameters required for the guidelines, and then in the final stages to confirm the recommendations with experienced stakeholders in recycling systems. The interviews with the material innovators were based on a full lifecycle description approach (Forst et al., 2023) and enabled a comprehensive understanding of the material's properties and transformation processes to related them to recycling criteria. The information concerning recycler parameters was drawn from previous project experience and then validated in a short series of discussions with experts in the field, most notably with The Circular Textiles Foundation, an organisation which acts as a mediator between brands and recyclers to enable change in the sector.

The work is *situated* within the context of sustainable material innovation. To make the

outcomes concrete, five materials were selected for experiments. They each represent a type of next-gen material that is currently finding its way into the market. The selection comprises of a recycled cotton, a recycled wool, a bio-polyester, a yarn from pineapple leaves, and a regenerated cellulose from hemp and flax waste. These materials represent the type of resources that designers currently strive to include in their collections as a strategy to reduce environmental impacts.



Figure 2. Selected Next-Gen materials

As a means for *situating* the knowledge of recyclability criteria explored in this work, a series of samples were produced collaboratively with a range of actors in the textile design system. Three partners provided their in-kind support to this work by taking on the emerging guidelines in their own commercial or community-based practice. These textile designers were selected to represent a spectrum of practices 'from contract to community'. One designer produces interior textiles manufactured in the UK for luxury homes and offices, one makes hand-woven designs for the fashion industry, and the third engages with a community of sustainable fashion enthusiasts through a monthly knit club. In addition to the independent practices of these partners, guided experimentation was carried out by a cohort of textile design students in undergrad and postgrad courses. Reflecting on the ease or challenges in adopting the circularity guidelines for next-gen materials with each of these stakeholders supported the iterations and refinement of the project outcome. The textile samples produced by each maker constitute a key outcome as an illustration of the application of the theoretical framework for circular textile design with next-gen materials.

Results

Two key project outcomes aim to disseminate the knowledge of circular textile design across its target community of textile designers and makers.

The Compatible Blending Guidebook

The guidebook for circular textile design with next-gen materials[1] constitutes a resource for designers wishing to take onboard the project principles. This succinct reference identifies the pathways to recycling for eight material types which include the five chosen next-gen materials explored in the project as well as others they can be used in combination with. By using the diagram which is at the centre of this guidebook, designers can identify what combinations of fibre types can be traced to the same recycling process and therefore be used together in the same textile. The flow chart is meant to act as a checkpoint when designers are considering combinations of resources for various aesthetic or functional reasons.

The guidebook is targeted to textile designers who have a direct influence on multiple stages of the creative process, therefore focusing on smaller studios. The guidebook aims to support them when sourcing yarns and considering how to combine them in woven or knitted materials. While the same logic can be used by designers in other fields involving next gen material sourcing, the project targets this specific type of designer-maker as those closest to the fibre's properties. The guide recommends that designers access next-gen materials as yarns in their least processed forms, and indicates the requirements of each recycling process regarding dyes and finishes as well as concerning blends. While the guidebook has mainly been used in the creation of new textiles inside the project, it is also adapted to repair

[1] Available at https://ualresearchonline.arts.ac.uk/id/eprint/23536/

practices in which the fibre types of yarns used for patching or darning must be compatible to base fabric.

The guidebook consists of three double spreads, the first one offering an introduction to the overall theory for circular textiles,

adoption of emerging materials (Forst et al., 2023). These antecedents contribute to a better understanding of the corelation between textile properties and recyclability specifications which translates to the context of emerging materials in this work. The guidebook offers a simplified classification of material types according to

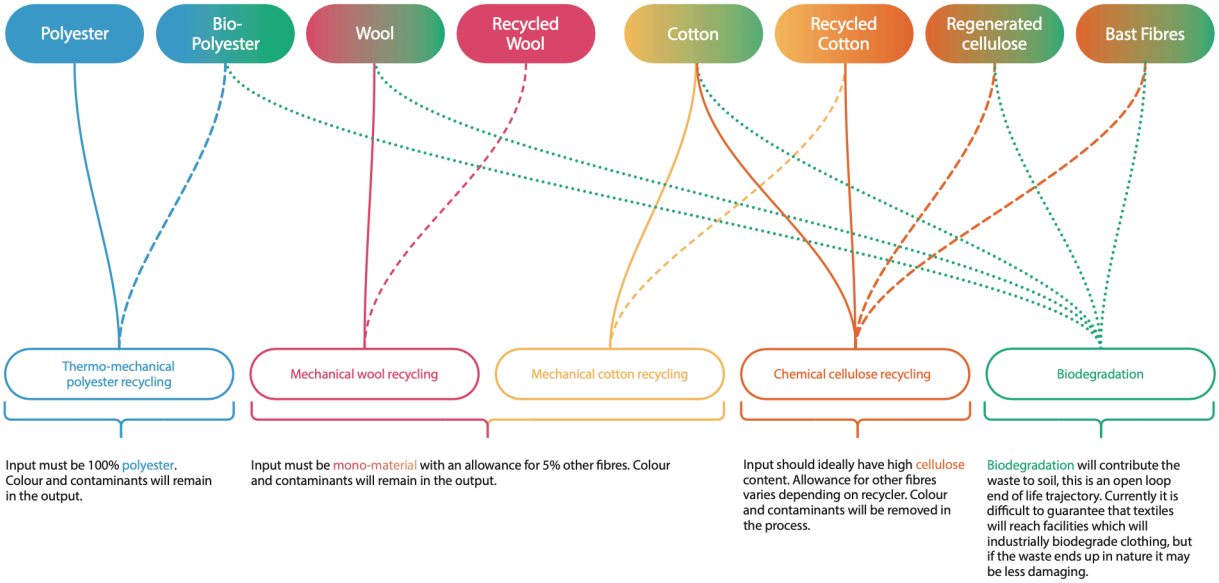


Figure 3. Compatible blending diagram

contextualising the recommendations within current and emerging recycling systems. The second puts forward a list of questions for designers to get to know their chosen Next-Gen material better. The third is the most important, and shows the diagram for compatible blending seen in figure 3. This guidebook was iteratively tested and refined through discussion with the project partners and in workshops with members of the community. Through these exchanges, the resource was sense-checked and made more user friendly to accompany the making process. A key modification in the trials

was to remove detailed information on material production and transformation and focus on a small set of questions and prompts for designers to interrogate their choice of materials at the start of the creative process.

The guidebook builds on previous work exploring material circularity either in creative practice (Forst, 2020), or in industry collaborations (Forst et al., Forthcoming). It is also informed by research on material literacy and transparency aiming to support the

their presumed recycling path, thus highlighting what fibre types can be compatible for recycling in blends. The recyclability criteria are built on interviews with recyclers and previous work in this field, they combine current technology requirements with assumptions for the evolution of the sector. In the diagram, the paths to recycling that are not yet workable at scale but which might be improved in the future are represented as a dotted line. The underlying aim of the guidebook is to provide a framework to understand material flows and lifecycles as a relation between fibre type and recycling route for designers to operate within the principles of circularity.

Demonstration Samples

Focusing on tangible textiles making, a key component of this work's results is the range of samples produced to exemplify the use of the guidelines. The designer-maker partners each interpreted the guidelines in their own practice, as is intended for these resources to be used beyond the timeframe of the project. During the

making process, frequent exchanges with the designers enabled regular feedback into the guidelines to increase their useability.

Samples were produced by different partners and participants in the research using the five selected next-gen materials in combination with a range of other sustainable or conventional materials. They demonstrate the range of composites that can be creatively assembled while fitting within the parameters of circularity, including durability through well thought-out material combinations, and be recycled at end of life. In these samples, blending occurs mainly at the yarn level, or more rarely, at the fibre level when the yarns sourced are already a combination of different fibres. This type of material combination fits with the experience of a textile designer sourcing yarn. It can be contextualised within a broader landscape of blend types as defined by Hall *et al.* (2023). The samples demonstrate a range of uses of the selection of next-gen materials, from technical properties aiming for physical durability, to emotional connections through the poetic power of natural fibres.

Two samples are selected and described here to demonstrate the range afforded by the circularity and compatible blending guidelines. These were produced in radically different settings with one being developed as sample for commercial applications, fitting within the company's identity, and the other made by an amateur textile enthusiast with strong crochet skills as a reflection on the material properties and no specific application in mind.



Figure 5. Wool and cotton sample made by Salt.

This sample explores the combination of a cotton and a wool yarn to provide complementary aesthetics and durability performance within the same material for an interior application. As the two resources are listed as incompatible for recycling in the guidebook, a design for disassembly approach is used, with a soluble yarn (visible in red) to connect the two layers of the textile. This work is in line with the partner's sober aesthetic which emphasises the material's qualities and explores themes of emotional durability.



Figure 6. Crochet sample with recycled wool (green) and Irish wool (white) made by a community workshop participant.

This crochet sample is made from a combination of recycled wool and virgin Irish wool. The participant started working with the recycled wool and then saw that it was liable to break while she was crocheting, she decided to reinforce the structure by replicating the zigzag pattern as an overlay, using a compatible material for mechanical wool recycling. This is one of 21 samples made by participants in the second of two community workshops held to reflect on the guidebook in development.

The portfolio of textile samples that is created as an interpretation of the guidelines serves as inspiration for other designers to take onboard when considering circular design with next-gen materials. It also provides a demonstration for the use of the five selected materials in a range of applications. These samples demonstrate a textile design approach which is based on an understanding of materials in a future recovery context, informed by the categorisation provided in the guidebook. The samples harness the aesthetic and functional properties of the next-gen and other chosen fibres in complementary blends, showing how the shortcomings of one resource can be compensated by another while still fitting in a circular textile-to-textile recycling flow.

Discussion

Next-gen materials are still in the process of infiltrating the textiles landscape, but it is not too early to consider how to use them in line with circular design principles. These materials offer great promise for reduced impacts in resource extraction and transformation processes (Solanki, 2018), yet they can easily be integrated into textiles and products in ways which negate their end-of-life recovery (Ellen MacArthur Foundation, 2017). To leverage the sustainability potential of next-gen materials, they must be understood across a full life cycle perspective, including design for longevity through strategic blending, and circulation of resources. It is therefore key to lay out the parameters for recyclability of these emerging innovations whether they are used as mono-materials or in blends.

Currently recyclers are limited in their ability to accept non-standard materials or materials that represent a small share of the market as efforts are geared towards the bulk of textile waste made of conventional cotton and polyester. However, the technology holds potential for the recycling of fibres which are similar to more conventional ones such as bio-polyester theoretically being compatible with polyester recycling, and viscose or other regenerated cellulose being recycled chemically with cotton. This research speculates a future in which circularity is the norm across all fibre types and a balance between material selection and future recyclability has been achieved. In line with this exploratory approach, it is mainly directed to micro and small businesses in the fashion sphere, who are some of those with the most freedom to spearhead the circular material landscape of the future, and yet face strong barriers to accessing innovative materials. The guidebook offers itself as a framework to interrogate textile design practice starting with where materials are from and how they are made, all the way to thinking about their next life through recycling.

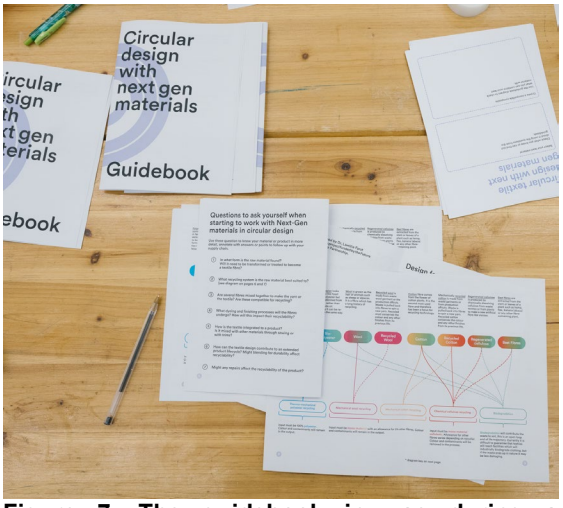


Figure 7. The guidebook in use during a workshop.

It aims to influence the practice of designers towards a holistic, circular approach. As put by one of the students participating in the project:

"Typically, my work relies more on intuitive and spontaneous creative processes, whereas this time I had to follow specific material choices and combination guidelines from the handbook. This taught me to think more systematically about the properties of materials and how to combine them effectively, bringing new challenges and insights to my creative process."

The collaborative process of developing the guidebook and testing it through textile sampling has highlighted some of the challenges faced by designers aiming to include next-gen materials in their offer.

There is still a lack of transparency over the composition and the processes involved in these materials, leading to difficulties in assessing their relative sustainability and their adequate recycling path. The guidebook offers a simple list of questions that designers can use as a starting point to open discussions with their supply chain to better understand materials.

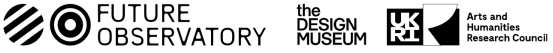
Accessing next-gen materials remains an issue for designers as minimum order quantities or costs can be prohibitive. Relationship building with innovators can be a slow and time-consuming process (Lee et al., 2020) which designers can ill afford. In this work, sourcing the materials centrally removed a barrier to access these fibres and enabled faster experimentation with the makers.

Conclusions

To achieve a circular textiles economy all materials must be considered as part of a journey from resource, to product, and back to resource. To match the impact reduction potential of fibre-to-fibre recycling (Nellström et al., 2025), alternative fibres which offer a chance to reduce the industry's reliance on virgin and fossil-based materials must also be considered in terms of their circulation through use and recycling systems. Optimal properties can be achieved through blending, leading to longer lifespans for products designed with functional and emotional durability in mind. This paper presents a guidebook with a material flow diagram intended for designers to follow when using innovative materials. This method is supported by a range of textile demonstrators showing the broad spectrum of creativity available with circularity parameters. While recycling technology is still evolving and improving, broad categories for compatibility between fibre type and recycling route are defined here. These serve as a framework for designers to adopt a circular textile design approach when using next-gen materials. The samples produced by the project partners show that creative expression can be supported within circularity parameters. There is an opportunity to review the samples produced by following the guidelines and assess them in terms of their functional and emotional performance to better define their role in extended material lifetimes. Future work may also expand on a wider range of fibres and develop more technical details for combination techniques and approaches for circular textiles.

Acknowledgments

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References

Biofabricate. (2024). *Summit Paris*. Biofabricate. https://www.biofabricate.co/summit

Canopy. (2018). *CanopyStyle 5th Anniversary Report*. https://canopyplanet.org/wp-content/uploads/2019/02/CanopyStyle-5th-Anniversary-Report.pdf

Coléchi. (2023). *AGREENCULTURE: Fashion and Farming*.

Duarte Poblete, S. S., Romani, A., & Rognoli, V. (2024). Emerging materials for transition: A taxonomy proposal from a design perspective. *Sustainable Futures*, 100155. https://doi.org/10.1016/j.sftr.2024.100155

Earley, R., & Forst, L. (2023, May 31). The BIO TEN Design Guidelines: Inspiring biobased, local, durable and circular innovation in fashion textiles. PLATE 5th Product Lifetimes and the Environment Conference, Aalto University, Finland. https://www.plateconference.org/

Ellen MacArthur Foundation. (2017). *A New Textiles Economy: Redesigning fashion's future*. http://www.ellenmacarthurfoundation.org/publications

Fashion for Good, & Accenture Strategy. (2019). *The Future of Circular Fashion Report*. https://fashionforgood.com/wp-content/uploads/2019/05/The-Future-of-Circular-Fashion-Report.pdf

Forst, L. (2020). *Textile Design for Disassembly: A creative textile design methodology for designing detachable connections for material combinations* [PhD, University of the Arts London]. https://www.lforst.com/

Forst, L., Goldsworthy, K., Cross, T., Valarino, J., & Fielding, P. (Forthcoming). Quantifying Circularity: Tools and insight for fashion design for recycling. *Proceedings of the Cumulus Conference (P)References of Design*. (P)References of Design, Budapest.

Forst, L., Goldsworthy, K., Hildenbrand, J., & Sànchez Domene, D. (2023, June 1). *Lifecycle Design: A method for supporting design decision-making with LCA knowledge in an interdisciplinary research project*. PLATE 5th Product Lifetimes and the Environment Conference, Aalto University, Finland. https://www.plateconference.org/

Global Fashion Agenda. (2017). *2020 Commitment*. https://www2.globalfashionagenda.com/commitment/

Hall, C., Forst, L., Goldsworthy, K., & Earley, R. (2023). Broken Butterfly Wings: Exploring the role of textile blends in the circular economy for recycling and disassembly. *Journal of Textile Design Research and Practice*, *11*(1–2), Article 1–2. DOI: 10.1080/20511787.2023.2208929

Hardingham, M. (1978). Illustrated dictionary of fabrics. Studio Vista.

Kaszynska, P., & Kimbell, L. (2024). Design Practice Research: Conditions and Outcomes. *Design and Culture*, 1–22. https://doi.org/10.1080/17547075.2024.2401240

Lee, S., Congdon, A., Parker, G., & Borst, C. (2020). *Understanding 'Bio' Material Innovations Report*. https://app.box.com/s/amjq9anszv8hvwdexoxg6wubes4aaxqa

Nellström, M., Lidfeldt, M., Martvall, A., Sandin Albertsson, G., & Andersson, S. (2025). Sustainability assessment of textile reuse and recycling in and outside of Europe. IVL Svenska Miljöinstitutet. https://urn.kb.se/resolve?urn=urn:nbn:se:ivl:diva-4495

Solanki, S. (2018). *Why materials matter: Responsible design for a better world*. Prestel.

Sustainabelle. (2024). *Next Gen to This Gen: Scaling Material Innovations in the Fashion Sector*. https://www.sustainabelle.net/resources

Sustainable Angle. (2024, August 6). *Future Fabrics Expo 2024*. https://thesustainableangle.org/future-fabrics-expo-2024/

Sustainable Ventures. (2024). *Investment for Climate Tech*. Sustainable Ventures. https://www.sustainableventures.co.uk/investment

Textile Exchange. (2020). *Preferred Fibres and Materials Report*. https://textileexchange.org/wp-content/uploads/2020/06/Textile-Exchange_Preferred-Fiber-Material-Market-Report_2020.pdf

Vear, C. (Ed.). (2022). *The Routledge international handbook of practice-based research* [Electronic resource]. Routledge. https://ebookcentral.proquest.com/lib/UAL/detail.action?docID=6818293

WRAP. (2023). *Textiles 2030 annual progress report 2022/23*. https://wrap.org.uk/sites/default/files/2023-11/textiles-2030-annual-progress-report-2022-23.pdf

Research paper
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Assessing socio-economic impacts of Lithium-Ion Battery recycling through Multi-Regional Input-Output Analysis

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Keywords: Lithium-ion batteries (LIB); Multi-Regional Input-Output analysis (MRIO); Recycling; End of Life (EoL); Socio-economic impacts.

Abstract: The expected rise in electromobility and the increasing use of lithium-ion batteries (LIBs) is generating new challenges and opportunities, particularly in the End-of-Life (EoL) management of batteries. One of these challenges are the socio-economic impacts associated with the EoL process steps on which this paper focuses on. With the method of Multi-Regional Input-Output (MRIO) analysis, a selected recycling process route in Europe is assessed regarding socio-economic impacts, first at current demand (baseline scenario) and followed by an upscaled demand. The results provide insight into differences in some socio-economic impact categories, such as employment, vulnerable employment, and worker remuneration. The scale-up scenarios show, among other things, an increase in the workforce and remuneration (positive impact). However, with an increase in vulnerable employment, negative socio-economic impacts are also evident in Europe-centered recycling processes. The results furthermore show that changing recycling processes can lead to sustainability trade-offs. Due to the limited number of indicators in the selected method, it is not possible to provide an overall picture of social impacts. However, this research shows a clear change in the individual impacts, which underlines the need for proactive measures to overcome infrastructure problems, expand recycling capacities, and improve employment conditions in all sectors.

Introduction

The transport sector is one of the main sources of greenhouse gas emissions. Road traffic, particularly vehicles, generates the most emissions in the transport sector. To reduce traffic-related emissions, electric vehicles powered by LIBs are a promising alternative to conventional vehicles with combustion engines. Such a substitution of conventional vehicles by electric vehicles leads to an expected increase in demand for LIBs. The forecast for the rising demand for LIBs depends on the scenario, but a tenfold increase until 2030 seems realistic (Usai et al, 2022). It is also predicted that future demand for lithium for LIBs in electric vehicles will exceed current raw material production in 2040 (Maisel et al, 2023).

The challenges in the life cycle of batteries, such as the scarcity of raw materials and the generation of waste, require effective EoL management strategies, such as effective recycling technologies. There are still substantial challenges in the EoL management of LIBs. The emergence of potential sustainability trade-offs underlines the challenges in LIB recycling processes. Sustainability trade-offs refer to the complex and often interrelated decisions that are made in the pursuit of sustainable outcomes, where improvements in one area may come at the expense of another (Morrison-Saunders & Pope, 2013). New Europe-centered recycling processes can improve the economic situation in certain countries (e.g., increasing employment). However, this could also lead to negative effects in countries currently involved in the EoL processes of LIBs. The use of labour-related indicators (e.g., through an MRIO analysis) can be a promising approach to analyzing sustainability trade-offs and the associated impacts (Zimek et al, 2022).

The ecological impacts of LIBs recycling are being increasingly addressed in scientific research (Meshram et al, 2020; Costa et al, 2021). The industry is likewise showing an increasing interest in reducing its environmental

impact (notably through the EU Battery Regulation [1] with mandatory raw material-dependent recycling quotas, which are to be implemented by 2030 and 2035). However, although research in LIB recycling is increasing, socio-economic impacts are often neglected, although the recycling of LIBs entails several socio-economic impacts that need to be identified and consequently avoided (see for example, Yıldızbaşı et al, 2022 or Koese et al, 2023).

This can be explained, for example, by the fact that there are no common and generally accepted methods for assessing the socio-economic impacts, especially of emerging technologies (Sanchez et al, 2021; Cecere et al, 2024) Socio-economic assessments differ considerably from environmental assessments as they focus on a broader range of qualitative and quantitative data, complex feedback loops and different stakeholder interests. This complexity makes standardization and consensus on assessment methods difficult (Ramos, 2024; Rebolledo-Leiva et al, 2023). Despite these challenges, it is increasingly recognized that socio-economic impacts need to be integrated into assessment methods, as they are essential for comprehensively evaluating the holistic impacts of technologies. The importance of assessing the socio-economic impacts of emerging technologies, such as new LIB recycling processes, is of particular relevance, as the structures in the recycling processes, the countries involved, and consequently, the social context can change.

Therefore, the research aim of this paper is to identify the socio-economic impacts of LIB recycling processes with a focus on a Europe-centered value chain (as part of the FREE4LIB[2] project). More precisely the aim is to answer the following research questions.

(1) What are the direct impacts of the lithium-ion battery recycling process for six socio-economic indicators throughout the phases of collection, pre-treatment, metal recovery, and assembly in different European countries?
(2) How do these impacts differ under scale-up scenarios driven by the increasing demand for batteries in the electric vehicle sector?

Methods

Depending on the field of application, different methods exist to assess socio-economic impacts. For the common field of application, the evaluation of (public) investments, tools like social return on investment or cost-benefit analysis are used (Cerioni et al, 2021). For the evaluation of value chains, life cycle assessment (e.g., with the help of the Social Hotspots Database) or MRIO analysis are often used (Zimek et al, 2022).

While life cycle assessment approaches are usually product or site-specific, MRIO follows a top-down approach. It is a quantitative approach which allows for an in-depth analysis. MRIO is a method used to assess the interregional flows of goods and services by linking the economic activities of multiple regions through their trade relationships (Wiedmann et al, 2011). Furthermore, socio-economic impacts often vary greatly depending on the region (country). Therefore, MRIO analysis is a well-suited method to account for potential regional disparities by tracking indirect effects along supply chains at the sectoral level (Miller and Blair, 2009). Several MRIO databases exist. For this research, the freely accessible database EXIOBASE v3.8 is used, with data from the year 2016, the most recent available data at the time when the research was done (Stadler et al, 2018).

This study follows a three-step approach, including:

(1) The preparation step: set up of a representative product system for the battery recycling, and selection of impact categories,
(2) The baseline calculation: calculation of the socio-economic impacts based on the default final demand, and
(3) The scale-up calculation: calculation of the socio-economic impacts in dependence on increasing battery recycling volumes.

First step: Preparation

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02006L0066-20180704

[2] FREE4LIB is an EU-funded research project on 21 technologies with the aim to develop new technologies (5-6 TRL) to achieve sustainable and efficient processes to recycle EOL LIBs, Source: https://www.freeforlib.eu/.

A product system of four phases is selected based on a literature review and information from the Horizon Europe project FREE4LIB. The process under study starts with the collection of EoL LIBs in Spain. This is followed by the pre-treatment in France and then the actual recycling, in this study through metal recovery, in Belgium. The final phase is the production and assembly of new LIBs in the Republic of Türkye. Next, due to the limited availability of sectors in the used EXIOBASE v3.8 database, each process step is matched with a representative related sector in the database (see Table 1 below).

Phase	Country	Sector in EXIOBASE v3.8
Phase 1: Collection	Spain	Other land transport
Phase 2: Pre-Treatment	France	Waste water treatment, other
Phase 3: Metal Recovery	Belgium	Re-processing of secondary precious metals
Phase 4: Assembly	Republic of Türkiye	Manufacture of electrical machinery and apparatus n.e.c.

Table 1. Phases included in MRIO analysis of LIB recycling showing country and respective sector in EXIOBASE v3.8

The next step in the preparation phase is the selection of socio-economic impact categories. The EXIOBASE v3.8 database used offers six socio-economic impact categories, all of which are used as impact categories in this study (see Table 2 below). The six socio-economic impact categories include:

- Employment: aggregated number of individuals involved in productive activities.
- Employment hours: total hours worked by all individuals together in one year.
- Value added: economic value created through the production of goods and services by subtracting the value of intermediate consumption.
- Compensation of employees: all forms of remuneration aggregated, including both cash and non-cash benefits.
- Vulnerable employment: aggregated number of individuals who work under difficult conditions, e.g., no formal employment contracts and no social protection.
- Vulnerable employment hours: total hours worked under vulnerable working conditions in one year.

High numbers as results for the different impact categories are sometimes interpreted as positive and sometimes interpreted as negative. For example, employment should be increased, so a high number is perceived as positive and vulnerable employment should be decreased, so a high number is perceived as negative. This is expressed by the term “high value perception”. Table 2 below shows the units of each impact category and the high value perception.

Socio-economic impact category	Unit	High value perception
Employment	in 1,000 persons (1000 p)	positive
Employment hours	hours (hrs)	positive
Value added	in millions of euros (M.EUR)	positive
Compensation of employees	in millions of euros (M.EUR)	positive
Vulnerable employment	in 1,000 persons (1000 p)	negative
Vulnerable employment hours	hours (hrs)	negative

Table 2. EXIOBASE v3.8 socio-economic impact categories.

Second step: Baseline calculation

The calculation of the baseline impacts consists of a filtering of the database by the selected sectors and regions. The obtained values for employment and vulnerable employment and employment hours and vulnerable employment hours are put into relation to calculate vulnerability ratios. Further, the results of the baseline calculation can be used to provide an

idea of the overall direct impacts of the product system in the selected sector and region. Lastly, the results are used as a benchmark for the scale-up scenarios.

Third step: Scale-up calculation

To simulate the consequences of the expected demand growth of LIBs in the following years, the final demand in the selected sectors and regions (see Table 1) is increased by factor 10. Then the whole system is updated to the new final demand and the impacts are filtered in a similar manner as in the baseline calculation. For the relative change to the baseline in percent (as displayed in Figure 2) the results are divided by the baseline impacts.

Results

Like the methods section, the results separately contribute to answering the two different research questions regarding baseline and scale-up scenario. While the analysis of the baseline focuses on the differences in impacts between the phases, the scale-up results look at the differences both within and between the phases

Baseline scenario

In the baseline scenario, phase 1 (collection) and phase 4 (assembly) exhibit notably high absolute values for all impact categories. Compared to phase 3 (metal recovery) which has low values for all impact categories, the values differ by several orders of magnitude. Phase 2 (pre-treatment) is somewhere in between. This result can be observed for all impact categories. Exemplary, here are the values for employment (in 1000 persons, see table 2):

- Phase 1 Collection: 258 000
- Phase 2 Pre-treatment: 6 760
- Phase 3 Metal recovery: 0.00273
- Phase 4 Assembly: 360 000

In comparison, the vulnerability ratio is rather balanced, with all results in the same order of magnitude. Figure 1 below shows the ratio of vulnerability for the different phases.

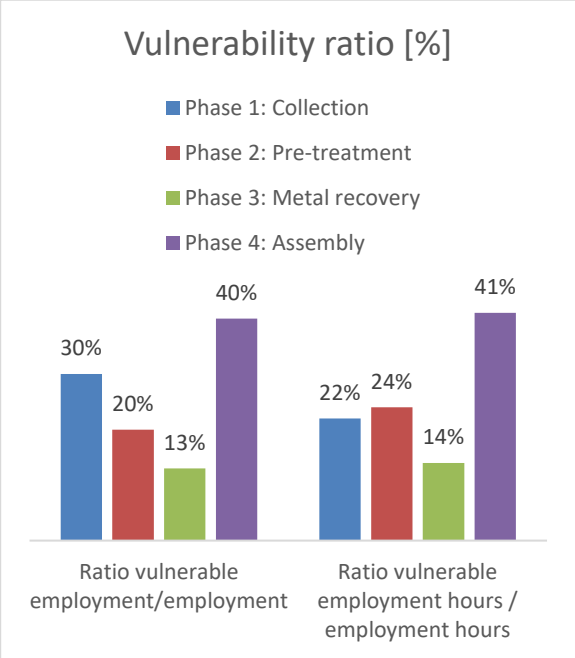


Figure 1. Relative vulnerability of different phases

A low vulnerability ratio represents a low share of vulnerable employment of the total employment. For both the employment ratio and the employment hour ratio, phase 3 (metal recovery) has the lowest value, while phase 4 (assembly) has the highest value. However, phase 1 stands out with a lower ratio when looking at employment hours compared to the number of employees ratio. Phase 4 has a very high share of vulnerability in both the number of employees and employment hours.

Scale-up scenario

Figure 2 below shows the results of the scale-up scenario for the six socio-economic impact categories in the four phases.

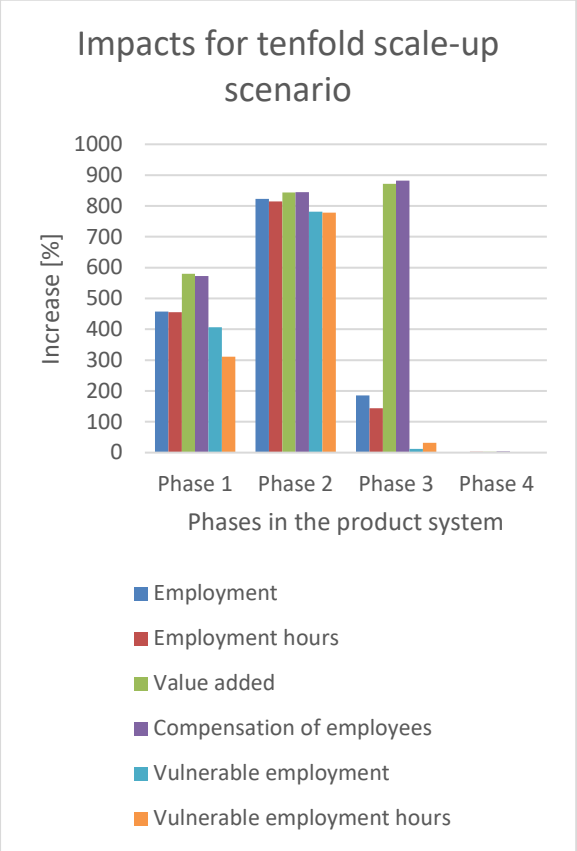


Figure 2. Comparative overview of the scaled-up impacts

The first observation is the increased impact in all phases and sectors through the scale-up of the demand. The increasing demand for LIBs leads to increased employment, compensation, and added value. However, this also results in an increase in the amount of vulnerable employment, particularly in phase 1 (collection) and phase 2 (pre-treatment). Interestingly, the impact of the different phases does not grow equally. A tenfold increase in the demand does not lead to a tenfold increase in the impacts. For example, while the compensation of employees grows by 573% for phase 1 (collection), phase 2 (pre-treatment), and phase 3 (metal recovery) increase between factors 8 and 9. Phase 4 (assembly) almost stays the same as in the baseline scenario. Therefore, the impact in the different phases increases at a different rate. However, the ratio of the different impact categories within one phase does not change ("linear combination" of the baseline, not observable in figure 2). A final observation is the minimal increase of the impacts in phase 4 (assembly), despite the relatively high impacts in the baseline scenario.

Discussion

The results of this study show that the socio-economic impacts of Europe-centered recycling of LIBs are rather complex. In most results, the impact categories with a positive high-value perception and a negative high-value perception (see table 2) show similar behavior (i.e., either both are high or both are low). This means that, in this case, the Europe-centered recycling of LIBs creates jobs, increases remuneration, but also leads to socio-economic trade-offs. These trade-offs include vulnerable employment and vulnerable employment hours, as in this research, but can also encompass other impact categories not included here.

Apart from the "local" trade-offs analyzed in this research, other countries and sectors may also be affected. Changes in processes, such as the introduction of new LIB recycling technologies and the substitution of economic activities, could lead to shifts in activity and therefore impact in other countries and sectors as well. For example, an increase in employment in one country and sector might result in a decrease in employment in other countries and sectors. The extent to which changes in the economic system are associated with socio-economic effects in other countries requires further analysis.

Regarding the scale-up scenarios, the results give an insight into potential future socio-economic challenges. In contrast to intuitive expectations, the impacts do not rise equally with the increased demand. The impacts of the different phases even increase at different rates which changes the priority of the different phases, to be addressed with policy measures, compared to the baseline scenario.

Possible reasons for the variance in the impact growth could be diverse, such as:

- different share of employment in the sectors, e.g., especially the assembly phase is characterized by a high number of employees and hours worked,
- the same growth in absolute values of sectors that already have a high baseline impact is less in relative values, and
- the overlap of direct effects (higher demand) and indirect effects (substitution with other products), e.g., while the manufacturing of electric vehicles rises, the manufacturing of conventional vehicles

decreases. This affects some sectors more than others.

The results align with findings from existing literature. As previously noted by Fleischmann et al. (2023), the notion that recycling can be financially beneficial is supported. Further, the finding from Zimek et al. (2022), that an increase in demand is projected to generate additional job opportunities is also supported.
Major policy implications arise for mitigating the negative socio-economic impacts associated with recycling LIBs. Policy recommendations should address the identified weaknesses, focusing on strengthening job security, improving the quality of employment, and mitigating potential negative socio-economic impacts. In addition, policymakers must recognize the broader impacts that go beyond the local context examined in this study. Shifts in economic activity resulting from changes in the recycling of LIBs can have cross-country and cross-sectoral impacts and require comprehensive policy measures to manage and mitigate unintended consequences. To this end, the development of collaborative strategies and mechanisms for information sharing and coordination between relevant stakeholders and authorities in different regions is important to address potential co-benefits and ensure a more coherent and effective approach to reduce negative socio-economic impacts.
The insights gained from the scale-up scenarios highlight potential future socio-economic challenges that require proactive policy measures. The observed difference in impact growth highlights the need for adaptive policy measures that can respond effectively to the changing landscape of LIB recycling, considering factors such as the distribution of employment, relative impact growth and the interplay of direct and indirect effects.

Limitations

One limitation of using MRIO is that the databases include rather limited recent data (such as from 2016 in this study). Other limitations are the country-specific factors that strongly influence the results, such as lower wages in the Republic of Türkyie versus higher wages in France and Spain. The product system is very specific, and the data availability is limited (rather new technology), especially for the metal recovery phase.

Conclusions

This research contributes to the knowledge gap of socio-economic impacts in the LIB EoL. While the baseline analysis helps to identify sensitive areas such as vulnerable employment in the assembly phase, the scale-up indicates that the growing demand for LIBs causes a substantial socio-economic transformation that should be anticipated. However, this transformation cannot be simply extrapolated from the status quo but can lead to surprising shifts in the areas of concern. Future research aims at modifying product systems by integrating more details and assessing the sensitivity of the results.

Acknowledgments

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References

Cecere, G, Hassan, R., Eltohamy, H. & Rigamonti, L. (2024). A socio-economic assessment of an emerging technology in the mining industry. The International Journal of Life Cycle Assessment, https://doi.org/10.1007/s11367-024-02392-w.

Cerioni, E., & Marasca, S. (2021). The methods of social impact assessment: The state of the art and limits of application. Calitatea, 22(183), 29–36.

Costa, C.M., Barbosa, J.C., Goncalves, R., Castro, H., Del Campo, F.J., LancerosMendez, S., Recycling and environmental issues of lithium-ion batteries: advances, challenges and opportunities, Energy Stor. Mater. 37 (2021) 433–465. https://doi.org/10.1016/j.ensm.2021.02.032

Fleischmann, J., Hanicke, M., Horetsky, E., Ibrahim, D., Jautelat, S., Linder, M., Schaufuss, P., Torscht, L., & van de Rijt, A. (2023). Battery 2030: Resilient, sustainable, and circular. McKinsey & Company, 2–18.

Koese, M., Blanco, C.F., Vert, V.B. & Vijver, M.G. (2023). A social life cycle assessment of vanadium redox flow and lithium-ion batteries for energy storage. Journal of

Industrial Ecology, 27(1), pp. 223-237. DOI: 10.1111/jiec.13347

Maisel, F., Neef, C., Marscheider-Weidemann, F. & Nissen, N.F. (2023). A forecast on future raw material demand and recycling potential of lithium-ion batteries in electric vehicles. Resources, Conservation and Recycling, 192, 106920. https://doi.org/10.1016/j.resconrec.2023.106920

Meshram P, Mishra A, Abhilash Sahu R. Environmental impact of spent lithium ion batteries and green recycling perspectives by organic acids - a review. Chemosphere 2020;242:125291.

Miller, R.E. & Blair, P.D. (2009). Input-output analysis: Foundations and Extensions, Second ed., Cambridge Univ. Press, Cambridge. https://doi.org/10.1017/CBO9780511626982

Morrison-Saunders, A. & Pope, J. (2013). Conceptualising and managing trade-offs in sustainability assessment. Environmental Impact Assessment Review, 38, pp. 54-63. https://doi.org/10.1016/j.eiar.2012.06.003

Ramos, A. (2024). Sustainability assessment in waste management: An exploratory study of the social perspective in waste-to-energy cases. Journal of Cleaner Production, 475, 143693. https://doi.org/10.1016/j.jclepro.2024.143693

Rebolledo-Leiva, r., Moreira, M.T. & González-García, S. (2023). Progress of social assessment in the framework of bioeconomy under a life cycle perspective. Renewable and Sustainable Energy Reviews, 175, 113162. DOI: 10.1016/j.rser.2023.113162

Sanchez, M., Sanz, S., & Ventosa, P. (2021). Review of economic and socio-economic studies on recycling topics. ENT Environment and Management for the European Commission, DG JRC, under contract number B.B651793.

Stadler K, R. Wood, T. Bulavskaya, C.J. Sodersten, M. Simas, S. Schmidt, A. Usubiaga, J. Acosta-Fernandez, J. Kuenen, M. Bruckner, S. Giljum, S. Lutter, S. Merciai, J.H. Schmidt, M.C. Theurl, C. Plutzar, T. Kastner, M. Eisenmenger, K. Erb, A. de Koning, A. Tukker (2018) EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables, Journal of Industrial Ecology 22(3)502-515. doi: 10.1111/jiec.12715

Usai, L. et al 2022 Environ. Res.: Infrastruct. Sustain. 2 011002. doi : https://doi.org/10.1088/2634-4505/ac49a0

Wiedmann, T., Wilting, H.C., Lenzen, M., Lutter, S. & Palm, V. (2011). Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input-output analysis, Ecological Economics, 70, pp. 1937-1945.

Yıldızbaşı, A., Öztürk, C., Yılmaz, İ. & Arıöz, Y. (2022). Key Challenges of Lithium-Ion Battery Recycling Process in Circular Economy Environment: Pythagorean Fuzzy AHP Approach. Lecture Notes in Networks and Systems, 308, pp. 561-568. DOI: 10.1007/978-3-030-85577-2_66

Zimek, M., Asada, R., Baumgartner, R.J., Brenner-Fliesser, M., Kaltenegger, I., & Hadler, M. (2022). Sustainability trade-offs in the steel industry – A MRIO-based social impact assessment of bio-economy innovations in a belgian steel mill. Cleaner Production Letters, 3, 100011. https://doi.org/10.1016/j.clpl.2022.100011

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Designing materials with living organisms for care-based practices: an analysis of case studies within the wearables domain

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Keywords: Care-based practices; More-than-Human Design; Design for Emotional Durability; Wearables; Biodesign.

Abstract: The unsustainable patterns of human consumption, exacerbated by materialism, digital technologies, disruptive global events and the mounting issue of e-waste, demand a fundamental shift in design approaches. In light of these challenges, this paper discusses how integrating living organisms into materials design can facilitate this transition, fostering innovative interactions and enabling care-based practices. By analysing three case studies in interaction design, the research highlights the transformative potential of incorporating biological matter like plants, moulds, bacteria and fungi into domains such as the one of wearables. The biodesign processes examined reveal commonalities, including the unpredictable, transient and time-consuming nature of designing with living organisms, as well as the evolving commitment and sensitivity of both designers and users towards the artefacts. The findings suggest that embracing non-human agency in the design field can nurture empathy and symbiosis and encourage users' ethical practices, responsibility, and emotional awareness. The study provides valuable insights into embedding care in design, redirecting the focus away from the traditional environmental products' durability to a designed temporality, capable of engendering long-term emotional durability.

Introduction

The contemporary world is marked by a rise in materialism, the pervasiveness of digital technology and the occurrence of significant global events. These phenomena represent a reflection of humans' profound impact on the Earth. Current production and consumption patterns reveal a lifestyle that is no longer sustainable for the ecosystem (Bocken & Short, 2021; Schor, 2005), with everyday goods representing biodiversity threats due to poor material decomposability or improper disposal practices.
Among many other products, electronic devices contribute significantly to these impacts, representing a growing market (Forti et al., 2020) unfortunately designed for obsolescence. E-waste, containing both harmful and valuable components, requires specialised recycling methods to mitigate environmental damage (Grant et al., 2013; He et al., 2024; Robinson, 2009).

Given these patterns of human consumption, a system that eliminates pollution and maintains the circulation of materials is now imperative (Ellen MacArthur Foundation, n.d.). The materials design field can lead this transition of paradigm from consumerism towards responsible systems (Duarte Poblete et al., 2024). From this perspective, designers should look beyond the products' environmental lifespan and disposability. They should also recognise the dynamic nature of matter (Bennett, 2010) and explore new approaches to enhance its emotional and communicative value. By activating attachment to objects, designers can overcome the utilitarian sense of sustainable materials and embrace the concept of artefacts as bearers of meanings that the consumers convey (Chapman, 2009). Such a shift in a designer's mindset could facilitate a transformation in the user's engagement, thereby fostering virtuous behaviours. Consequently, designers should grasp strategies to implement durability at two levels, focusing on the materials' environmental impact and the sensorial experience and emotional responses they evoke (Karana et al., 2015).

Recently, several academics have been experimenting with the integration of living organisms to accomplish this goal, featuring "unique functionalities" (Karana et al., 2020) and mechanisms to change user-product interactions (Kim et al., 2023; Moisy & Pschetz,

2017; Pataranutaporn et al., 2020). In the design field, this emerging approach – incorporating biological matter into materials, processes, and tools – is referred to as biodesign (Myers, 2012).

The paper aims to delineate the potential of integrating living organisms into design as a means of fostering transformative change through innovative care-based practices. Using a case study methodology of wearables projects situated at the nexus of biodesign, materials design, and interaction design, the authors posit that including a non-human perspective in artefacts may promote the emergence of novel avenues that move from traditional products' durability to a designed temporality comprising interactions that may foster emotional durability over the long term.

Living Materials and Potentialities: when care shapes product durability

Biodesign represents an interdisciplinary design practice that integrates biological knowledge with design principles by incorporating organisms, such as algae, bacteria, fungi, plants and moulds. By feeling, growing, regenerating, adapting, and decaying, living components impart design artefacts with a material quality defined as "livingness" (Karana et al., 2020).

The speculative and pioneering nature of biodesign is based on methods like biofabrication, coming for biomedical applications and generating complex biological products of living and non-living matter (Mironov et al., 2009). These processes demand minimal energy inputs and generate biodegradable materials, aligning with environmental implementations and closed-loop systems essential in the present era (Camere & Karana, 2018). However, living artefacts extend beyond the realms of sustainability and circularity, fostering a holistic and renewable perspective that overcomes the duality between humans and nature (Cole, 2012) and promotes regenerative ecologies (Karana et al., 2023).

The intricate relationship established in integrating living organisms into materials transcends the boundaries of typical interactions, involving a post-humanist, "more-than-human" perspective (Tarcan et al., 2022). The concept of "designing with" living organisms marks a significant shift in the traditional, centralised design approach in which humans are the primary agents of change (Tomico et al., 2023). This transition – affecting not only designers but also users – towards an interrelationship between "cooperators" (Pinto et al., 2013) compels the adoption of participatory actions (Ooms et al., 2022). Within this framework, non-humans act as co-performers in shaping the scope of design and co-creating futures (Giaccardi, 2020) through behavioural constructs such as "collaborative survival" (Karana et al., 2023) or "symbiosis" (van den Broek et al., 2022).

A foundational concept underlying biodesign and, more in general, More-than-Human design (MtHD) is that of "mutualistic care," outlined as "a reciprocal and evolving relationship between humans and living artefacts" (Karana et al., 2020). The human being, in this context, embodies the subject of affective concern and the one who benefits from it, thereby assuming the roles of both "caregiver" and "care receiver" (van den Broek et al., 2022). Amongst several studies on the topic (Chen et al., 2021; Key et al., 2021; Ooms et al., 2022), Lu and Lopes (2022) reflect on the concept of "care-based interactions" and how integrating living organisms into interactive devices alters the user-interface relationship. Unlike conventional electronics that embed living organisms solely for functional purposes, their work elucidates the biological potential for sustainable interactions and deeper material considerations.

Through concrete examples and speculative theories, de la Bellacasa (2017) shows how care can be instrumentalised to become a transformative practice capable of redefining ways of living and interacting with technological and natural worlds. Similarly, Mattern (2018) suggests that care can serve as a crucial lever that "practitioners who design our material world" – together with policymakers and citizens – could use to construct equitable, responsible systems. Additionally, Moriggi and colleagues (2020) identify three main dimensions of care – "ethically-informed practices", "relational response-ability", and "emotional awareness" – which they propose can reframe human power and establish interdependence between subjects. Hence, they prove the potential of caring practices by

developing "interactivities" that instruct individuals to act consciously and challenge unethical behaviour. Thus, the notion of care in MtHD extends beyond human-centred empathy, encompassing an ethical and political commitment to non-human entities as well.

Methodology

Founded on a constructivist epistemological position, the paper employs a case study methodology – a research strategy comprehending qualitative tools like logical design, data collection techniques and data analysis approaches (Creswell & Creswell, 2017; Yin, 2006). More in detail, this study uses a comparative method on three cases from the wearables domain, guided by the following research question: ***Which specific features, activated through the integration of living organisms, can stimulate care-based practices and serve as catalysts for emotional durability?***

The selection of specific case studies is based on the application of clearly defined criteria. First, the cases are drawn from the field of interaction design and examine the same product properties to avoid substantial differences that could divert the focus of the study. Secondly, the case studies encompass a diverse range of living organisms and techniques to broaden the scope of evaluation. Additionally, each case study presents concrete outcomes and is accompanied by textual documentation, providing a comprehensive understanding of the design phases and analysis of users' perspectives. At last, the cases are subjected to an initial overview of the projects' information and an examination of the specific aspects of each project to determine key common features characterising the process of interacting with living organisms.

FloraWear

FloraWear by Nam, Campbell, Webb and Harmon (2023) combines fashion and horticulture, encouraging personal interaction with plants and promoting biophilia. The designers propose a DIY approach, allowing users to select a desired shape (necklace, ring, or bracelet) and customise it through an open-source platform for 3D printing. Subsequently, customers can cultivate seeds of different species on the substrate, providing daily irrigation and monitoring. The wearable can be replanted and reused at the end of a plant's lifecycle, reinforcing sustainable and circular practices. The interviews resulting from the project reveal the presence of emotional bonds forged through the users' direct, embodied engagement with nurturing plants.

Slime mould smartwatch

This smartwatch, developed by Lu and Lopes (2022), incorporates the living slime mould species of *Physarum polycephalum* to challenge the conventional notions of interactive technologies. The wearable blends living and non-living components, using the slime mould as both a functional heart-rate sensor and a symbolic element. To maintain functionality, the slime mould requires regular care in the form of water and nutrients. Neglecting its upkeep, the organism enters a dormant state and effectively disables the smartwatch's sensing capabilities. Therefore, the integration of the living component into the device creates a unique symbiotic relationship between users and devices characterised by responsibility and empathy.

Loupe & Lightbox

This project by Boer, Bewley, Jenkins, Homewood, Almeida, and Vallgårda (2020) explores alternative gut health self-tracking technologies by challenging the embarrassment due to illness forms assessment and fostering a more intuitive and tangible understanding of wellness over time. The authors first collaborated with user experts on the gut-brain relationship, inspiring the design brief for the devices. These studies revealed that users could develop a nurturing relationship with their gut microbiota, viewing self-tracking as a form of cultivation rather than mere data collection. Therefore, the project led to the design of two devices: *Loupe*, a wearable viewer designed to externalise gut biota, allowing users to closely examine and aesthetically appreciate their microbiome; *Lightbox*, complementing the wearable as a support to observe the agar-based Petri dishes and reflect upon the cultivated gut bacteria, enhancing the user's engagement and understanding.

Results

The case studies examined showcase diverse approaches in integrating living organisms in artefacts at the convergence of biodesign,

materials design and interaction design, each prioritising sustainable and interactive material use.

What emerges from the initial analysis and comparison of these artefacts – summarised in Table 1 – is that *FloraWear* promotes the integration of living materials for biophilic connections through wearable forms, while *Loupe & Lightbox* reimagine self-tracking tools for the gut microbiome and related mental well-being as cultivation devices that foster long-term nurturing relationships. The *Slime mould smartwatch* goes beyond the previous wearables design, integrating the digital functionality of microorganisms to encourage tangible care.

Each project explores the dynamic behaviour of living organisms, with particular attention to the involvement of users. The three projects represent "wearable provotypes" (Chen et al., 2024) that – rather than focusing on market-driven devices – mediate human-nonhuman interactions, speculating on alternative materialities and activating high emotional connections through care and symbiosis.

All projects highlight iterative design methodologies, employing experimentation and documentation to ensure materials interact seamlessly with users. Furthermore, an overlapping theme across the cases is the need for a balance between material considerations, aesthetic appeal, and user engagement.

	FloraWear	**Slime mould smartwatch**	**Loupe & Lightbox**
Designers	Hye Yeon Nam, JaNiece Campbell, Andrew Webb & Brendan Harmon 	Jasmine Lu & Pedro Lopes 	Laurens Boer, Harvey Bewley, Tom Jenkins, Sarah Homewood, Teresa Almeida, & Anna Vallgårda 
Main living organisms and materials	Plants (*Arugula, Alfalfa, Amaranth, Basil, Bean, Beets, Broccoli, Chia, Chives, Cilantro, Kale, Mint, Parsley, Peppermint, Radish, Rosemary, Thyme, Sage, Wildflowers*)	Slime mould *(Physarum polycephalum)*	Gut Bacteria, (contingent) Fungi
Typology of wearables and functionality	Jewellery-like wearables (necklaces, bracelets and rings) with living plants for co-living	Smartwatch for heart-rate sensing	Necklace-like wearable viewer complemented with a lightbox
Projects objectives	Foster empathy and biophilia	Empower users through physical care/responsibility	Design an alternative gut self-tracking device for aesthetic appreciation and closer self-awareness
Methodology of materials interaction investigation	Experimentation; documentation; designers' material experience; user studies analysis (questionnaires and interviews)	Experimentation; documentation; technical evaluation; designers' material experience; user studies analysis (interviews and diaries)	Experimentation; documentation; technical evaluation; designers' material experience; user studies analysis (probes and reports)
Interaction level (designers)	High: *plant growth; substrate experimentation*	Medium: *laboratory-based exploration*	High: *bacteria exploration and growth; substrate experimentation with dyes*

Interaction level (users)	High: *sensorial connection; empathy; nurturing process*	High: *functional connection; sensorial connection; empathy; nurturing process*	High: *functional connection; sensorial connection; empathy; nurturing process*
Required care level	High: *daily watering of plants*	High: *regular feeding and hydration*	High: *regular monitoring and collection of bacteria*
Fabrication approaches, methods and techniques	DIY-bio approach; hybrid craft; biofabrication; material layering; horticulture; 3D printing	Laboratory development; 3D printing; material layering; electronics embedding	Laboratory development; DIY dying; hybrid craft; biofabrication; culturing; 3D printing
Sustainability and Longevity aspects	Compostability of plants; regeneration of plants; reusability of substrate	Reusability and recyclability of casing; regeneration of mould; reusability of electronics	Regeneration of bacteria; biodegradability and regeneration of agar substrates

Table 1. Overview of case studies. © All images are copyrighted by the respective authors of the works cited in this paper.

The second examination enabled the authors to correlate the procedural and emotional information provided in the designers' theoretical dissemination, determining the innovative characteristics implied in the integration of living materials into wearables. The resulting specific elements of each product can be traced back to more generic categories of emerging common features, emphasising the user interaction with livingness and the creation of care-based bonds. Hereafter, each feature is examined in correlation with emotional durability.

As visible in Table 2, materials' "growth duration" periods vary significantly, ranging from 30 days to continuous cycles. The emerging feature here is the **time-consuming nature** of the process. The actors involved experience various temporal scales in different ways. This could be perceived as either an investment of effort or a ritual of care, directly connecting to emotional durability by fostering attachment or annoyance (if the user is unwilling to commit time). Common "growth variabilities" include dependency on environmental conditions (e.g., temperature, light, humidity, gravity), internal conditions (e.g. user gut health) and user behaviour. This results in a variable evolution of the product generating curiosity and engagement but also uncertainty. Emotional durability here hinges on whether **unpredictability** is seen as exciting or overwhelming. The "challenges" associated with these wearables also include the organisms' responses to environmental factors and the risk of other microorganisms' contamination, leading to a **loss of control** by humans over the process. While this may cause anxiety, it also encourages the adoption of collaboration with living, intelligent agents. The "requirements" for maintaining these wearables involve constant upkeep and care efforts, which may induce the burden of worry, stress and attachment in the user. This fosters a **sense of responsibility** towards the wearables, enhancing emotional durability by strengthening the user-product bond. Additionally, "materiality and sustainability aspects" further reinforce this relationship by embracing organic textures, transformations from dormancy to activation, natural dyes, and biodegradability. These characteristics highlight the **imperfect and transient nature** of the product, shifting its perception from a static object to a living actor, which encourages users to accept change and evolution as part of the experience. "Use modes" involve repetitive refinements and continuous symbiosis between the user and the organism, reinforcing the emerging feature of **iterative and collaborative actions**. This makes the user an active cooperator, increasing emotional investment and attachment. Similarly, "innovative and unusual aspects" such as dormancy, growth, decay phases and changing behaviours require the user to develop **tolerance and acceptance** towards unfamiliar biological phenomena, further enriching emotional engagement. According to the willingness of the projects' designers, the "typology of connection" with the products is grounded in interactivities unlocked by livingness, transforming the wearable from a mere accessory into a companion. This aspect directly unlocks the emerging feature of **empathy and symbiotic attachment**. Finally, "interaction responses", as results of all the previously described aspects, encompass joy, stress, or frustration tied to the growth and decay of the organisms, with variable emotional reactions depending on the organism's success

or dormancy. The deriving **emotional fluctuations** enhance engagement but also introduce potential instability in user attachment.

These distinctive dimensions of integrating living organisms in products shift the design paradigms from inert to evolving and interactive experiences based on the care notion. In doing so, they support behaviours and practices in users that can serve as seeds for a future in which product durability extends beyond mere functionality and is also rooted in an emotional dimension.

	FloraWear	**Slime mould smartwatch**	**Loupe & Lightbox**	**Emerging shared features**
Growth duration	30 days (entire lifecycle)	Continuous (regular feeding and care)	Continuous (regular monitoring and care)	**Time-Consuming Process**
Growth variabilities	Health depends on user care and varies with external parameters (temperature, light, water, gravity, etc.)	Behaviour and durability depend on user care and vary with internal and external parameters (temperature, light, etc.)	Behaviour and durability depend on user care and vary with internal (user gut bacteria health) and external parameters (temperature, light, etc.)	**Unpredictability**
Challenges	Organisms' responses to environment; Micro-organisms contamination	Organisms' responses to environment; Micro-organisms contamination	Organisms' responses to environment; Micro-organisms contamination	**Loss of Control of the process**
Requirements	Management of standard external parameters; Maintenance; Care efforts; Sense of worry or stress	Management of standard external parameters; Maintenance; Care efforts; Sense of worry or stress	Management of standard external parameters; Maintenance of bacteria viability; Care efforts; Sense of worry or stress	**Sense of Responsibility**
Materiality and sustainability aspects	Organic shapes; Changes of matter from dormancy to activation; Biodegradability	Organic shapes and textures; Changes of matter from dormancy to activation	Organic shapes and textures; Natural dyes; Biodegradability	**Imperfect and Transient Nature**
Use modes	Repetition of actions to refine design; Plant care and co-living	Continuous symbiosis between user and organism	Repetition of actions to cultivate bacteria; Continuous symbiosis between user and organism	**Iterative and Collaborative Actions**
Innovative and unusual aspects	Dormancy, growth and decay phases	Slime mould's natural behaviour	Gut bacteria's direct visualisation and growth	**Tolerance and Acceptance**
Typology of connection with the product	Emotional bonds with plants through care	Symbiotic relationship through care	Nurturing relationship through care	**Empathy and Symbiotic Attachment**
Interaction responses	Joy, stress or frustration with plants' growth and decay	Variable feelings tied to the organism's success or dormancy	Variable feelings tied to gut-mental health and bacteria's aesthetic appearance	**Emotional Fluctuations**

Table 2. Analysis of cases' key aspects, highlighting the resulting shared traits of biodesign processes.

Discussion and Conclusions

This paper examines the potential of care in integrating living organisms, such as plants, bacteria, fungi and moulds, into design. Using a multiple-case analysis of three wearable projects at the intersection of biodesign, materials design, and interaction design, the study highlights how the inclusion of living organisms fosters innovative, caring interrelationships.

Drawing on Moriggi et al. (2020), the analysis findings can be traced back to the three pillars of care. Sustainability aspects, the sense of responsibility, the lack of control over the process and iterative and collaborative actions all contribute to shaping "ethically-informed practices" through interdependencies and commitment. Responsibility – together with empathy, symbiosis, emotional fluctuations and interactions – implies "relational response-ability", proving the ability to respond and adapt to other agents' needs. Moreover, as also observed by Pinto and colleagues (2013), the imperfection and transience of living artefacts act as catalysts for "spaces of feelings" while interacting with living organisms, supporting the third care-based dimension of "emotional awareness" (Moriggi et al., 2020).

The authors acknowledge the focus on experimental projects confined to the limited domain of wearables. Therefore, they recognise that the virtuous behaviours unlocked by living artefacts may not necessarily be conducive to sustainable and responsible transition. The mindful consideration of the traditional products' lifespans remains a decisive factor in design. However, this study can serve as an illustrative example to inform further research in other design domains.

Ultimately, this paper puts forward biodesign as an approach to materials design that serves as a stimulus to acknowledge the possibilities of more-than-human collaboration. The resulting intentional and transient interactions – eliciting empathy, cooperation and symbiosis – shift the focus away from traditional material durability towards a concept of designed temporality. Consequently, the insights encourage designers to embed care-based practices into products, paving the way for emotional durability in future production and consumption patterns.

References

Bennett, J. (2010). *Vibrant Matter. A political ecology of things*. Duke University Press.

Bocken, N. M. P. & Short, S. W. (2021). Unsustainable business models – Recognising and resolving institutionalised social and environmental harm. *Journal of Cleaner Production*, *312*, 127828. https://doi.org/10.1016/j.jclepro.2021.127828

Boer, L., Bewley, H., Jenkins, T., Homewood, S., Almeida, T. & Vallgårda, A. (2020). Gut-Tracking as Cultivation. *Proceedings of the 2020 ACM Designing Interactive Systems Conference*, 561–574. https://doi.org/10.1145/3357236.3395588

Camere, S. & Karana, E. (2018). Fabricating materials from living organisms: An emerging design practice. *Journal of Cleaner Production*, *186*, 570–584. https://doi.org/10.1016/j.jclepro.2018.03.081

Chapman, J. (2009). Design for (Emotional) Durability. *Design Issues*, *25*(4), 29–35. https://doi.org/10.1162/desi.2009.25.4.29

Chen, D., Seong, Y. ah, Ogura, H., Mitani, Y., Sekiya, N. & Moriya, K. (2021). Nukabot: Design of Care for Human-Microbe Relationships. *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–7. https://doi.org/10.1145/3411763.3451605

Chen, S. N., Flanagan, P. & Akmal, H. A. (2024). Escaping Human Experience: An Entry into Otherness Through Wearable Technology. *ISEA 2024 - International Symposium on Electronic Art.*

Cole, R. J. (2012). Regenerative design and development: current theory and practice. *Building Research & Information*, *40*(1), 1–6. https://doi.org/10.1080/09613218.2012.617516

Creswell, J. W. & Creswell, J. D. (2017). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications, Inc.

de la Bellacasa, M. P. (2017). *Matters of Care: Speculative Ethics in More than Human Worlds*. University of Minnesota Press.

Duarte Poblete, S. S., Romani, A. & Rognoli, V. (2024). Emerging materials for transition: A taxonomy proposal from a design perspective. *Sustainable Futures*, *7*, 100155. https://doi.org/10.1016/j.sftr.2024.100155

Ellen MacArthur Foundation. (n.d.). *Circular Economy Introduction. Overview*. Retrieved 29 November 2024, from https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview#principles

Forti, V., Baldé, C. P., Kuehr, R. & Bel, G. (2020). *The Global E-waste Monitor 2020. Quantities, flows, and the circular economy potential*. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam. https://ewastemonitor.info/wp-content/uploads/2020/11/GEM_2020_def_july1_low.pdf

Giaccardi, E. (2020). Casting Things As Partners In Design: Toward A More-Than-Human Design Practice. In *Relating to Things* (pp. 99–132). Bloomsbury Publishing Plc. https://doi.org/10.5040/9781350124288.ch-006

Grant, K., Goldizen, F. C., Sly, P. D., Brune, M.N., Neira, M., van den Berg, M. & Norman, R. E. (2013). Health consequences of exposure to e-waste: a systematic review. *The Lancet Global Health*, *1*(6), e350–e361. https://doi.org/10.1016/S2214-109X(13)70101-3

He, Y., Kiehbadroudinezhad, M., Hosseinzadeh-Bandbafha, H., Gupta, V. K., Peng, W., Lam, S. S., Tabatabaei, M. & Aghbashlo, M. (2024). Driving sustainable circular economy in electronics: A comprehensive review on environmental life cycle assessment of e-waste recycling. *Environmental Pollution*, *342*, 123081. https://doi.org/10.1016/j.envpol.2023.123081

Karana, E., Barati, B. & Giaccardi, E. (2020). Living artefacts: Conceptualizing livingness as a material quality in everyday artefacts. *International Journal of Design*, *14*(3), 37-53.

Karana, E., McQuillan, H., Rognoli, V. & Giaccardi, E. (2023). Living artefacts for regenerative ecologies. *Research Directions: Biotechnology Design*, *1*, e16. https://doi.org/10.1017/btd.2023.10

Karana, E., Pedgley, O. & Rognoli, V. (2015). On Materials Experience. *Design Issues*, *31*(3), 16–27. https://doi.org/10.1162/DESI_a_00335

Key, C., Browne, F., Taylor, N. & Rogers, J. (2021). Proceed with Care: Reimagining Home IoT Through a Care Perspective. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–15. https://doi.org/10.1145/3411764.3445602

Kim, R., Risseeuw, C., Groutars, E. G. & Karana, E. (2023). Surfacing Livingness in Microbial Displays. *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, 1–21. https://doi.org/10.1145/3544548.3581417

Lu, J. & Lopes, P. (2022). Integrating Living Organisms in Devices to Implement Care-based Interactions. *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology*, 1–13. https://doi.org/10.1145/3526113.3545629

Mattern, S. (2018). Maintenance and Care. *Places Journal*. https://doi.org/10.22269/181120

Mironov, V., Trusk, T., Kasyanov, V., Little, S., Swaja, R. & Markwald, R. (2009). Biofabrication: a 21st century manufacturing paradigm. *Biofabrication*, *1*(2), 022001. https://doi.org/10.1088/1758-5082/1/2/022001

Moisy, A. & Pschetz, L. (2017). Designing with living organisms. *Proceedings of the 3rd Biennial Research through Design Conference RTD'17*, 323–339. https://doi.org/10.6084/m9.figshare.4746994.v1

Moriggi, A., Soini, K., Franklin, A. & Roep, D. (2020). A Care-Based Approach to Transformative Change: Ethically-Informed Practices, Relational Response-Ability & Emotional Awareness. *Ethics, Policy & Environment*, *23*(3), 281–298. https://doi.org/10.1080/21550085.2020.1848186

Myers, W. (2012). *Biodesign. Nature, Science, Creativity* (1st ed.). Thames & Hudson.

Nam, H. Y., Campbell, J., Webb, A. M. & Harmon, B. (2023). FloraWear: Wearable Living Interface. *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction*, 1–15. https://doi.org/10.1145/3569009.3572801

Ooms, D., Barati, B., Bruns, M. & van Dongen, T. (2022). From Concern to Care: A Transformative Reflection on Designing-with the Living. *Nordic Human-Computer Interaction Conference*, 1–15. https://doi.org/10.1145/3546155.3547285

Pataranutaporn, P., Vujic, A., Kong, D. S., Maes, P. & Sra, M. (2020). Living Bits: Opportunities and Challenges for Integrating Living Microorganisms in Human-Computer Interaction. *Proceedings of the Augmented Humans International Conference*, 1–12. https://doi.org/10.1145/3384657.3384783

Pinto, R., Carvalhais, M. & Atkinson, P. (2013). Generative designing with biological systems - searching for production tools aimed at individualization. *Proceedings of the 10th European Academy of Design Conference 2013, Gothenburg.*

Robinson, B. H. (2009). E-waste: An assessment of global production and environmental impacts. *Science of The Total Environment*, *408*(2), 183–191. https://doi.org/10.1016/j.scitotenv.2009.09.044

Schor, J. B. (2005). Prices and quantities: Unsustainable consumption and the global economy. *Ecological Economics*, *55*(3), 309–320. https://doi.org/10.1016/j.ecolecon.2005.07.030

Tarcan, B., Pettersen, I. N. & Edwards, F. (2022). Making-with the environment through more-than-human design. In D. Lockton, S. Lenzi, P. Hekkert, A. Oak, J. Sádaba & P. Lloyd (Eds.), *DRS2022: Bilbao*. Design Research Society (DRS), 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.347

Tomico, O., Wakkary, R. & Andersen, K. (2023). Living-with and Designing-with Plants. *Interactions*, *30*(1), 30–34. https://doi.org/10.1145/3571589

van den Broek, S., de Rooij, A. & van Dartel, M. (2022). Living with living artefacts: Six concepts for designing user acceptance of living artefacts. In D. Lockton, S. Lenzi, P. Hekkert, A. Oak, J. Sádaba & P. Lloyd (Eds.), *DRS2022: Bilbao*. Design Research Society (DRS), 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.261

Yin, R. K. (2006). Case Study Methods. In J. L. Green, G. Camilli & P. B. Elmore (Eds.), *Handbook of complementary methods in education research* (pp. 111–122). Lawrence Erlbaum Associates Publishers.

Research paper
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Upcycling from 'One-of-a-Kind' to Industry Scale: Leveraging Strategies to Prolong the Life of Industrial Waste Materials

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Keywords: By-products, Upcycling. Scrap. Material. Lifetime. Industrial Design.

Abstract:
Industrial production generates waste in the form of scrapped, returned, or otherwise discarded materials, many of which are downcycled into lower-quality outputs. Upcycling offers a sustainable alternative by transforming waste into higher-value products while maintaining material integrity and leveraging more than just its basic composition. This study examines how product designers upcycle industrial scraps at an industrial scale. Through analysis of ten Danish field experiments with materials such as wood, concrete, leather, and fabric, we identified five leveraging strategies that distinguish the design processes of successful market entries from those that did not. These strategies are: (1) Linking the material to a portfolio to explore gaps and product line-up extensions, (2) Utilizing the material by leveraging locally available processing capabilities, (3) Shaping a by-product by adjusting ongoing production operations, (4) Leveraging the existing brand image, and (5) Leveraging 'Un-qualification as a Quality. The findings propose a framework for integrating upcycling into industrial contexts by strategically aligning products with company goals, resources, brand identity, and market position, to increase the likelihood of scaling upcycling from one-of-a-kind efforts to continued industrial practice.

Introduction

Industrial manufacturing facilities in Denmark alone generate about 1.2 million tons of waste yearly (Miljøstyrelsen, 2023) and similarly, companies in the EU alone generate over 2.2 billion tons of waste annually (Eurostat, 2022). Discarded materials include off-cuts or off-quality rejects of raw materials or end products. With growing resource scarcity and regulations on waste management, companies need to find new ways to reduce, reuse, and recycle the waste they generate. While existing recycling possibilities are developing, recycling methods require significant energy. Recycling is economically costly and, environmentally, a less energy-efficient recovery process, where materials are typically 'granulated' or melted into their primary state before reprocessing them into new products. Recycling often results in a material output of lesser quality and for this reason is also referred to as "downcycling" of the resource (McDonough & Braungart, 2013) (Wang, 2011).

A more favorable way of maintaining the lifetime of materials is through the 'upcycling' of resources and materials, and seeing waste materials as potential By-products (European Parliament, 2008) functioning as raw materials and feedstock for new or existing products or processes (Lee, 2011). Bridgens et al. (2018) define upcycling as giving new value to materials that are discarded or are not being used anymore. (Janigo & Wu, 2015) describe it as retaining the high quality and value of used or wasted materials in an open-loop industrial cycle to create higher-quality products. (Szaky, 2014) further unfolds that "an item is 'upcycled' when we leverage the 'form' and the 'composition, and not only the compound and substance of the material, utilizing the material at its existing integrity level. In this paper we define Upcycling, as the process of leveraging the form and composition of discarded materials or products by designing them into items of higher quality or value. Research argues that upcycling has the potential become a significant business opportunity, while also contributing to reduce global greenhouse gas emissions and bearing several benefits for both environment and society, by increasing material efficiency and lifetime, and thereby reduce energy consumption (Singh et al., 2019, 2019; Sung et al., 2019).

For example, a single case of upcycling industrial waste suggested a 67% energy saving, and approx. 40% cost reduction when repurposing car body window cutouts into architectural façade panels (Ali et al., 2019) However, upcycling today is currently seen as a niche practice having arts and crafts connotations (Sung et al., 2021). To move beyond art and crafts and similar demonstrational cases, researchers argue companies need to strive towards a systematic process and methodology for upcycling, which involves relevant stakeholders that can make use of the results. (Singh et al., 2019) The aim should be 'industrial scale', and not one-of-a-kind solutions (Ebbert et al., 2017)

Research shows that designing from industrial scraps follows an almost reversed logic, where multiple product potentials need to be investigated and explored. This process involves iteratively exploring where, for whom, and how the material can provide the most value. When scrap material is the starting point, designing entails a material-driven process, where the problem-solution is open-ended (Feast & Laursen, 2023). Coming up with ideas for reusing materials isn't the problem, but qualifying and selecting among the ideas is the real challenge (Ordoñez & Rexfelt, 2017). Questions such as: What is the most effective use of the available material? How to use it to its full potential? Is this reuse of the material more efficient than established ways to recycle? Designers qualify what makes sense to create from the material, ranking ideas for reuse, based on the scrap material's potential to become a functional product with the highest possible monetary value (Sander et al., 2024).

While research discusses how to assess the potential of scrapped materials, these studies are mainly based on material experts, researchers, or students. In many cases these do not fully consider the origin of the scrap, both in terms of market, product category, and production process, which we argue may be an important parameter for integrating it into existing industrial production and achieving larger-scale upcycling. In this study, we investigate how professional designers leverage more than just the form of discarded materials, to identify a fitting product category and design a successful product. We study the design rationales to uncover the leveraging strategies of products that succeed in entering the market and thus reach a scale that goes beyond one-of-a-kind prototypes.

Theory

In literature, there are different streams concerning designing with waste materials. From an engineering and product development perspective, propose a methodology for generating and evaluating product potentials value. Here ideas are evaluated based on market demand and their economic and environmental potential. The engineering design approach focuses on deriving product functionality from scraps that meet existing market needs and evaluating concepts for product architectures and configurations, based on operational factors, such as the number of machining processes required and the need for additional components in the product configuration. These factors help determine whether reusing and modifying scrap materials makes sense from an industrial production standpoint. Subsequently a preliminary, quantifiable analysis compares the economic and environmental benefits of creating a product from scrap materials versus manufacturing an identical product from new raw materials. This approach assesses the feasibility and value of manufacturing and transforms the scrap material into functionality that meets a customer's need and focuses on the cost-effectiveness and environmental sustainability of doing so.

The industrial design discipline approaches it differently from the engineering discipline. While providing the functionality to customers in a cost-effective way is a prevalent part of designing a product, the primary focus of the design perspective goes beyond the use of materials and manufacturing processes to solve functional needs (Barati & Karana, 2019) (Rognoli & Levi, 2004); (van Kesteren, 2008);(Pedgley, 2009) Research highlights how designers use materials and manufacturing processes to address emotional sensorial aspects by designing a *Product Personality.* (Ashby & Johnson, 2013). Personality refers to the aspects of a design that encompasses aesthetic attributes, associations, and perceptions. Designers use the expressive potential of materials and manufacturing processes - the shaping, finishing, and joining, to form a product's personality. Although these design factors also contribute to production costs, they also play a crucial role in the designer's intentions of influencing consumer evaluations and perceptions

of the product. They aid in creating a clear identity, meaning, or character for the product. Expanding on the notion of *form follows function,* (Ashby & Johnson, 2002) organized the key elements of product design into a structured framework, see Figure 1.

- The **Context** provides the foundation for articulating design intentions
- The **Function** and features form the central core of the design.

- The **Materials**, combined with
- The **Processes** that shape, join, and finish the product, together form its *physiological design.*

- Usability addresses ergonomics and user interaction, essential for interactive products. In combination with;
- The **Product Personality**, encompassing aesthetics, associations, and perceptions, contributes to the psychology of the product.

The starting point for conventional design processes is figuring out how to prove valuable to consumers, companies, and markets (Haase & Laursen, 2022). To succeed in being competitive in the market, it must offer clear advantages over existing products, often through unique features (Porter, 1980). These advantages can come from cost leadership, or meeting user needs in new ways, excelling in physical qualities, or adding emotional and symbolic value (Kotler et al., 2017). Additionally, the product must align with the company's offerings and image to strengthen its brand reputation (Kotler, 2003). It should also support the company's resources, skills, and technologies while reflecting its purpose and values. (Buijs, 2012). This ensures the product fits the market and user demands and supports the company's long-term goals and image (Haase & Laursen, 2022).

When upcycling material scraps on an industrial scale, the design process begins with the material already defined, and designers must iteratively identify potential applications and assess their value to narrow the solution space. (Sander et al., 2024). The design challenge shifts to a process of creating an endogenous artefact, an effectual design approach where design solutions are grounded in the limitations and possibilities of the situation (Feast & Laursen, 2023). Designers must create products that address user needs, align with the strategic objectives of the company commercializing the product, and demonstrate relevance within the target market. When exploring a product's potential and considering its various elements of the product character, the design process must take situational and contextual factors into account, primarily the specific circumstances of the company.

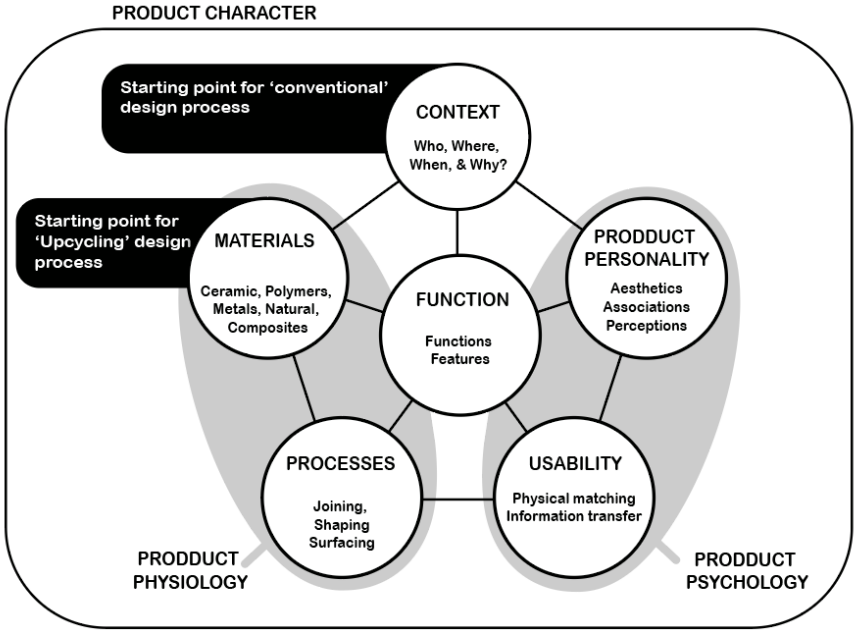


Figure 1. The dissection of Product Character, adapted from (Ashby & Johnson, 2002)

#	Discard scrap material description	Origin	Proposed product	Designer	Succeeding in entering market
1	Cutouts of Compact laminate, and Oak tabletop sink and cook plate	Kitchen countertop manufacturer	Compact laminate Side table, with wooden oak legs	Carpenter with +10 yrs Experience	X
2	Off-Quality Knotty pine boards	Wooden flooring manufacturer	Pine Door with Patchwork joined panels	Architect with +10 yrs Experience	X
3	Off-color, Off-Quality & returned Pants	Men's apparel company	3 colored, paneled branded tote bag	Industrial Designer with +10 Experience	X
4	Concrete consistency test slump,	Concrete element producer	Outdoor table & bench	Industrial Designer with <2 yrs Experience	X
5	Off-cut trims in ceramic tile	Kitchen countertop manufacturer	Soap Bar display	Industrial Designer with >5 Experience	X
6	Off-quality, leather trims	Furniture Upholstery	Leather Notebook Cover	Industrial Designer with <2 yrs Experience	X
7	Off-quality, leather trims from upholstery	Furniture Upholstery	Leather seat	Saddle maker with 10 yrs Experience	
8	Offcuts, fabric, and trims from upholstery	Furniture Upholstery	Braided accessories bag	Designer with +10 Experience	
9	Offcut, Steel plates with circular cutouts	Point of sale Products	Architectural plates	Industrial Designer with +10 Experience	
10	Fiber-reinforced PVC, Width trim offcuts on long reels from	Transportation belt manufacturer.	Parametric Light sculpture, with PVC panels	Industrial Designer with >5 Experience	

Table 1. List of cases from the experiments

Methodology and research design

This study investigates the upcycling of industrial scrap materials through 10 field experiments conducted within the *ReshapeWaste* and *ZeroWaste* projects in Denmark. See Table 1. These experiments involved professional designers, including industrial designers, architects, or craftsmen, collaborating with manufacturing companies to explore creative and functional uses for waste materials.

1) **Site Visits:** Designers visited production facilities to observe operations and examine the discarded materials and their origin.
2) **Concept Development**: Designers ideated and developed initial product concepts, proposing multiple scenarios for utilizing the identified scrap materials. They refined ideas into concepts, selecting a subset of ideas deemed most suitable for further exploration.
3) **Milestone presentations**: Designers presented their selected concepts to company representatives, providing arguments for the relevance of their proposals.
4) **Development and Implementation**: Concepts were developed into prototypes, and after proof of concept, some were commercialized, thus succeeding in entering the market, not only as a one-of-a-kind solution but as industrialized products with multiple quantities.

Data Collection and Analysis

The data collected included archival data in the form of presentation materials, observations of meetings and milestone presentations, 10 semi-structured interviews conducted with the designers varying from 45 minutes to 1 hour and 15 minutes.

These interviews were transcribed and analyzed to reveal how the designers argued for the alignment between the elements of the product character, and the context now being the situation of the company. Each case was analyzed using affinity diagramming (Hanington & Martin, 2019; Harboe & Huang, 2015), by sampling the quotes and rationales from the designers, and labeling each of the quotes, pinpointing which part of the product character; Functionality, Usability, Product Personality, Material, and Manufacturing Process, was associated with the quote, to reveal cross case comparable patterns in argumentation for the different aspects of the product.

Results & discussion

Among the 6 successful cases, we identified 5 different, and cross-case comparable rationales, aimed at amplifying a product's overall relevance for company and market dimensions. In the following, we uncover the data analysis, giving examples of the coding of the quotes, to unfold the five leveraging strategies identified.

Leveraging strategy 1. Linking the material to a portfolio to explore gaps & product line-up extensions

When coming up with a new product, and arguing what material scrap should function as, most cases took offset in exploring a company's portfolio and point of sales. The designers proposed or aimed to create a product that complemented either the scrap-producing company, or another specific known company, and their existing offerings. See Figure 2.

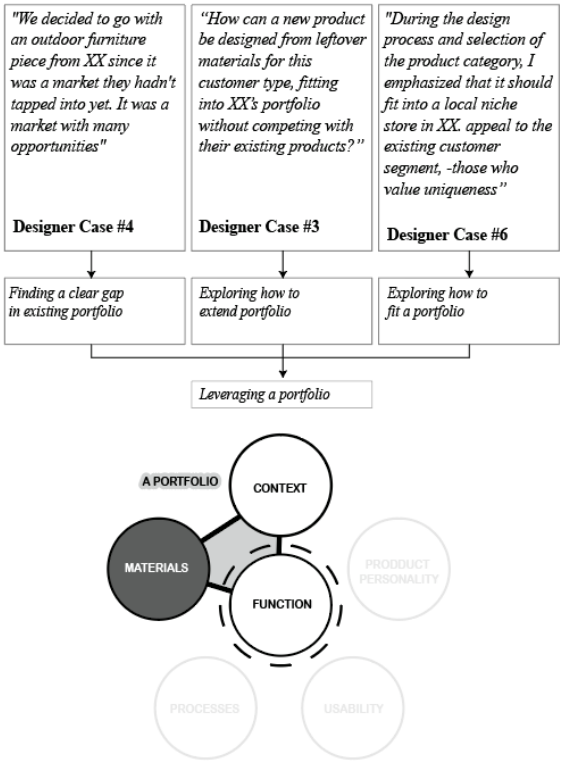


Figure 2. Example of analyzing quotes regarding exploration of functionality.

The focus here was on either identifying a product category where the materials could provide functionality that fitted the company's current product or introducing a new category within the same market segment, leveraging and identifying opportunities for portfolio gaps & product line-up extensions. By positioning the designs within the market the company already operates in, designers capitalized on the company's existing strengths and customer base.

Leveraging strategy 2. Utilizing the material by leveraging locally available processing

When deciding on manufacturing processes for product proposals, most designers relied on the company's existing production capabilities. They utilized available shaping, joining, and surfacing techniques to enhance product appeal, particularly where CNC machinery allowed for complex shapes and detailed joinery. See Figure 3.

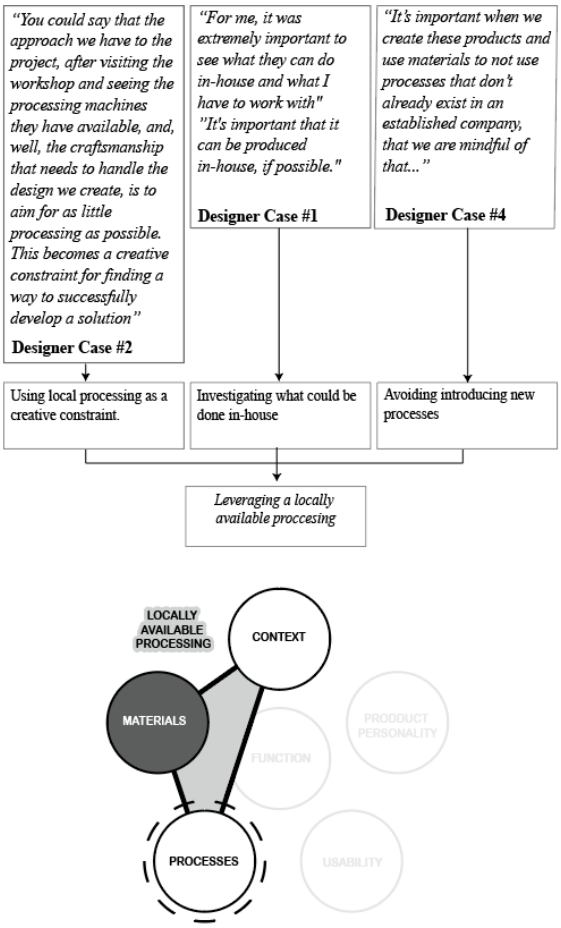


Figure 3. Example of analyzing quotes regarding Processes.

In contrast, when specialized equipment was absent, manual operations like those for tote bags or leather notebook cases were prioritized to be minimal, to ensure possibility for local production and minimized costs, avoiding new inventory investments or higher logistics expenses to far external processing.

Leveraging strategy 3. Shaping a by-product, by adjusting Ongoing Operations

A common strategy identified was the shaping upcycled by-product or its components using the same process as the primary product, applied in various ways. See Figure 4.

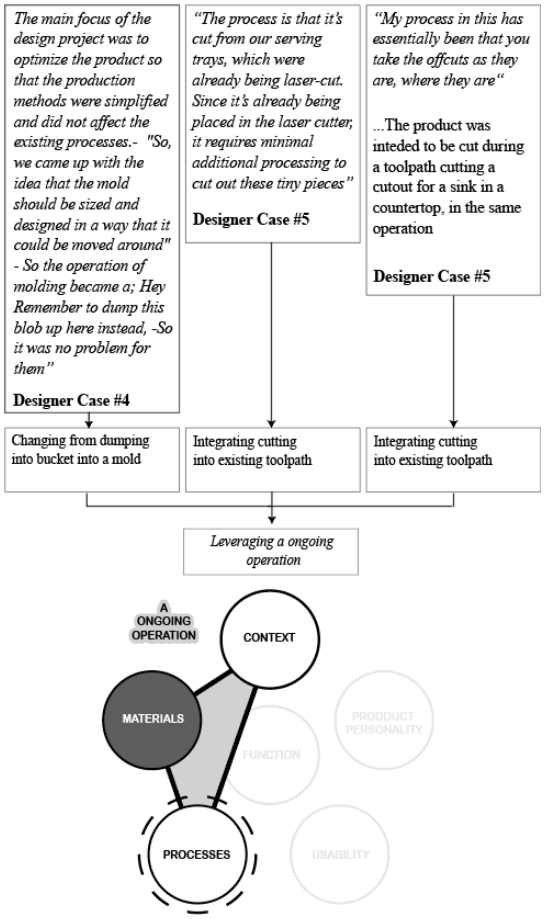


Figure 4. Example of analyzing quotes regarding Processes.

While companies typically ignored the appearance of by-products destined for disposal, designers proposed rethinking these processes by integrating steps or modifying operations to shape by-products coincidently to the primary product. For instance, in outdoor seating, discarded concrete test slumps, dropped to test consistency, were placed into a mobile mold instead of a dumpster, turning the wasted slump into a functional component for the bench. Similarly, for the soap bar holder, adjusting the cutting toolpath was proposed to shape the feet, reducing costs and eliminating extra handling and setup when processing the scrap.

Leveraging strategy 4. Leveraging a "Brand image"

In the design proposals the product personality was built on the company's **branding** and symbolic value to enhance the perceived value of their product concepts. Unlike Portfolio lever, which prioritized functional alignment and market gaps, this strategy focused on aligning the product's personality with the brand's image. See Figure 5.

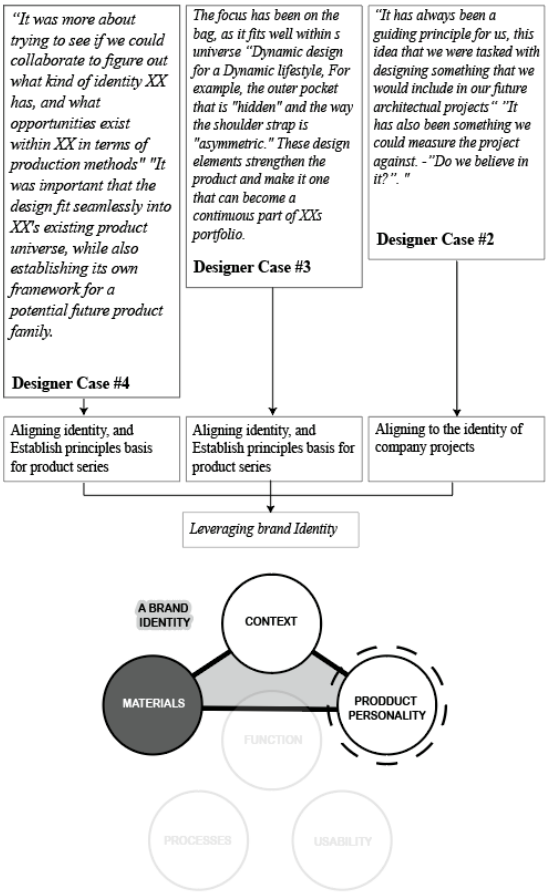


Figure 5. Example of analyzing quotes regarding exploration of product personality.

Designers achieved this by shaping, joining, and surfacing materials to reflect the brand's values. For example, in the tote bag case, the leather label from a pair of pants was carefully removed and reused as a central joining detail on the bag. This not only reinforced the storytelling, highlighting the bag's origin as a pair of pants, but also attributed the brand's identity to the product, strengthening its symbolic value. Similarly, in the outdoor bench seating, design-

ers emphasised brand coherence by incorporating wooden slats and large visible bolts, showcasing the craftsmanship the company is known for. By focusing on expressive qualities and aligning the product's personality with the brand, these designs were presented as more than isolated concepts. They were framed as foundational principles for a potential product series, ensuring long-term market integration. This approach justified development investments and reinforced the brand's presence in the marketplace.

Leveraging strategy 5. Leveraging "Un-Qualification as a Quality"

This last identified strategy involves transforming the very characteristics that disqualified the scrapped material from being part of the primary product into something that differentiates the product in its category and frames it as being an advantage. Designers embraced a strategy of reframing these "flaws" as unique features or qualities. See Figure 6.

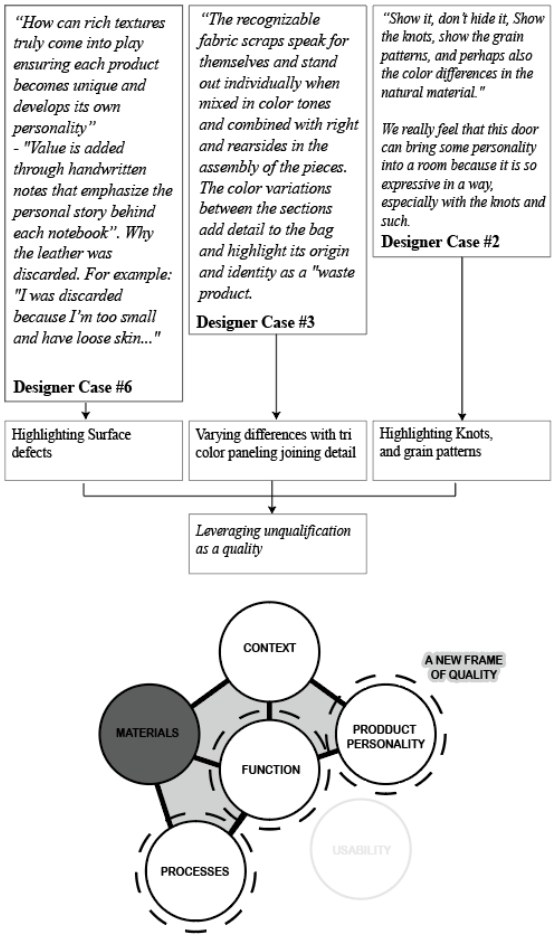


Figure 6. Example of analysing quotes with aligning Functionality, Product personality, and Processes.

This was achieved in various ways, in the tote bag and pine door, using joining variations, the materials were made into aesthetically pleasing unions that highlighted differences in color or texture. Likewise, the approach also involved purposefully using flawed materials in a product function where the material's defects carried symbolic or emotional meaning. For instance, in the case of a notebook cover, the scrap material's story - "I was discarded because I am too small and have loose skin" - was cleverly incorporated into the product's narrative. This aligned well with a diary's emotional and personal nature, turning the material's imperfections into a meaningful design element for the product.

Concluding and discussion

In our study, we identified strategies employed by designers when working with industrial scraps. We framed these as leveraging strategies, emphasising that upcycling (Szaky, 2014) involves reusing discarded materials by drawing on their composition and form. At an industrial scale, our findings suggest that successful upcycling requires the strategic leveraging of company capabilities on top. Although the study is based on a small and context-specific sample, the analysis provides preliminary insights into how such strategies may support upcycling efforts within industrial settings.

Designing from scraps presents an open-ended, context-sensitive challenge, one that is shaped by what is already at hand rather than by fixed goals (Feast & Laursen, 2023). It is inherently a situated practice, requiring designers to adapt to constraints and opportunities as they arise, in response to the open-ended nature of the task. When integrating elements of a product's character, functionality, processes, and personality (Ashby & Johnson, 2002), designers must leverage an understanding of the company's resources, skills, and technologies, while also reflecting its purpose and values (Buijs, 2012). In this way, the focus in the problem of applying materials in product design shifts from the use context and situation to the discarded materials and the operational context of the company in which it is embedded, making it the main situation to address, similar to (Ebbert et al., 2017). The elements of the product character are addressed with self-set constraints to narrow the solutions, and become central to how they rationalise their ideas and solutions, in an effort to ensure alignment with

broader company priorities, reducing company risk, and improving market relevance.

While assessing monetary potential in application and substitution (Sander et al., 2024) and evaluating efficiency in doing so (Pacelli et al., 2015) remain essential, our study contributes to the theory of designing from scraps by showing that success also depends on the strategic leveraging of internal capabilities, brand positioning, and operational alignment. When reviewing the ten cases, a clear pattern emerged: in all six successful outcomes, designers leveraged at least four of the identified strategies when bringing products to market. This suggests that the combination of multiple leveraging strategies may play a key role in enabling upcycled products to move beyond one-off prototypes. The leveraging strategies identified can also support prioritisation during the conceptual phase, helping to ensure that resulting designs are not only environmentally and economically sound but also practically viable and aligned with broader business objectives.

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References

Ali, A. K., Wang, Y., & Alvarado, J. L. (2019). Facilitating industrial symbiosis to achieve circular economy using value-added by design: A case study in transforming the automobile industry sheet metal waste-flow into Voronoi facade systems. *Journal of Cleaner Production*, *234*, 1033–1044. https://doi.org/10.1016/j.jclepro.2019.06.202

Ashby, M. F., & Johnson, K. (2002). *Materials and Design: The Art and Science of Material Selection in Product Design*. Butterworth-Heinemann.

Ashby, M. F., & Johnson, K. (2013). *Materials and Design: The Art and Science of Material Selection in Product Design*. Butterworth-Heinemann.

Barati, B., & Karana, E. (2019). Affordances as materials potential: What design can do for materials development. *International Journal of Design*. https://www.semanticscholar.org/paper/Affordances-as-materials-potential-%3A-What-design-do-Barati-Karana/ab3d9f61bca32c737270c19503456818ac03ec8f

Buijs, J. (2012). *The Delft Innovation Method: A Design Thinker's Guide to Innovation*. Eleven International Publishing.

Ebbert, C., Rexfelt, O., & Ordonez, I. (2017). Beyond Lampshades—Teaching Upcycling in a Meaningful Way. In A. Berg, E. Bohemia, L. Buck, T. Gulden, A. Kovacevic, & N. Pavel (Eds.), *BUILDING COMMUNITY: DESIGN EDUCATION FOR A SUSTAINABLE FUTURE* (pp. 740–745). Design Soc. https://www.webofscience.com/wos/woscc/full-record/WOS:000441174300124

European Parliament. (2008, November 19). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)*. http://data.europa.eu/eli/dir/2008/98/oj/eng

Eurostat. (2022). *Generation of waste by waste category, hazardousness and NACE Rev. 2 activity* [Dataset]. Eurostat. https://doi.org/10.2908/ENV_WASGEN

Feast, L., & Laursen, L. (2023). Design from Waste Materials: Situation, Problem, and Solution. *Learn X Design Conference Series*. https://dl.designresearchsociety.org/learnxdesign/learnxdesign2023/full-paper/16

Haase, L. M., & Laursen, L. N. (2022). *Designing for Longevity: Expert Strategies for Creating Long-Lasting Products*. Routledge.

Hanington, B., & Martin, B. (2019). *Universal Methods of Design Expanded and Revised: 125 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*. Rockport Publishers.

Harboe, G., & Huang, E. M. (2015). Real-World Affinity Diagramming Practices: Bridging the Paper-Digital Gap. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 95–104. https://doi.org/10.1145/2702123.2702561

Janigo, K. A., & Wu, J. (2015). Collaborative Redesign of Used Clothes as a Sustainable Fashion Solution and Potential Business Opportunity. *Fashion Practice*. https://www.tandfonline.com/doi/abs/10.2752/175693815X14182200335736

Kotler, P. (2003). *Marketing Management*. Prentice Hall.

Kotler, P., Armstrong, G., Harris, L. C., & Piercy, N. F. (2017). *Principles of Marketing*. Pearson.

Lee, D. (2011). *Turning Waste into By-Product* (SSRN Scholarly Paper 1337751). Social Science Research Network. https://doi.org/10.2139/ssrn.1337751

McDonough, W., & Braungart, M. (2013). *The Upcycle: Beyond Sustainability--Designing for Abundance*. Farrar, Straus and Giroux.

Miljøstyrelsen. (2023). *Affaldsstatistik 2021 Revideret udgave*.

Ordoñez, I., & Rexfelt, O. (2017). Designing from the dumpster: Experiences of developing products using discards. *International Journal of Sustainable Design*, *3*, 61. https://doi.org/10.1504/IJSDES.2017.091701

Pedgley, O. (2009). *Influence of Stakeholders on Industrial Design Materials and Manufacturing Selection*. https://www.semanticscholar.org/paper/Influence-of-Stakeholders-on-Industrial-Design-and-Pedgley/3f803f5d2b3b2f01a8a5dbb2b5c5ed95d1c86713

Porter, M. E. (with Chandler, A. D., & Doriot, G. F.). (1980). *Competitive strategy: Techniques for analyzing industries and competitors*. Free Press.

Rognoli, V., & Levi, M. (2004). *Emotions in Design through Materials. An expressive-sensorial atlas as a project tool for design of materials.* Middle East Technical University. https://re.public.polimi.it/handle/11311/561956

Sander, N., Laursen, L. N., Bak, B. L. V., & Damgaard-Møller, E. (2024). Starting from scraps: Design reuse assessment of waste materials. *DRS Biennial Conference Series*. https://doi.org/10.21606/drs.2024.888

Singh, J., Sung, K., Cooper, T., West, K., & Mont, O. (2019). Challenges and opportunities for scaling up upcycling businesses – The case of textile and wood upcycling businesses in the UK. *Resources, Conservation and Recycling*, *150*, 104439. https://doi.org/10.1016/j.resconrec.2019.104439

Sung, K., Cooper, T., & Kettley, S. (2019). Developing Interventions for Scaling Up UK Upcycling. *Energies*, *12*(14), Article 14. https://doi.org/10.3390/en12142778

Sung, K., Singh, J., Bridgens, B., & Cooper, T. (2021). *Introduction: State-of-the-Art Upcycling Research and Practice*. https://doi.org/10.1007/978-3-030-72640-9_1

Szaky, T. (2014). *Outsmart waste: The modern idea of garbage and how to think our way out of it* (First Edition). Berrett-Koehler Publishers, Inc. http://www.tandfonline.com/doi/full/10.1080/00207233.2014.947739

van Kesteren, I. E. H. (2008). Product designers' information needs in materials selection. *Materials & Design*, *29*(1), 133–145. https://doi.org/10.1016/j.matdes.2006.11.008

Wang, J. (2011, March 22). *Upcycling Becomes a Treasure Trove for Green Business Ideas*. Entrepreneur. https://www.entrepreneur.com/starting-a-business/upcycling-becomes-a-treasure-trove-for-green-business-ideas/219310

Research paper
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Material discard reasons: Categorising and characterising industrial waste materials

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Keywords: Industrial waste; Sustainability; Materials characteristics; Product design; Variety.

Abstract: This paper investigates industrial waste and its characteristics from a design perspective with the objective of assessing why so many materials are discarded. Industrial waste emerges pre-consumer and poses potential as material resources for new product designs on an industrial scale. Most research assesses post-consumer waste, but more than 230 million tons of waste emerge from manufacturing, hence pre-consumer. Current research on industrial waste divides it into scraps and rejects with varying characteristics of predictability and seriality. We add to the research through a two-year research project on designing with industrial waste from Danish manufacturing companies. Through observations, registrations, and semi-structured interviews, we study 24 discarded material cases and assess the challenges for industrial design. From a designer's perspective, we investigate where and why materials are discarded, the categories, and how they can be further characterised. The result is a division of industrial waste into five types: 1) offcuts, 2) rejected materials, 3) rejected objects, 4) process waste, and 5) excess material. They vary in predictability, uniformity, presence of flaws, and data availability. These are characteristics that designers must consider when extending the material lifetime and keeping the material at its integrity level in new product designs.

Introduction

Earth is a limited system, where it is central that we utilise already circulating resources and leave the linear economy of take-make-dispose behind (Ellen MacArthur Foundation, 2013). Similarly, it is essential that we significantly reduce the generation of waste, starting with the production of new products. Numbers from the European Union state that the EU annually generates more than 230 million tons of waste from manufacturing; in Denmark alone, the number is over 1 million tons (Eurostat, 2022). Despite the enormous amounts, waste from manufacturing companies is typically overlooked in discussions of circular economy.

Industrial waste is discarded materials that emerge during the manufacturing of products before they have been in circulation with consumers. (Pacelli et al., 2015) Some material discards, such as the cut-out for a sink when producing a marble kitchen tabletop, cannot be prevented. Others are discarded due to high-quality standards of material surfaces, such as scratches or impurities in an acrylic lamp shade for a designer lamp. Although these material examples are discarded in one manufacturing, they still have a utilisation potential elsewhere. According to the waste hierarchy of prevention – reuse – recycling – recovery – disposal (European Parliament, 2008), the marble material from the kitchen tabletop should be utilised at the highest possible level, reuse, as prevention is not an option. However, the marble is currently granulated down and downcycled into asphalt manufacturing. Ideally, this material could be used in new products where the current size and processing are a quality, as opposed to downcycling and recycling, a standard industry practice (Awogbemi et al., 2022).

When waste materials are recycled, they require significant energy contributions, hence losing the intrinsic economic and environmental value inherent in their composition and shape (Ali et al., 2019). Thus, it is valuable to increase knowledge within this area to support practitioners in transitioning discarded materials into a resource to extend the lifetime of the material before downcycling. However, we lack knowledge of these materials' categories, characteristics, and definitions that emerge pre-consumer.

The research aims to investigate what the industry wastes – and why. The aim is to categorise and characterise discarded

materials in manufacturing for two incentives: first, to support designers in using already generated discarded materials in new product designs as a substitute for virgin materials, and second, to outline material characteristics designers must take their origin in to design products that allow a broader inclusion of material "imperfections" in new product designs, hence, to reduce material discard reasons. Thus, this study aims to answer the research question: **What are the categories and characteristics of discarded materials from manufacturing?**

Theory

Extending material lifetime

Much is written about extending the lifetime of products in the use phase and thereby slowing the resource loops, e.g. design for durability, repair, emotional attachment, and second-hand (Haase & Laursen, 2022; Frahm et al., 2024). In comparison, the research on extending material lifetime pre-consumer is limited. While industry and research have examined recycling (Awogbemi et al., 2022; Venkatachalam et al., 2024), the challenge of keeping and utilising discarded materials at their processing stage is an overlooked area. A study by Ali et al. (2019) has found that the economic and environmental advantages of reusing the material rather than recycling point towards a 40% cost saving and 67% saving in energy consumption (Ali et al., 2019).

However, extending the material lifetime of industrial waste is challenging as the discarded materials come in a particular form. The characteristics include small sizes, various shapes and surfaces, and various mechanical and sensorial properties and flaws that vary according to the situation (Feast & Laursen, 2023). This increases the difficulty for the designer as the designer must be able to work with the mistakes in the material that have caused it to become discarded. Still, the material poses value and opportunities to be utilised, which must be understood to design and manufacture with it.

Waste research

Waste research within the circular economy covers areas assessing waste by type, origin, or activities. The term "waste" covers materials, substances, and products, including raw materials, final products, and remnants (Awogbemi et al., 2022). The origin spans from manufacturing at a pre-consumer stage (Pacelli et al., 2015) to post-consumer waste, treating end-of-use/life products as waste (Moalem & Kerndrup, 2023). Literature on waste activities include, among others, the waste hierarchy (European Parliament, 2008) and various R-strategies that extend the hierarchy with more circular strategies (Kirchherr et al., 2017; Potting et al., 2017). Additional activities include zero waste manufacturing (ZWM) on designing products for recycling and reusing post-consumer into manufacturing new products (Kerdlap et al., 2019; Singh et al., 2017), and design for circular production processes through distributed manufacturing, open design, and design for value recovery (Van Dam et al., 2020). Upcycling activities involve upgrading, reusing, repairing, and repurposing products after the use stage but they are currently a niche practice (Caldera et al., 2022).

While most of the literature investigates waste from a post-consumer perspective, the waste treatment pre-consumer is less explored. Studying industrial waste to be utilised with respect to the material's size, form, and processing is found in the mentioned study by Ali et al. (2019), whilst a few other studies supplement by investigating the design process and methods herein when designing with scraps and rejects rather than virgin materials (Feast & Laursen, 2023; Pacelli et al., 2015; Sander et al., 2024). Adding to the research, we dive deeper into the characteristics of industrial waste. We hypothesise that designers must design differently with different types of discarded materials to utilise the already carried out processing and form of the material, thereby respecting the integrity level of the material instead of recycling or downcycling, where the processing and form are lost.

Industrial waste: discarded materials

Pre-consumer waste from the manufacturing industry is defined as manufacturing waste (Awogbemi et al., 2022) or industrial waste (Pacelli et al., 2015). Both terms refer to discarded material resources that are not utilised. Manufacturing waste: *"…consists of any materials left unused or left over after the completion of manufacturing processes."* (Awogbemi et al., 2022, p. 2). Similarly, according to Pacelli et al. (2015): *"Industrial wastes are produced by many manufacturing sectors involving different materials and technologies. Wastes can be defined also as*

the non-value results of a manufacturing process set up to realize specific components." (Pacelli et al., 2015, p. 79). Despite the term "non-value," current research highlights the potential in discarded materials as value streams rather than waste streams (Moalem & Kerndrup, 2023). Moving forward, we use the term industrial waste.

Industrial waste is divided into two main typologies: scraps and rejects. **Scraps** are exactly predictable waste from manufacturing processes, are directly proportional to designed components, and have some serial and reproducible characteristics. **Rejects** are defective components caused by various factors, which are only statistically predictable and have potentially high variability. (Pacelli et al., 2015) Thus, the characteristics of the waste concern parameters of predictability in amounts and variability in size and shape regarding seriality. Those are important parameters to consider as they emphasise the substantial challenge of using otherwise discarded materials in industrial-scale production compared to new product development processes. (Pacelli et al., 2015)

In upcycling practices, the object is valued for its composition and form (Szaky, 2014). Similarly, industrial waste has built-in value in the composition of the material and the shaping that builds up in the manufacturing process. "Value" is tricky, as it depends on many factors, such as the specific value chain, commercial opportunities, and technological options. Thus, this study simply highlights a shape characteristic when identified.

Method

This study stems from a two-year research project with 20 Danish manufacturing companies that discard materials and thus generate waste (Table 1). The cases have been selected based on collecting a variety of materials to study, being a small/medium-sized company, and having the desire to transform their discarded materials in new products. Each company is matched with a designer, whose task is to 1) understand the discarded material to 2) design new product proposal(s) based on the specific material. Some cases reveal more waste fractions, wherefore this study presents 24 materials. Over approximately two years, we have observed, registered and followed the processes from the first meeting to the presentation of a product proposal.

In this study, we focus on assessing how to categorise and characterise types of discarded materials from an industrial design perspective. With this, the data collection comprises field notes and material registrations from start-up meetings, milestones and final meetings. At the start-up meetings located at the manufacturing companies, we have seen the production, including where and how the waste emerges and what the condition of the material is. Additional semi-structured interviews with each representative from the manufacturing companies were added to the data collection.

The data is analysed through clustering and division of industrial waste into industrial waste categories based on Pacelli et al.'s research (2015). Secondly, the data is analysed to assess the challenges from an industrial design perspective (regarding predictability and variability). Lastly, characteristics and definitions for the categories are synthesised.

#	Material	Description	Discard reason
1	Leather	Irregular pieces of upholstery leather	Scars, imperfections, small sizes
2	Compact laminate	From tabletops	Offcuts from sink or cooking plate
3	Ceramics	From tabletops	Offcuts from sink or cooking plate
4	Metal	Profiled metal sheets for roofs and facing	Scratches an incorrect adjustment of machinery + excess material
5	Wood	From tabletops	Offcuts from sink or cooking plate
6	Textile	Trousers	Wrong colour, wrong size
7	Concrete	Smaller sample of concrete	Testing consistency
8	Wood	Solid wooden floor	Knots, cracks and deviations in shape

9	Acrylic	Full and flat sheet size	Air bubbles and/or scratches
10	Textile	Pieces of various textiles	Small sizes, not fitting with pattern + excess material
11	Metal	Small bits and perforated sheets	Offcuts from punch holes and the punched full sheet
12	Powder coating	Collection of various colours/types	Cleaning pipes in between variant
13	Metal	Oblong pieces, perforated sheets	Offcuts and punched full sheet
14	Cement-bonded wood wool	Baffle plates	Imperfections in surface or broken corners
15	MDF w. veneer	Thin slats with veneer in full length from baffle plates	Broken slats or colour nuance compared to the other slats
16	Felt	Sheets from acoustic panels	Damage on surface after removal of damaged slats
17	Powder coating	Collection of various colours/types	Cleaning pipes in between variants
18	Iron	From tabletops	Offcuts from sink or cooking plate
19	Steel	From tabletops	Offcuts from sink or cooking plate
20	Aluminium	From tabletops	Offcuts from sink or cooking plate
21	PVC	Slimmer rolls of conveyor belts	Adjustment of roll width
22	Rubber	Slimmer rolls of conveyor belts	Adjustment of roll width
23	Aluminium	Smaller sheets with punch-holes	Holes are not centred + excess material
24	Marble	From tabletops	Offcuts from sink or cooking plate

Table 1. Case description of the discarded materials.

Results

Five categories of industrial waste

Table 2 reveals five identified categories of industrial waste: offcuts, rejected materials, rejected objects, process waste, and excess materials (Table 2). The categories emerge at different places in the manufacturing line and for different reasons (Figure 1). The further in the process, the more energy, time, and processing is put into the materials. Excess materials can emerge at more stages, but they will be most utilisation-ready if they emerge at the beginning of manufacturing before the shaping begins.

Industrial waste has a material composition and a shape (Szaky, 2014). Both may be leveraged by designers in new products; however, the composition is easier to utilise in a broad solution field compared to the shape, as it narrows the application areas but increases the intrinsic energy put into the processing.

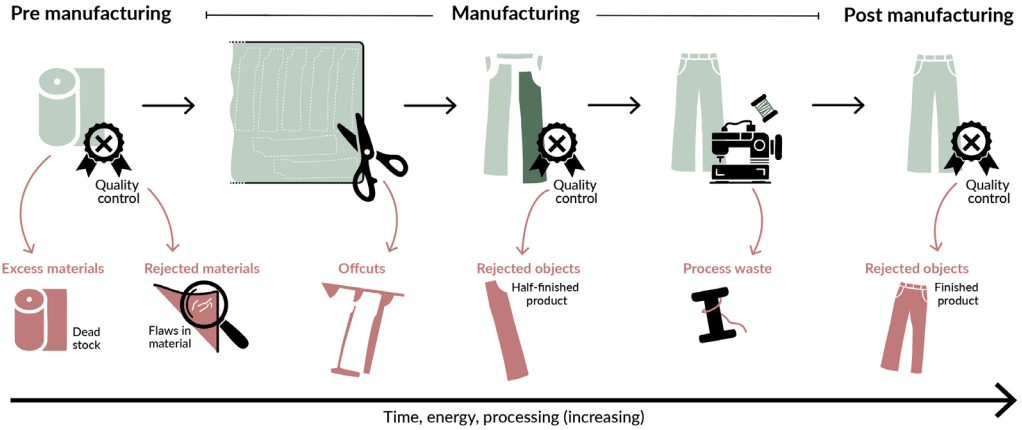


Figure 1. Manufacturing line, generation of discarded materials

#	Material	Scraps/ Offcuts	Rejects		Process waste	Excess materials
			Rejected materials	Rejected objects		
1	Leather	x		x		
2	Compact laminate	x				
3	Ceramics	x				
4	Metal	x		x		x
5	Wood	x				
6	Textile			x		
7	Concrete				x	
8	Wood	x		x		
9	Acrylic		x			
10	Textile	x				x
11	Metal	x				
12	Powder coating				x	
13	Metal	x		x		
14	Cement-bonded wood wool			x		
15	MDF w. veneer			x		
16	Felt			x		
17	Powder coating				x	
18	Iron	x				
19	Steel	x				
20	Aluminium	x				
21	PVC	x				
22	Rubber	x				
23	Aluminium			x		x
24	Marble	x				

Table 2. Where and how in the manufacturing does the discarded materials emerge

Challenges for industrial design

The reasons for discarding the investigated materials vary; small sizes and forms are discarding reasons for offcuts. The rejects are discarded due to various flaws and imperfections in the material or form, typically for aesthetic reasons. The process waste is not rejected because of flaws, but because they are consequences of a manufacturing line. Lastly, excess material is discarded due to purchasing too much material that has become surplus and potentially aesthetically obsolete.

These discard reasons affect the predictability and variability of the materials. Thus, designers face various challenges when designing with discarded materials. The challenges of predictability and variability are assessed case by case (Table 3). These present constraints for the designer to evaluate in the specific cases.

#	Material	Predictability	Variability/uniformity
1	Leather	Medium predictability in quantity, depends on material quality.	Variety in size and shape. 4 flaws: loose skin (around stomach), different structure (at neck spine), scars, and holes.
2	Compact laminate	High predictability in size and shape. Quantity is proportional to production.	Variety in surface according to popularity.
3	Ceramics	See #2	See #2
4	Metal	High predictability in size and shape. Statistical predictable quantity for each colour and profile.	2 types of profiles. 12 colours (80% greyscale, 10% red scale, 10% blue/green/yellow) + excess special colours
5	Wood	High predictability in size and shape. Quantity is proportional to production.	High uniformity, only small natural varieties in the wood.
6	Textile	Low predictability (only statistical) because rejection occurs in quality control.	Always the same form but variety in size or colour.
7	Concrete	High predictability in masses. Proportional to the production.	Variety in roughness, but general uniformity of the consistency for each variant.
8	Wood	Statistical predictability in quantity due to the naturalness of the material.	3 aspects of rejection: knots, cracks, and colour difference.
9	Acrylic	Statistical predictability in quantity, fails in quality control before internal processing.	High uniformity in size and shape but variety in location and number of flaws.
10	Textile	Low predictability on size, shape, type, and amount due to special orders and different markets. Statistical predictability according to orders.	2 types of offcuts: top stitching on textile roll, and offcuts emerging when cutting out the patterns. Additionally excess textile from special colours.
11	Metal	High predictability in amount, proportional with production. Low predictability in size and shape.	High variability in material thickness, sizes, and shapes as they are not sorted (high amounts of each offcut). Variation in offcuts due to adjustment in machinery and design.
12	Powder coating	High predictability in amount. Statistical predictability in colour.	Variety in powder coatings, causing greyscale colour (and quality) mixes.
13	Metal	High predictability in amount. Statistical predictability of rejected objects.	High variety of shapes and sizes of offcuts.
14	Cement-bonded wood wool	Statistical predictable amount.	2 types of flaws: broken corners or imperfections in surface.
15	MDF w. veneer	Statistical predictable amount.	High variety in veneer. 2 types of rejections: damaged surface or colour variety in comparison with surrounding slats.
16	Felt	Low predictability. Depends on rejections of slats (#15)	High uniformity. Different positions of flaws.
17	Powder coating	High predictability in amount. Statistical predictability in colour.	15 colours, 75% grey. Uniformity in mixed colour.
18	Iron	High predictability in size and shape. Quantity is proportional to production.	Uniformity in surface. 4 sizes/shapes.
19	Steel	See #18	See #18
20	Aluminium	See #18	See #18
21	PVC	Highly predictable that offcuts occur, but medium predictability in size of offcuts.	Variety in size and colour.
22	Rubber	See #21	Variety in size.
23	Aluminium	Statistical predictable amount. High predictability in size, shape and surface.	High uniformity.
24	Marble	High predictability in size and shape. Quantity is proportional to production.	High uniformity, variability in surface due to popularity of material and natural variety.

Table 3. Case-specific challenges for industrial design

Characteristics of industrial waste

Summing up the findings, we synthesise the definitions and characteristics of the identified industrial waste categories (Table 4). The characteristics stem from the intrinsic challenges of the cases on predictability and variability/uniformity, including the presence of flaws and data availability observed and discussed in the cases.

Category	Definition	Characteristics

Offcuts	Materials that are cut off in the manufacturing process.
	
	"A good example of this is when we produce kitchen tabletops. This is leftover material [from a sink] that is difficult for us to transform into new tabletops." (#5)
		• Predictable quantity, proportional to production
		• Context-depended predictability in size and shape
		  • Uniformity in industrial manufacturing (built-in shape)
		  • Variability in manual manufacturing (no specific shape)
		• No flaws
		• Data available

Rejected materials	Materials where the rejection occurs pre-manufacturing because they do not meet the quality requirements. *"He has those sunshades on the trucks. And here, they unfortunately have a whole lot that is rejected because it doesn't meet the company's requirements for how it should look."* (#9)	• Not predictable quantity, only statistical • Predictable size • Presence of flaws • Variety in position + type of flaw • Uniform size • Data available
Rejected objects	Materials that have been shaped into a half-finished or finished product that is rejected in manufacturing or post-manufacturing due to e.g. failure in quality control. *"The trousers had been sorted out after production due to issues such as colour differences, stitching, size variations, and similar minor defects."* (#6)	• Not predictable quantity, only statistical • Presence of flaws • Variety in rejection cause • Specific size and shape (built-in shape)
Process waste	Materials that emerge supporting manufacturing processes or tests of materials. "*When we perform quality control of our concrete regarding consistency, we end up with surplus material."* (#7)	• Predictable quantity • Predictable size • Variety in quality (data not available) • Uniformity within a scale • No flaws
Excess material	Materials that are surplus after a manufacturing process/project, often due to special projects and purchase of non-typical colour. *"We encounter situations where something is customer specific. It could be a clinic that orders some chairs in a specific design because they have a certain light pink colour in their clinic, and it must match. So, in those cases, we also have materials that are entirely customer specific."* (#10)	• Predictability depended on special purchases • Variety in quality • Uniform size • No flaws • Data available

Table 4. Categorization of industrial waste and their characteristics

Concluding discussion

Predictability and variability

Scraps/offcuts have been defined by current literature as being "exactly predictable" (Pacelli et al., 2015). However, we have identified two factors influencing predictability and uniformity: 1) manual or industrial manufacturing process and 2) natural or synthetic material (Figure 2).

The generation of leather offcuts (#1, Table 3) is predictable, but the uniformity varies in surface and shape as the manufacturing is

manual and the material is natural (lower left corner). Oppositely, compact laminate from the tabletop industry (#2, Table 3) is highly predictable in shape and size as the manufacturing is industrial, and the material's surface is uniform as it is synthetic (upper right corner). The two remaining corners (upper left and lower right) are medium predictable. However, the upper left is categorised as more predictable as it is easier to streamline manufacturing a new product with a variety in surface rather than shape.

Predictability is also identified to cover both 1) size and shape, 2) surface, and 3) amount. Whereas Pacelli et al. (2015) emphasises amount as predictability, we argue that size, shape, and surface must also be assessed for its predictability as a challenge for industrial design, as it restricts the design process.

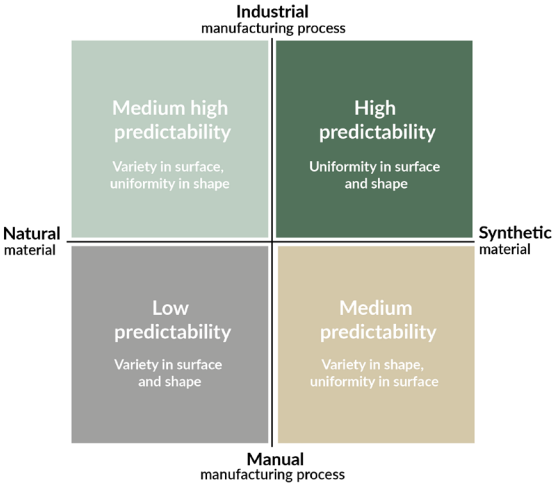


Figure 2. Predictability in offcuts according to material and manufacturing process.

Including discarded materials

Designers face a lot of challenges when including otherwise discarded materials into new product designs due to the predictability, variability, and general characteristics of the materials. They may cause both technical, logistical and aesthetic challenges, which varies according to waste category. Designing new products to include more materials with imperfections rely on the designer's ability to find solutions that are both viable technically and aesthetically to successfully implement material variability to the market with a design where "imperfections" are read as being on purpose and not as a flaw.

Conclusions

Industrial waste is discarded materials that emerge at a pre-consumer stage and should be used in new product designs instead of being wasted. Designers must consider the challenges and characteristics of discarded materials to design solutions that utilise their intrinsic shape, size, and processing, thereby extending their lifetime. Prior research categorises industrial waste into scraps or rejects, varying in predictability and seriality. Our analysis of 24 discarded materials proposes an extended categorisation into five industrial waste types from a design perspective: 1) offcuts, 2) rejected materials, 3) rejected objects, 4) process waste, and 5) excess materials. These categories vary in predictability, uniformity, flaws, and data availability. Specifically, offcuts' predictability depends on the manufacturing process and material type.

Size, shape, and surface information on the discarded materials reveal challenges to be considered in new design opportunities. Understanding the reasons for discarding is crucial for respecting the already carried out processing and intrinsic value of the material. Utilising the discarded materials may add further processing but should focus on optimising shape and size rather than granulating.

This paper focuses on discarded materials within industrial waste and divides them into categories and characteristics. Implications for further research include assessing the activity of designing with industrial waste, thus investigating how the characteristics are utilised in new designs and how the challenges of including material discards in new product designs are solved. Future studies could explore sectors where material aesthetics are crucial, examining the aesthetic challenges of including imperfections and comparing natural versus synthetic materials.

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References

Ali, A. K., Wang, Y., & Alvarado, J. L. (2019). Facilitating industrial symbiosis to achieve circular economy using value-added by design: A case study in transforming the automobile industry sheet metal waste-flow into Voronoi facade systems. *Journal of Cleaner Production*, *234*, 1033–1044. https://doi.org/10.1016/j.jclepro.2019.06.202

Awogbemi, O., Kallon, D. V. V., & Bello, K. A. (2022). Resource Recycling with the Aim of Achieving Zero-Waste Manufacturing. *Sustainability*, *14*(8), 4503. https://doi.org/10.3390/su14084503

Caldera, S., Jayasinghe, R., Desha, C., Dawes, L., & Ferguson, S. (2022). Evaluating Barriers, Enablers and Opportunities for Closing the Loop through 'Waste Upcycling': A Systematic Literature Review. *Journal of Sustainable Development of Energy, Water and Environment Systems*, *10*(1), 1–20. https://doi.org/10.13044/j.sdewes.d8.0367

Ellen MacArthur Foundation. (2013). *Towards the circular economy Vol. 1: An economic and business rationale for an accelerated transition*. https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

European Parliament. (2008, November 19). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)*. http://data.europa.eu/eli/dir/2008/98/oj/eng

Eurostat. (2022). *Generation of waste by waste category, hazardousness and NACE Rev. 2 activity* [Dataset]. Eurostat. https://doi.org/10.2908/ENV_WASGEN

Feast, L., & Laursen, L. N. (2023). Design from Waste Materials: Situation, Problem, and Solution. *LearnxDesign 2023*. LearnXDesign 2023. https://doi.org/10.21606/drslxd.2024.056

Frahm, L. B., Boks, C., & Laursen, L. N. (2024). It's Intertwined! Barriers and Motivations for Second-hand Product Consumption. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-024-00441-y

Haase, L. M., & Laursen, L. N. (2022). *Designing for Longevity: Expert Strategies for Creating Long-Lasting Products*. Routledge. https://doi.org/10.4324/9781003296959

Kerdlap, P., Low, J. S. C., & Ramakrishna, S. (2019). Zero waste manufacturing: A framework and review of technology, research, and implementation barriers for enabling a circular economy transition in Singapore. *Resources, Conservation and Recycling*, *151*, 104438. https://doi.org/10.1016/j.resconrec.2019.104438

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Moalem, R. M., & Kerndrup, S. (2023). The entrepreneurial role of waste companies in transforming waste streams to value streams: Lessons from a Danish Municipal waste company. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *41*(3), 620–634. https://doi.org/10.1177/0734242X221124048

Pacelli, F., Ostuzzi, F., & Levi, M. (2015). Reducing and reusing industrial scraps: A proposed method for industrial designers. *Journal of Cleaner Production*, *86*, 78–87. https://doi.org/10.1016/j.jclepro.2014.08.088

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). *Circular Economy: Measuring innovation in the product chain*.

Sander, N., Laursen, Linda Nhu, Bak, Brian Lau Verndal, & Damgaard-Møller, Emil. (2024). *Starting from scraps: Design reuse assessment of waste materials*. DRS2024: Boston. https://doi.org/10.21606/drs.2024.888

Singh, S., Ramakrishna, S., & Gupta, M. K. (2017). Towards zero waste manufacturing: A multidisciplinary review. *Journal of Cleaner Production*, *168*, 1230–1243. https://doi.org/10.1016/j.jclepro.2017.09.108

Szaky, T. (2014). *Outsmart waste: The modern idea of garbage and how to think our way out of it* (First Edition). Berrett-Koehler Publishers, Inc. http://www.tandfonline.com/doi/full/10.1080/00207233.2014.947739

Van Dam, K., Simeone, L., Keskin, D., Baldassarre, B., Niero, M., & Morelli, N. (2020). Circular Economy in Industrial Design Research: A Review. *Sustainability*, *12*(24), 10279. https://doi.org/10.3390/su122410279

Venkatachalam, V., Spierling, S., Celik, Y., Shamsuyeva, M., & Endres, H.-J. (2024). Recycling of Plastic Wastes – Substitution Potential of Recyclates based on Technical and Environmental Performance. *Procedia CIRP*, *122*, 425–430. https://doi.org/10.1016/j.procir.2024.01.062

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Introducing the Reshape strategy: Preserving material integrity

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Keywords: Circular economy; Industrial waste; Product design; Discarded materials; Sustainability.

Abstract: One of the significant challenges of today's society is the unsustainable overconsumption of resources, coupled with the generating of enormous amounts of waste. European manufacturing produces over 230 million tons of waste annually, much of which remains unaddressed within existing circular economy frameworks that predominantly focus on post-consumer waste. This paper introduces the Reshape strategy, which aims to respect, incorporate, and utilise pre-consumer industrial waste to create new products, thereby reducing dependence on virgin materials. Positioned within current R-frameworks, the Reshape strategy addresses a theoretical gap in circular economy literature, where the Recycling strategy is commonly used and Reuse often being misapplied, leading to theoretical ambiguity. Reshaping emphasises the extension of material lifetimes rather than downcycling through recycling. Therefore, this research explores the potential of industrial waste as a resource through 19 case studies from a Danish research project focused on designing with industrial waste materials. The findings emphasise the inherent qualities of industrial waste and outline activities within the Reshape strategy that leverage the material's integrity in terms of function, form, or material composition, thereby extending its lifetime. By leveraging these qualities, this study contributes theoretically to the circular economy by refining terminology and advancing the understanding of pre-consumer waste within circular systems. The Reshape strategy aligns with circular economy principles, aiming to keep materials in productive loops while addressing the significant untapped potential of discarded materials.

Introduction

The circular economy concept revolves around an industrial regenerative system to eliminate waste through intention and design. It tackles resource scarcity, which is one of today's fundamental challenges. (Ellen MacArthur Foundation, 2013) Various R-strategies and ladders are defined to support the industry and designers in decreasing the discarding of materials and resources. Frameworks such as the 6R Framework (Sihvonen & Ritola, 2015) and the 9R Framework (Potting et al., 2017) propose strategies to achieve less resource and material consumption. (Kirchherr et al., 2017) These frameworks extend the waste hierarchy defined by the European Parliament in the 2008/98/CE directive, which includes Prevention, Reuse, Recycling, Recovery, and Disposal (Figure 1) (European Parliament, 2008). The 4R Framework of Reduce, Reuse, Recycle, and Recover is much in line with the waste hierarchy, only leaving out disposal (Kirchherr et al., 2017). The top strategy of Prevention/Reduce treats how not to generate waste, whereas the latter stages of the hierarchy treat waste at a product stage that has gone through a consumer. Hence, the hierarchy and 4R Framework assumes no waste treatment between prevention and the consumer stage.

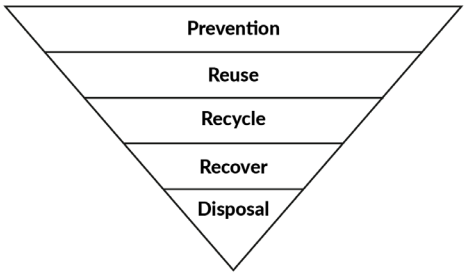


Figure 1. Waste hierarchy (European Parliament, 2008)

However, waste also emerges at a pre-consumer stage, where materials are discarded in the manufacturing of new products. European manufacturing companies generate over 230 million tons of industrial waste annually (Eurostat, 2022), occurring at the manufacturer stages in the Butterfly diagram by Ellen MacArthur Foundation (Figure 2) (Ellen MacArthur Foundation, 2019). In standard practices, discarded materials are often recycled, causing downcycling of the material

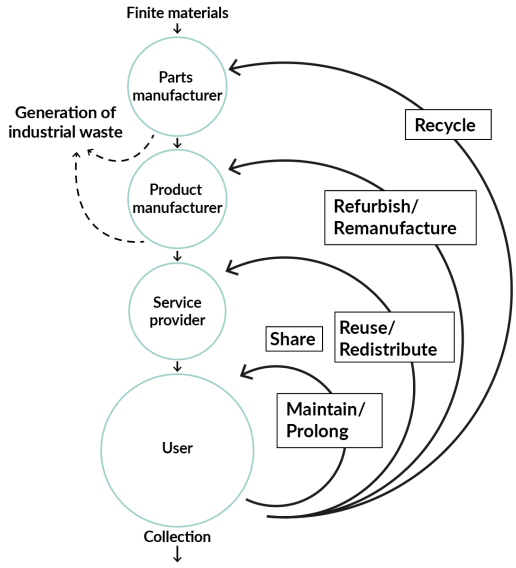


Figure 2. The Butterfly Diagram adapted from (Ellen MacArthur Foundation, 2019)

(Awogbemi et al., 2022). However, energy and time have been put into the form and composition of the materials to fit a specific intention before they were marked as waste and thus discarded (Szaky, 2014). Utilising this as a substitute for virgin materials in new product designs adds a design perspective to the discussion on material utilisation with emphasis on respecting and including material discards to benefit from the craftsmanship, time, and energy that has been put into processing the materials. It is challenging, as materials provide technical functionality and personality to a product (Ashby & Johnson, 2014), which will be affected when the material is discarded. It may result in a new materials aesthetic that includes imperfect materials (Rognoli & Karana, 2014). Intervening industrial waste's intrinsic potential by extending the lifetime of the material into the resource of new products may lead to a 40% reduction in cost and 67% energy savings compared to recycling (Ali et al., 2019). Thus, there is great potential in a circular strategy that reintegrates discarded materials pre-consumer in new manufacturing cycles before they reach recycling or disposal.

Through the work of examining cases from a Danish research project on designing new products from industrial waste, confusion has emerged in trying to position the activity of leveraging industrial waste in the waste hierarchy (Figure 1) or any of the currently defined R-strategies, without causing theoretical ambiguity. This confusion aligns with other researchers who state that the terminologies of the circular strategies are understood and applied differently in practice (Dokter et al., 2021), potentially resulting in a collapse of the concept if the definitions are not coherent (Kirchherr et al., 2017).

We identify a theoretical gap within the literature on waste treatment and -hierarchy in the circular economy and argue for a missing, yet important, area with the wasted materials that have not yet been in circulation with consumers. Therefore, the research aims to establish a circular strategy that treats the activity of leveraging industrial waste materials and assesses its position in existing circular frameworks. The objective is to understand the activity of elevating the opportunities in discarded materials from a design perspective, aiming to include more materials in manufacturing, not least formerly discarded materials. Thus, the research question is: **What is the circular strategy for leveraging industrial waste, and how does it support the inclusion of discarded materials in new products?**

Extending lifetime of materials and products

Circular R-strategies

The R frameworks are core principles of the circular economy (Kirchherr et al., 2017). Frameworks beyond the 4Rs, such as the 9R Framework, offer more nuanced strategies aimed at maintaining the a product's primary function, thereby preserving its highest integrity level and minimising processing time and energy (Potting et al., 2017). Circularity increases as strategies are positioned higher in the hierarchy. In the 9R Framework, strategies for smarter product use and manufacturing reduce the addition of natural resources in a product chain, corresponding to the Reduce strategy in the simpler 4R Framework (Table 1). This is also seen as narrowing the resource loop regarding efficiency (Bocken et al., 2016). Strategies below this level treat the circularity of products and parts at the consumer stage or post-consumer to extend the lifetime. (Potting et al., 2017) Hence, Reuse, Repair, Refurbish, Remanufacture, and Repurpose all concerns slowing the resource loop by extending the use period of products at the consumer stage, compared to the Recycle strategy, which closes the loop between post-use and manufacturing (Bocken et al., 2016).

4R Framework (Kirchherr et al., 2017)	9R Framework (Potting et al., 2017)	
Reduce	**R0 Refuse** Make product redundant by abandoning its function or by offering the same function with radically different product.	Smarter product use and manu-facturing
	R1 Rethink Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market).	
	R2 Reduce Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.	
Reuse	**R3 Reuse** Reuse by another consumer of discarded product which is still in good condition and fulfils its original function.	Extend lifespan of product and its parts
	R4 Repair Repair and maintenance of defective product so it can be used with its original function.	
	R5 Refurbish Restore an old product and bring it up to date.	
	R6 Remanufacture Use parts of discarded product in a new product with the same function.	
	R7 Repurpose Use discarded product or its parts in a new product with a different function.	
Recycle	**R8 Recycle** Process materials to obtain the same (high grade) or lower (low grade) quality.	Useful application of material
Recover	**R9 Recover** Incineration of materials with energy recovery.	

Table 1. The 4R and 9R Framework, definitions from (Potting et al., 2017, p. 5)

Figure 3 illustrates the application of the 9R strategies at relevant points in a product chain, providing an overview of processes and chain actors, and identifying intervention points to enhance circularity. (Potting et al., 2017) The illustration includes resource inflow and the outflow of waste. We have added the waste streams, as they were absent from the original figure.

In summary, the Butterfly diagram, 9R Framework, and the Product chain figure overlook industrial waste, as they focus on the product and consumer stages rather than the pre-product and pre-consumer stages. This results in a confusing mix of definitions in circular economy and waste treatment research (Singh et al., 2017). For instance, “reuse” is defined in post-consumer loops and typically refers to a product being reused by a second owner but with the same function (Potting et al., 2017). However, studies on utilising industrial waste at a pre-consumer level also describe this as being “reuse” (e.g., (Pacelli et al., 2015; Sander et al., 2024). While the intention of using the resource again at the same integrity level may be similar, the multiuse of the term creates confusion.

Whilst the descriptions of the post-consumer strategies in the frameworks that cover extending the lifespan of products may also be applicable at a pre-consumer stage, it adds to the confusion if these are to be mixed. We propose streamlining the definitions to separate strategies pre- and post-consumer for further theoretical development. The principal difference between pre- and post-consumer is the starting point of the strategy, whether it is a product that has been used (post-consumer) or not (pre-consumer). An additional potential layer of confusion is introduced when mixing resource states in the strategies, thus focusing on particles (including materials) or products. Blomsma and Tennant (2020) propose the Resource States framework to clarify the differences and connections with circular strategies (Blomsma & Tennant, 2020).

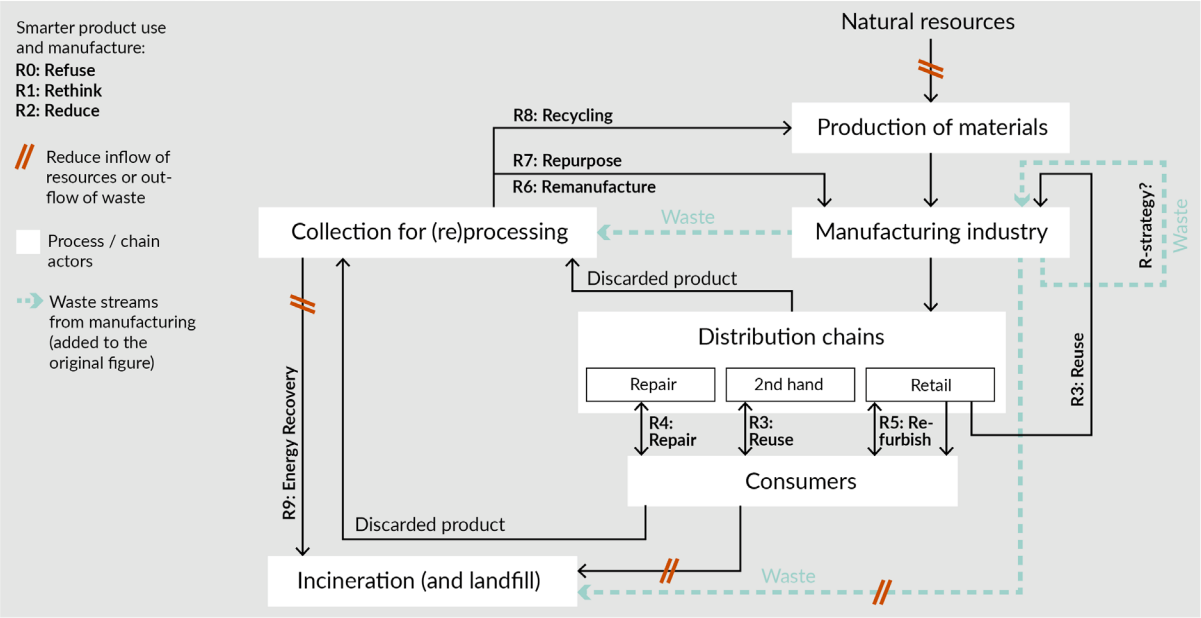


Figure 3. Product chain with applied R-strategies, including the introduction of waste streams, adapted from (Potting et al., 2017)

Leveraging on integrity level

Industrial waste, or manufacturing waste, comprises various materials that emerge from manufacturing products and are discarded (Awogbemi et al., 2022). In some scenarios with certain conditions, industrial waste may be considered a by-product if a secondary product can be made from it (European Parliament, 2008). The two typical typologies of industrial waste are scraps or rejects (Pacelli et al., 2015), covering both off-cuts and rejected objects in quality control. According to the situation, these heterogeneous materials vary in size, shape, and quantities, as well as mechanical and sensorial properties (Feast & Laursen, 2023).

These characteristics define the material's integrity level. The integrity level is described with various focuses in the current literature on a post-consumer stage, such as the 9R Framework that focuses on maintaining the function of the products (Potting et al., 2017), while others describe it with the level of disassembly and identity (Sihvonen & Ritola, 2015). Upcycling literature views a product's value in terms of composition, form, and intention. The upcycling activity leverages the form and composition but not the intention. (Szaky, 2014) These three levels of function, form, and composition can also describe the integrity level of discarded materials at a pre-consumer stage, framing the potentials based on prior material processing. For example, discarded wooden floorboards due to unacceptable colour variants or knots in one manufacturing line may still be used for flooring in another company, hence leveraging the original function/intention of the material. If this cannot be leveraged in a new product design, maybe the form and size of the boards can. If this is not possible, the material composition of solid wood may be leveraged into smaller trays.

In summary, we argue for a missing strategy to leverage the integrity level of the discarded industrial material based on the situation and business in which it may be used. From a design perspective, this study investigates industrial waste to identify how to include this in new product design, hence looping the flow of wasted materials back into the manufacturing industry. Additionally, the details of this circulation loop strategy are investigated to support material inclusion for designers.

Method

This multiple-case study assesses 19 cases from a two-year exploratory research project on how to design from industrial waste materials (Table 2). The cases involve various waste materials from Danish small/medium-sized manufacturing companies where designers have assessed the materials and developed new product proposals based on the specific waste. This study investigates if we, through the design competence, can create smaller loops of resource utilisation to retain most of the

value in the discarded materials without unnecessary use of both time and energy, thereby respecting the materials at their integrity level. Hence not resort to recycling as the preferred waste management.

The collected data comprises field notes from start-up meetings, status meetings, and final meetings. Additional visual material developed along the design processes has been collected for all the cases. The cases are analysed and mapped against using the materials in the new product design(s) to assess how the integrity level is leveraged.

#	Discarded material	Description	New product proposal(s)
1	Leather (from upholstery industry)	Pieces of upholstery leather, rejected due to scars, imperfections and small sizes	a) Door handle, b) cushion, and c) notebook cover
2	Ceramics (from kitchen tabletops)	Sink or cooking plate size, offcuts	Soap display
3	Metal (from roofing)	Profiled metal sheets, rejected due to scratches an incorrect adjustment of machinery	Facing for a recycling centre building
4	Wood (from kitchen tabletops)	Offcuts from sink and/or cooking plate	Side table
5	Textile (from clothing industry)	Trousers, rejected for wrong colour or size	Tote bag
6	Concrete (from building industry)	Smaller sample of concrete for testing consistency before casting elements	Table and bench set
7	Wood (from flooring)	Solid wooden floor, rejected due to knots, cracks, and other imperfections	Indoor door
8	Acrylic (from automotive industry)	Full and flat sheet size, rejected because of air bubbles and scratches	Bench
9	Textile (from furniture industry)	Offcuts of textile pieces	a) Cushions, b) storage solution, and c) LED lamp
10	Metal (from shop furniture)	Offcuts from punch holes and the punched full sheets	Designer waste sheets
11	Metal (machines and equipment)	Offcuts of oblong pieces and perforated sheets	Trolley
12	Cement-bonded wood wool (from building industry)	Baffle plates rejected due to imperfections in surface or broken corners	Acoustic wall art
13	Felt (from building industry)	Sheets from acoustic panels, rejected due to damages on surface	Organisers
14	Powder coating (from taps and fittings)	Collection of various colours of powder coating when cleaning pipes in between colours/types	Speckled powder coating
15	Steel (from kitchen tabletops)	Offcuts from sink and/or cooking plate	a) Shelf, and b) side table
16	PVC (from conveyor belts)	Offcuts of conveyor belts to adjust width	Lamp
17	Aluminium (from acoustic ceilings)	Smaller sheets with punch-holes, rejected because holes are not centred	Embossed acoustics panels
18	Marble / stone (from kitchen tabletops)	Offcuts from sink and/or cooking plate	a) Hooks, bowl, shelf and b) bedside table
19	Textile (from furniture industry)	Offcuts of textile pieces	Upholstery of designer chair

Table 2. Case descriptions including waste material, original application, and new product proposal

Results

Preserving material integrity level

Leveraging the integrity level of industrial waste to extend the material lifetime is at the core of designing with pre-consumer waste. The 19 cases are analysed according to the industrial waste's function, form, and material composition (hence, the integrity level) compared to which aspects are leveraged in the new product proposal. Some cases have more product solutions. Thus, 25 designs are assessed according to what the designer has preserved and elevated.

Leveraging on the original function/intention of the material is the most difficult, as the material has been rejected due to not living up to this intention. However, the leverage point poses the most significant potential in respecting and maintaining the already carried out processing. The form and material composition are automatically leveraged when leveraging on the function. The second-best option is to utilise the form of the material. Lastly, if it is not possible to leverage either function or form, the composition of the material will be utilised, thereby using the material properties in a new product. For the cases where the material does not come with a form (#6 concrete and #14 powder coating), they cannot be leveraged on a higher level than the material composition.

Eight designs have managed to leverage the function/intention of the waste materials in new products, whereas six cases leverage the form. The remaining 11 designs only leverage the material composition (Figure 4). An example of leveraging the function is case #17. Aluminium sheets from acoustic ceilings were rejected for flaws in the pattern. Through the reshape strategy, they have been embossed with a pattern that makes the flaws blend in, and the new product will again function as an acoustic ceiling.

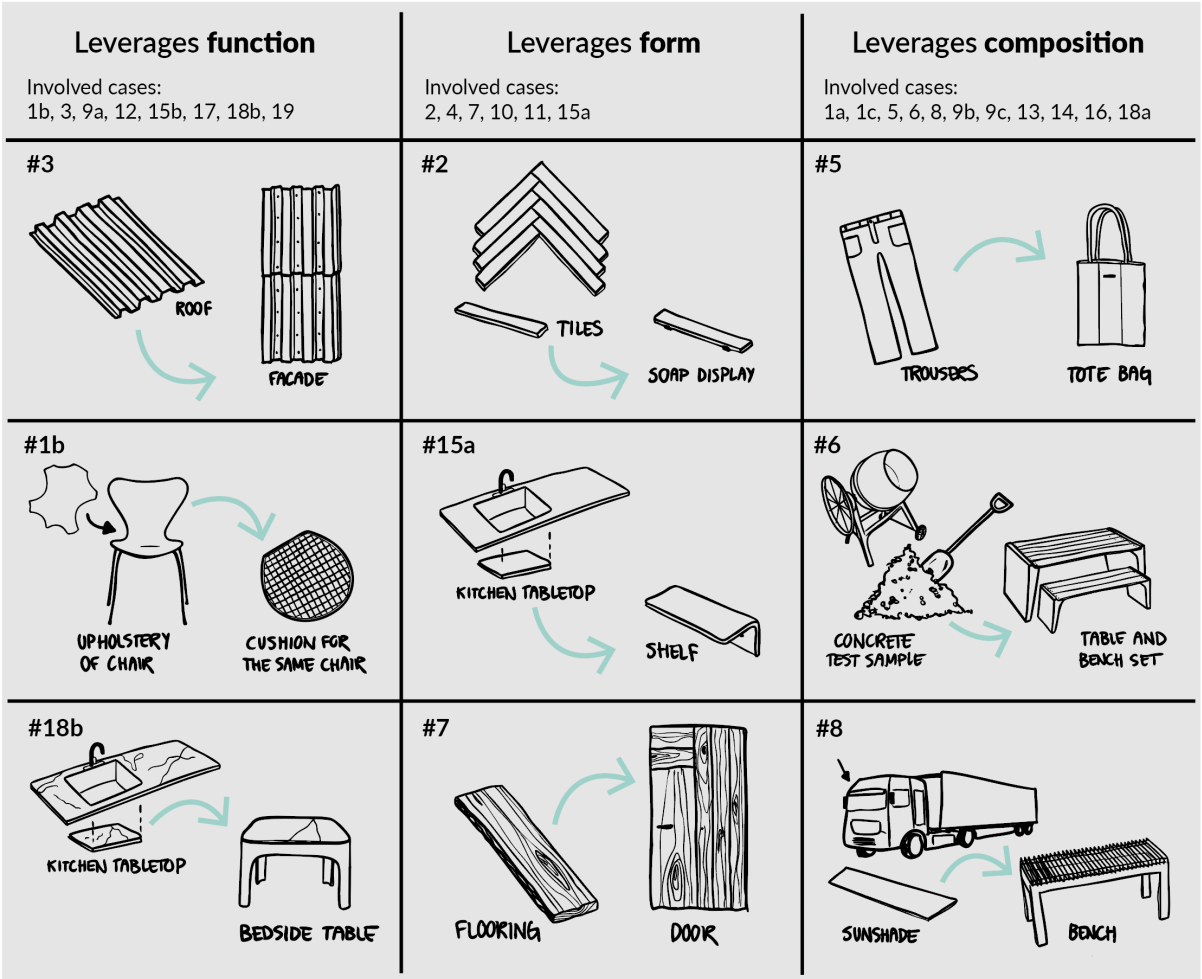


Figure 4. Mapping of cases according to leveraging on either function, form, or material composition. Nine case examples of the elevation of the material's integrity level in the new design

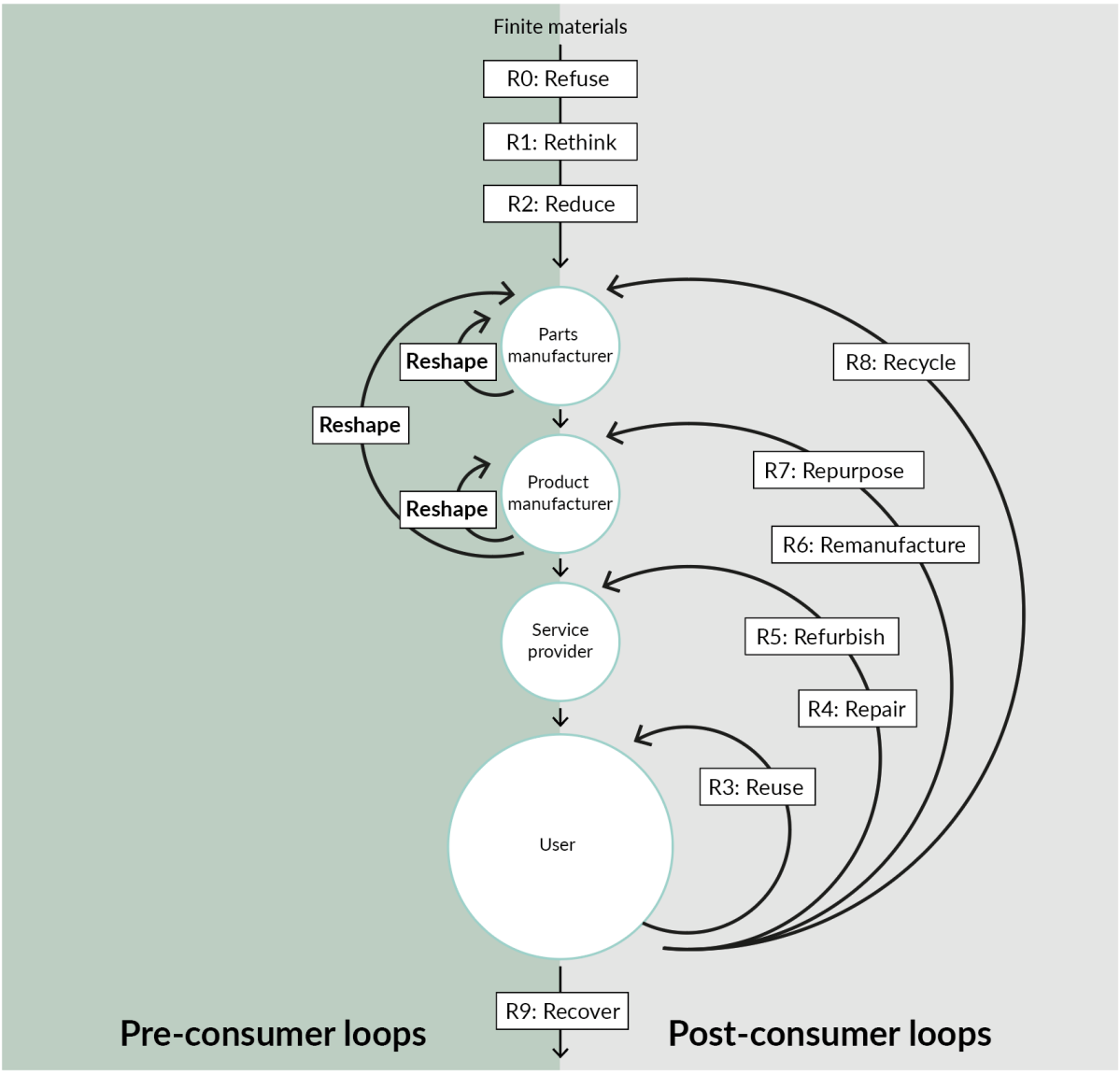


Figure 5. Development and division of the Butterfly diagram to pre-consumer and post-consumer loops with the introduction of the Reshape strategy. Adopted from (Ellen MacArthur Foundation, 2019; Potting et al., 2017)

The Reshape strategy

Through the analysis of the investigated cases, we empathise that circulation loops also occur at the pre-consumer stage (Figure 5), looping into the manufacturing industry without the necessity of going through the consumer and circulating through remanufacturing or recycling. The cases in this study focus on reshaping industrial waste into new products, an activity not covered by current strategies.

Thus, we suggest the introduction of the Reshape strategy that relates to the activity of leveraging industrial waste materials pre-consumer at the highest possible integrity level. We define the Reshape strategy as *Reshaping resources aiming to maintain the highest integrity level by leveraging function, form or material composition in new products*.

The strategy occurs pre-consumer in the development of new products (Table 3). We position it in existing frameworks underneath prevention/reduce and above the reuse strategy and the subsequent strategies that

extend product lifetime and/or use of parts from a used product.

4R Framework (Kirchherr et al., 2017)	**9R Framework** (Potting et al., 2017)	
Reduce	**R0 Refuse** Make product redundant by abandoning its function or by offering the same function with radically different product.	Smarter product use and manu-facturing
	R1 Rethink Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market).	
	R2 Reduce Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.	
Reshape	**Reshape** Reshaping resources aiming to maintain the highest integrity level by leveraging function, form or material composition in new products	
Reuse	**R3 Reuse** Reuse by another consumer of discarded product which is still in good condition and fulfils its original function.	Extend lifespan of product and its parts
	R4 Repair Repair and maintenance of defective product so it can be used with its original function.	
	R5 Refurbish Restore an old product and bring it up to date.	
	R6 Remanufacture Use parts of discarded product in a new product with the same function.	
	R7 Repurpose Use discarded product or its parts in a new product with a different function.	
Recycle	**R8 Recycle** Process materials to obtain the same (high grade) or lower (low grade) quality.	Useful application of material
Recover	**R9 Recover** Incineration of materials with energy recovery.	

Table 3. The 4R and 9R Framework including the Reshape strategy, definitions from (Potting et al., 2017)

The strategy reshapes resources according to three leveraging levels, outlined with the position of the Reshape strategy in the waste hierarchy (Figure 6).

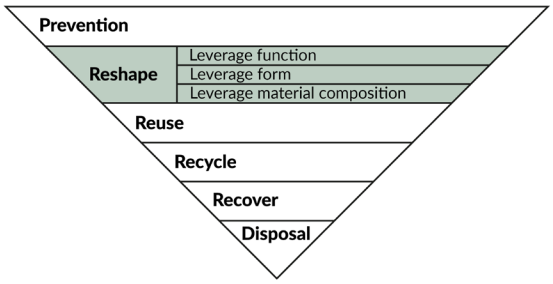


Figure 6. Reshape in the waste hierarchy

Concluding discussion

In the research on sustainable product design, circular R-strategies propose activities to increase the use of already circulating resources. However, the R-strategies are targeted at a post-consumer level; hence, industrial waste is overlooked. Through this study of analysing 19 case experiments with designing with waste materials, we introduce the Reshape strategy for preserving material integrity and extending the lifetime of materials in the circular economy concept. The strategy addresses waste in the manufacturing industry and loops back to manufacture new products. It supports designing inclusively with discarded materials by leveraging the function, and/or form, and/or composition of the material, thereby elevating the highest integrity level of the material starting point. The Reshape strategy proposes a design activity that preserves the integrity of the material by respecting and elevating the craftsmanship, time and energy that has been put into the processing of the materials.

With this research, we hope to contribute to the theoretical development of the circular economy concept by identifying and defining a circular strategy to support designers and

practitioners in including industrial waste pre-consumer in new products.

There are many perspectives on the R-strategies. The Reshape strategy introduces a timely perspective, as it only comes into play at a pre-consumer stage, hereby challenging why and when this strategy should be chosen over others. Developing further aspects of the Reshape strategy would cement its position as a valuable strategy for reducing discarded materials that are downcycled or disposed of. Through our analyses, we have identified challenges with the manufacturing flows, e.g., whether the waste loops back into the same manufacturing chain and business or enters a new. It is considerable for waste utilisation, as it causes various opportunities and barriers according to business situations and involved actors, which calls for further research. Lastly, we propose examining how designers perform the activity of reshaping waste regarding e.g., technical, and aesthetic challenges.

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References

Ali, A. K., Wang, Y., & Alvarado, J. L. (2019). Facilitating industrial symbiosis to achieve circular economy using value-added by design: A case study in transforming the automobile industry sheet metal waste-flow into Voronoi facade systems. Journal of Cleaner Production, 234, 1033–1044. https://doi.org/10.1016/j.jclepro.2019.06.202

Ashby, M., & Johnson, K. (2014). Materials and Design: The Art and Science of Material Selection in Product Design (Third Edition).

Awogbemi, O., Kallon, D. V. V., & Bello, K. A. (2022). Resource Recycling with the Aim of Achieving Zero-Waste Manufacturing. Sustainability, 14(8), 4503. https://doi.org/10.3390/su14084503

Blomsma, F., & Tennant, M. (2020). Circular economy: Preserving materials or products? Introducing the Resource States framework. Resources, Conservation and Recycling, 156, 104698. https://doi.org/10.1016/j.resconrec.2020.104698

Bocken, N. M. P., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Dokter, G., Thuvander, L., & Rahe, U. (2021). How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy. Sustainable Production and Consumption, 26, 692–708. https://doi.org/10.1016/j.spc.2020.12.032

Ellen MacArthur Foundation. (2013). Towards the circular economy Vol. 1: An economic and business rationale for an accelerated transition. https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

Ellen MacArthur Foundation. (2019). Circular economy systems diagram. https://www.ellenmacarthurfoundation.org/circular-economy-diagram

European Parliament. (2008, November 19). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance). http://data.europa.eu/eli/dir/2008/98/oj/eng

Eurostat. (2022). Generation of waste by waste category, hazardousness and NACE Rev. 2 activity [Dataset]. Eurostat. https://doi.org/10.2908/ENV_WASGEN

Feast, L., & Laursen, L. N. (2023). Design from Waste Materials: Situation, Problem, and Solution. LearnxDesign 2023. LearnXDesign 2023. https://doi.org/10.21606/drslxd.2024.056

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Pacelli, F., Ostuzzi, F., & Levi, M. (2015). Reducing and reusing industrial scraps: A proposed method for industrial designers. Journal of Cleaner Production, 86, 78–87. https://doi.org/10.1016/j.jclepro.2014.08.088

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring innovation in the product chain.

Rognoli, V., & Karana, E. (2014). Toward a New Materials Aesthetic Based on Imperfection and Graceful Aging. In Materials Experience (pp. 145–154). Elsevier. https://doi.org/10.1016/B978-0-08-099359-1.00011-4

Sander, N., Laursen, Linda Nhu, Bak, Brian Lau Verndal, & Damgaard-Møller, Emil. (2024). Starting from scraps: Design reuse assessment of waste materials. DRS2024:

Boston. https://doi.org/10.21606/drs.2024.888

Sihvonen, S., & Ritola, T. (2015). Conceptualizing ReX for Aggregating End-of-life Strategies in Product Development. Procedia CIRP, 29, 639–644. https://doi.org/10.1016/j.procir.2015.01.026

Singh, S., Ramakrishna, S., & Gupta, M. K. (2017). Towards zero waste manufacturing: A multidisciplinary review. Journal of Cleaner Production, 168, 1230–1243. https://doi.org/10.1016/j.jclepro.2017.09.108

Szaky, T. (2014). Outsmart waste: The modern idea of garbage and how to think our way out of it (First Edition). Berrett-Koehler Publishers, Inc. http://www.tandfonline.com/doi/full/10.1080/00207233.2014.947739

Research paper
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Longevity and Biodegradability Assessment of Biobased Lighting Fixture Design for Interiors

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Keywords: Biobased lighting fixture; biocomposites; bacterial cellulose; material longevity.

Abstract: Biobased materials are often associated with fast degradation due to their inherent biodegradability, limiting their adoption in long-term applications. This study explores the dual potential of biobased composites, particularly bacterial cellulose-based materials, through the case of lighting fixture design in interior spaces. While these materials naturally degrade under specific environmental conditions, their lifespan can be extended significantly through thoughtful design and controlled usage. The research involves a four stage methodology to focus on developing and testing composite materials by combining bacterial cellulose biofilms with various biobased agents to enhance light transmission and durability. The study then evaluates the performance of these composites in terms of illuminance quality and biodegradation in interior use and composting, comparing them to one of the conventional lighting fixture materials, polypropylene plastic. The results have shown that this study challenges the perception of biobased materials as inherently fast-degrading due to maintenance requirements, by demonstrating their capacity for longevity when utilized in stable indoor environments. The findings contribute to biodesign discourse by showcasing how biobased composites can balance biodegradability and extended usability, offering innovative pathways for a variety of ecological design applications.

Introduction

Biobased materials have gained significant attention in recent years due to their potential to address pressing environmental challenges such as resource depletion, high carbon emissions, and non-biodegradable waste. However, these materials are often criticized for their inherent biodegradability, which limits their use in long-term applications. While rapid degradation is desirable for specific scenarios such as compostable packaging, it poses challenges in contexts requiring material longevity, such as interior product design.

This duality raises a critical question: Can biobased materials offer durability and biodegradability, depending on their intended application and environment? This study explores this question through the lens of lighting fixture design for interiors, a domain where materials must balance energy efficiency, aesthetic quality, and functional durability.

Among biobased materials, bacterial cellulose (BC), also known as microbial cellulose, deposited from bacteria such as *Acetobacter Xylinum* thanks to their metabolic activities, emerges as a promising candidate due to its lightweight nature, excellent mechanical properties, and compatibility with various biobased additives. Despite these advantages, its applicability in products requiring extended usability remains underexplored. This research aims to bridge this gap by developing bacterial cellulose-based composites tailored for interior lighting fixtures. The study investigates how biodesign interventions for different biobased material formulations can extend the lifespan of these biocomposites without compromising their biodegradability under end-of-life conditions.

The paper also addresses the broader perception of biobased materials as inherently short-lived, arguing that through thoughtful design and controlled use, their lifespans can be significantly enhanced. By examining these composites' performance in terms of light transmission through illuminance tests, this study also contributes to the discourse on ecological interior lighting design. It emphasizes the potential of biobased materials to meet contemporary demands for ecological responsibility and product longevity, challenging traditional paradigms in sustainable design.

Theoretical framework

Biodegradability and Longevity Challenges in Biobased Composites

Biobased composites are renowned for their potential to reduce environmental impact due to their renewable nature and inherent biodegradability. However, these same properties often present challenges when considering the material's longevity. One of the primary issues is the degradation of biocomposites when exposed to environmental factors like moisture, ultraviolet (UV) radiation, and microbial activity. These challenges are especially critical for applications requiring durability and extended performance, as uncontrolled degradation can compromise the structural integrity and usability of the material over time (Lepoittevin et al., 2023; Salmén & Gatenholm, 2022).
To address these issues, researchers have focused on modifying biocomposites at both microstructural, chemical and facial bonding levels. Incorporating hydrophobic agents, crosslinkers, UV stabilizers, or reinforcement fillers has been shown to significantly enhance durability. For example, combining bacterial cellulose with bio-based additives, such as lignin or *polyhydroxyalkanoates* (PHA), has improved moisture resistance and mechanical strength while retaining biodegradability under controlled conditions (Gorgieva & Trček, 2023; Nawab et al., 2021). There are also studies that demonstrate the incorporation of calcium, magnesium, iron, sulfate ions could lead to the formation of different material properties such as antibacterial properties or ferroelectric properties etc. (Wang et al., 2024; Zhao et al., 2023).

Advancements in Biocomposites for Durability and Sustainability

Studies exploring the enhancement of biocomposites have yielded promising results in balancing environmental benefits with practical performance. For instance, the addition of nanocellulose as a reinforcement in *polylactic acid* (PLA) matrices has been found to significantly increase tensile strength and thermal stability (Kargarzadeh et al., 2018). Similarly, biocomposites infused with chitosan and tannin have demonstrated resistance to microbial degradation while maintaining biodegradability under composting conditions (Sahoo et al., 2023). These advancements highlight the potential for biobased materials to address longevity concerns without compromising their sustainable credentials.
However, challenges remain, particularly in applications subjected to fluctuating environmental conditions, such as lighting fixtures. Prolonged exposure to heat and UV radiation can accelerate material degradation, necessitating frequent maintenance or replacement. This has spurred research into coatings and treatments that can shield biocomposites from environmental stressors, prolonging their usability in demanding environments (Huang et al., 2023).

Balancing Environmental Benefits with Performance in Sustainable Design

The dual goals of biodegradability and longevity often appear contradictory, but they can coexist with thoughtful material selection and design strategies. In interior applications, such as lighting fixture design, biobased composites can be utilized in controlled environments where factors like moisture and UV exposure are minimized. This strategic use not only extends the material's lifespan but also ensures that its biodegradability is activated only at the end of its functional life cycle (Lee et al., 2023). Sustainable design practices must prioritize materials that offer both ecological benefits and practical performance. The integration of life-cycle assessment (LCA) tools into the material selection process enables designers to evaluate trade-offs between environmental impact and durability, fostering a more holistic approach to sustainable design (Salmén & Gatenholm, 2022). By demonstrating the feasibility of biobased composites in long-term applications, this research aims to shift perceptions of these materials as inherently short-lived, paving the way for broader adoption in interior and architectural design.

Methodology

The methodology followed a four stage framework, consisting of bacterial cellulose cultivation, sterilization, composite formulations, and testing (Figure 1).

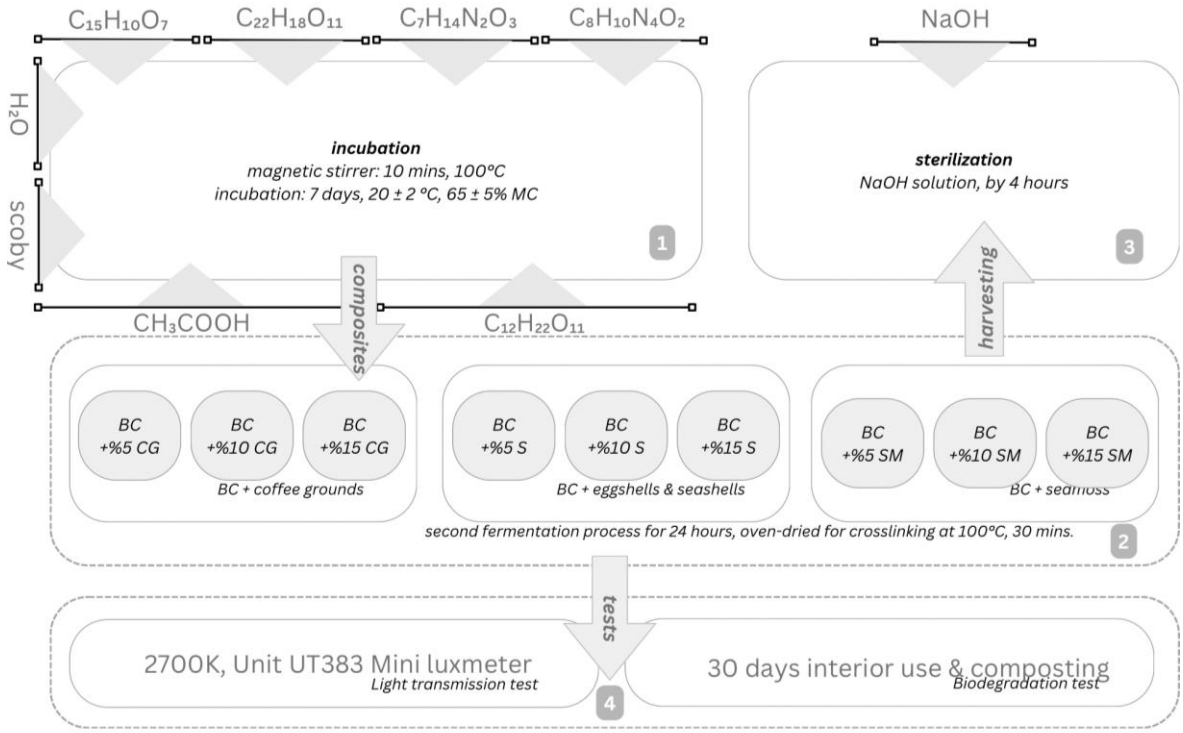


Figure 1. Methodological flowchart.

Bacterial cellulose cultivation

Bacterial cellulose (BC) was cultivated following the methods described in XXX (2022), where *Acetobacter xylinus* was the main collaborator to produce the microbial strain for BC production. The BC cultivation process involved the preparation of a sterile medium, which supported bacterial growth and cellulose synthesis, containing the bacteria and yeast from a piece of scoby, $C_{12}H_{22}O_{11}$ (*sucrose*), $C_2H_4O_2$ (*acetic acid*), *catechins* such as $C_{22}H_{18}O_{11}$ (*Epigallocatechin gallate*), *amino acids* such as $C_7H_{14}N_2O_3$ (*theanine*), $C_8H_{10}N_4O_2$ (*caffeine*), *flavonoids* such as $C_{15}H_{10}O_7$ (*quercetin*), and minerals such as Mg (*magnesium ion*) and Mn (*manganese ion*). The culture was incubated for 7 days (20 ± 2 °C, 65 ± 5% MC), after which the BC biofilms were harvested, distilled in NaOH solution to get rid of the residue.

Composite formulations

To enhance the properties of BC and test the viability of biobased composites for lighting fixture applications, BC biofilms were modified by incorporating a range of biobased agents (Figure 2). The selected agents—coffee grounds, eggshells & seashells, and sea moss—were chosen based on their potential to improve the mechanical properties, durability, and sustainability of the BC composites. These materials are often available as waste products and sustainable resources with potential for positive contributions to biocomposite materials. These agents were ground into fine powders and mixed with the cultivated BC biofilms in varying proportions (5%, 10%, and 15%) to develop composite materials. The mixtures were then subjected to a second fermentation process for 24 hours, ensuring uniform distribution of the additives within the BC matrix. Afterward, the composites were oven-dried at 100°C for a better crosslinking for 30 minutes and then they were soaked into NaOH solution for sterilization, by 4 hours of time intervals, and finally air-dried at room temperature to be tested for light transmission and biodegradability.

Coffee Grounds

Coffee grounds are a rich source of organic compounds, including antioxidants, which can potentially improve the structural integrity and UV resistance of biobased composites. The studies in the literature have explored the incorporation of coffee grounds into various materials, demonstrating their ability to enhance mechanical properties while maintaining biodegradability (Berg, 2019; Jafari et al., 2021).

Eggshells and Seashells mix

Eggshells are primarily composed of calcium carbonate, which has been shown to enhance the mechanical properties of composites. The incorporation of eggshells in biobased materials has been investigated for its potential to improve the rigidity and strength of composites, as well as to contribute to their environmental sustainability (Bach et al., 2020). Eggshells also have a potential antimicrobial effect, which could benefit the longevity of materials used in indoor environments (Li et al., 2021).
Seashells, particularly those rich in calcium carbonate, are often used to enhance the mechanical properties of biocomposites. Studies have demonstrated that seashells can increase the hardness and durability of biocomposites, making them suitable for applications that require higher resistance to wear and environmental stress (Yang et al., 2021; Almeida et al., 2023).

Sea Moss

Sea moss, a type of algae, is known for its unique gelling properties due to its high content of *carrageenan*. Incorporating sea moss into biocomposites could potentially enhance the material's flexibility and moisture resistance, which are important for applications such as lighting fixtures in varying environmental conditions (González et al., 2020; Sharma et al., 2022).



Figure 2. Bacterial cellulose composite biofilms.

Testing

The final BC composites were developed into a minimal lighting fixture, and tested in terms of their light transmission and biodegradability to assess their suitability for interior lighting applications.

Light Transmission

The light transmission of the composites was evaluated by measuring the transmittance of 2700K light through the biofilms using a lux meter equipped with photoelectric sensing technology. This device converts light intensity into electrical signals, processes the data, and displays the results on the Unit UT383 Mini's LCD screen. The percentage of light transmitted through the composites was calculated and compared to one of the standard lighting fixture materials, polypropylene plastic (Figure 3).

Biodegradability

Biodegradation tests were performed where the composites were placed in a controlled interior environment, as well as in an environment with soil to compost and biodegrade. The weight loss and material degradation were monitored over a 30 days period. Damage due to the heat was also observed to evaluate the biodegradability of the composites and their potential for both operational and end-of-life applications.

Results and discussion

This section outlines the findings from the development and testing of bacterial cellulose (BC) composites, mechanically enhanced with various biobased agents, for use in interior lighting fixtures. The materials were tested for light transmission and biodegradability to determine their potential for both longevity and sustainability.

Light Transmission

The light transmission properties of the tested materials varied significantly based on composition and concentration, offering insights into their potential applications in lighting design for interiors (Figure 3). The baseline material, polypropylene plastic, exhibited approximately 80% light transmission, serving as a reference point for comparison. Among the biocomposites, the BC-coffee grounds composite demonstrated the highest light transmission at 89% with 5% concentration, outperforming the baseline plastic. This value dropped to 74% at 10% concentration and further to 61% at 15%, indicating that increased coffee ground content reduces translucency.

The BC-eggshells and seashells composites showed moderate light transmission capabilities, ranging from 59% at 5% concentration to 48% at 10% and 24% at 15%. The reduction in light transmission for these composites can be attributed to the inherent opacity and larger particle sizes of the additive agents, which scatter light more significantly. Meanwhile, the BC-sea moss composites exhibited light transmission values of 62% at 5% concentration, 51% at 10%, and 32% at 15%. Sea moss's gelling properties contributed to light diffusion but with increasing concentration, the overall translucency was diminished.

In the overall case, results indicate that while biocomposites generally have lower light transmission than polypropylene plastic, their ability to diffuse light effectively makes them viable for ambient lighting applications, particularly where sustainability and material innovation are priorities.

Biodegradability

The biodegradability of the composites was assessed through composting tests conducted over a 30 days period (Figure 4). The composites showed varied rates of degradation based on the types of additives incorporated. The BC composite with 15% sea moss demonstrated the most rapid biodegradation, losing approximately 35% of its weight over 30 days. The composites with shells followed closely, with a weight loss of 20–25%. However, coffee grounds exhibited a weight loss of 8-12%.

This result aligns with the findings in the literature on biocomposites, indicating that the biodegradation rate is influenced by the nature of the biobased agents. Organic additives tend to accelerate biodegradation due to their high organic content (González et al., 2020; Jafari et al., 2021), whereas inorganic additives contribute to slower degradation, providing more stability during the material's life cycle (Yang et al., 2021). Nevertheless, the BC

composite with 5% coffee grounds lost dramatically less weight, approximately 8%, in the biodegradation for a given time.



Figure 3. Comparison of shades: Polypropylene plastic vs biocomposites.



Figure 4. Comparison of biodegradation: Composting in soil vs. in use for 30 days.

Conclusion

The findings of this study suggest that biobased BC composites, enhanced with coffee grounds, eggshells, seashells, and sea moss, are promising candidates for sustainable lighting fixture applications, offering a balanced combination of light transmission and biodegradability. Other biobased agents for different composite formulations could be explored to build up a composite profile for a variety of design applications.

The light transmission results suggest that the biobased composites did not match the high translucency of conventional materials such as polypropylene plastic, yet they still offer viable alternatives for diffused lighting applications, especially for calm environments such as bedrooms or cozy interiors. These findings underscore the potential of biobased composites to meet specific design needs, such as diffused lighting, while maintaining a sustainable and environmentally friendly profile.

The biodegradation tests hinted that the biobased composites can decompose efficiently at the end of their life cycle, with composites incorporating organic agents showing faster degradation rates. This aligns with the growing trend in materials science toward designing for end-of-life biodegradability, reducing environmental impact after use. The slower degradation observed in the 5% coffee ground composite suggests that this material can be more suitable for longer-lasting applications.

The integration of waste-derived materials such as coffee grounds, eggshells, seashells, and sea moss not only enhances the mechanical and aesthetic properties of the BC composites but also contributes to reduce reliance on non-renewable resources and promote a circular economy in material design. The ability to mold these biocomposites into different forms is only one promising side; utilizing advanced robotic technologies could also open up possibilities for innovative, custom lighting designs that align with ecological design principles.

While the study demonstrates promising results, further optimization of the biobased composite formulations is necessary to achieve a balance between biodegradability and light transmission that meets industry standards. It is essential to highlight that the primary focus was on the functionality and biodegradability of the materials, while durability still remains an area for further investigation, requiring long-term testing (exceeding 30 days) to align with the expected lifespan of an interior lighting fixture.

The next steps would also include refining the additives' proportions, observing other agents and exploring additional processing techniques to further enhance the composites' performance and sustainability, offering a novel approach to lighting fixtures that supports both longevity and biodegradability.

Nevertheless, the adaptability of bacterial cellulose (BC) in lighting fixture design is particularly relevant in contexts where semi-durable materials like paper and fabric are traditionally favored, such as pendant lamps, table lampshades, and wall sconces. These applications benefit from BC's translucency, flexibility, and potential for reinforcement through fiber integration, allowing for controlled illuminance and enhanced structural integrity. By varying fiber composition, designers can modulate light diffusion, creating soft ambient lighting or more directional illumination tailored to specific spatial needs. Moreover, the potential of BC composites extends beyond lighting; its acoustic absorption properties and compatibility with digital fabrication techniques open avenues for broader interior applications, such as modular partition panels or decorative wall treatments. These design implications position BC as a viable alternative to conventional materials, offering sustainable and customizable solutions for contemporary interior environments.

References

Almeida, S., Pereira, R. M., & Silva, R. R. (2023). Application of seashells in composite materials for enhancing mechanical properties. Journal of Sustainable Materials, 8(2), 45–53.

Bach, T. J., Bonilla, R., & Swanson, E. (2020). Eggshells as a sustainable filler for biocomposite materials: A review. Materials Science & Engineering, 51(1), 98–109.

Berg, J. (2019). Exploring the potential of coffee grounds in biopolymer composites for packaging applications. Journal of Renewable Materials, 7(6), 543–552.

González, L. I., Martínez, J. A., & Flores, M. P. (2020). Sea moss as a biofiller for sustainable composites: A review. Marine Materials Journal, 12(4), 305–317.

Gorgieva, S., & Trček, J. (2023). From nature to lab: Sustainable bacterial cellulose production and modification with

synthetic biology. Polymers, 15(16), 3466. DOI: 10.3390/polym15163466

Huang, C., Chen, X., & Hu, X. (2023). Microbial bricks for ecological restoration: A review of production methods and applications. Ecological Engineering, 195, 106992.

Jafari, M., Rahmani, R., & Aliakbarian, H. (2021). Coffee ground-based biocomposites for sustainable packaging: A case study. Journal of Biobased Materials and Bioenergy, 15(1), 36–43.

Kargarzadeh, H., Mariano, M., & Dufresne, A. (2018). Advances in biobased composites reinforced with nanocellulose: A review. Carbohydrate Polymers, 202, 429-450.

Lepoittevin, B., Salmén, L., & Gatenholm, P. (2023). Moisture and UV resistance in biocomposites: Applications in architecture. Composites Science and Technology, 235, 109385.

Lee, J., Park, Y., & Kim, H. (2023). Advances in bacterial cellulose: Applications in biomaterials and sustainable technologies. Biotechnology Advances, 64, 107564.

Li, W., Chen, L., & Wang, Z. (2021). Eggshell-derived biocomposites: Enhancing mechanical properties and environmental sustainability. Composites Science and Technology, 188, 107–115.

Nawab, Y., Zia, S., & Shaikh, Z. (2021). Biocomposites for sustainable interior design: Advances and challenges. Journal of Cleaner Production, 296, 126439.

Sahoo, S., Gohil, J., & Pandey, J. (2023). Enhancing the durability of biobased composites through chitosan and tannin additives. Green Chemistry, 25(4), 512-528.

Salmén, L., & Gatenholm, P. (2022). Life-cycle assessment of biobased materials in sustainable design. Sustainable Materials and Technologies, 35, e00337.

Sharma, P., Singh, P., & Bhattacharya, S. (2022). Sea moss as an innovative biocomposite for environmentally friendly packaging materials. Environmental Materials Research, 4(1), 123–135.

Yang, X., Liu, Q., & Yu, H. (2021). Seashell-based biocomposites for improved durability in construction and design. Journal of Eco-Friendly Materials, 5(3), 210–219.

Wang, Z., Zeng, Y., Ahmed, Z., Qin, H., Bhatti, I.A., Cao, H. (2024). Exploration, 4, 20230099.

Zhao, H., Han, Y., Liang, M., Han, Z., Woo, J., Meng, L., Chi, X., Tucker, M. E., Han, C., Zhao, Y., Zhao, Y., & Yan, H. (2023). Effect of Magnesium and Ferric Ions on the Biomineralization of Calcium Carbonate Induced by Synechocystis sp. PCC 6803. Minerals, 13(12), 1486.

Extended Abstract
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Exploring Parental Engagement in Sustainable Practices for School Uniforms: A Circular Economy Perspective

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Keywords: School uniforms; circular economy; textile waste; sustainability; second-hand clothing; parental behaviour; Australia

Introduction

The transition to a circular economy (CE) offers transformative solutions for mitigating the environmental, economic, and social challenges posed by the traditional linear 'take-make-dispose' model (Gorokhova et.al., 2023). This study investigates the integration of CE principles within the school uniform sector, focusing on parental behaviour, drivers, and barriers in purchasing school uniforms. The research aims to provide actionable recommendations for schools to enhance sustainability and reduce textile waste.

Parental attitudes towards sustainability in school uniforms are influenced by both economic and environmental considerations. The desire for affordability aligns with research indicating that cost is a primary driver of sustainable consumer behaviour (Shao & Ünal, 2019). However, logistical barriers such as limited availability and quality concerns must be addressed to enhance the adoption of sustainable practices. Community engagement, through initiatives like uniform swaps and educational campaigns, can play a crucial role in normalizing sustainable behaviors and reducing social stigma associated with second-hand uniforms (Bianchi & Birtwistle, 2011).

Methodology

The study employs a mixed-methods approach, combining material flow analysis, surveys, and focus groups. A survey of 102 parents from a secondary school in Victoria, Australia, was conducted to gather data on uniform purchasing behaviour. Additionally, a one-hour focus group discussion was conducted with six parents to gain deeper insights into their expectations and concerns regarding the quality, durability, and functionality of school uniforms.

Findings

Material Flow Analysis

Understanding the composition, lifecycle, and environmental impact of school uniforms are essential for evaluating their sustainability within a circular economy framework. A detailed examination of the materials used in the school's uniforms was undertaken, as shown in Figure 1.

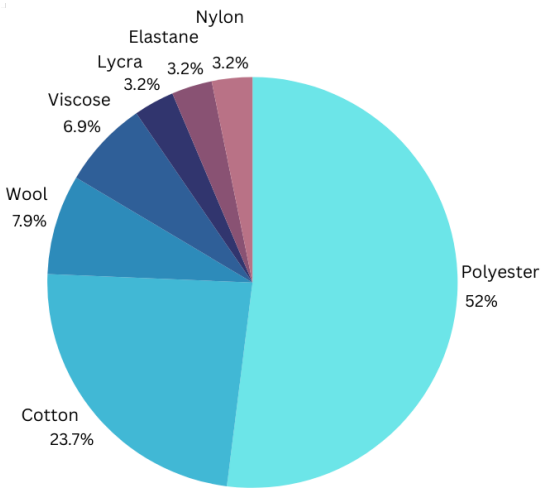


Figure 1. Material composition of school uniforms from the school used in this case study.

The current study reveals that school uniforms are made from a variety of fibres, with polyester being the most common at 52.1%, followed by cotton (23.7%) and wool (7.9%). The blending of numerous fibers to make uniforms poses significant recycling challenges. Therefore, alternative strategies are needed to incorporate circular economy principles. Following this, surveys and focus groups explored stakeholder perspectives on sustainable practices and their openness to alternative uniform management

solutions. This preliminary analysis underscores the critical need to understand parents' consumption behavior regarding school uniforms.

Survey and Focus Group Findings and Analysis

The findings highlight several key aspects of cost and accessibility, environmental awareness, and quality concerns in the context of school uniforms. Affordability emerged as a significant factor in this study, with 86% of parents who opted for second-hand uniforms citing cost savings as their primary motivation. Many families view second-hand purchases as a practical solution to the high costs associated with new uniforms. This aligns with reports indicating that in New South Wales, the average annual expenditure for public-school uniforms ranges from AUD 250 to 300 (Vincent, 2022). Findings from this study reveal that 31% of parents purchase new uniforms every year, 25% buy uniforms only once every two years or more, and 11% purchase uniforms every semester. Additionally, 24% of parents prefer second-hand options for cost savings. However, despite their willingness to embrace second-hand options, 44% of parents identified the limited availability of sizes and styles as a significant barrier.

Environmental awareness is also driving changes in consumer behavior. A notable 61% of parents chose second-hand uniforms to reduce their environmental impact, reflecting a growing trend towards sustainable choices (Abbate et al., 2023). However, quality concerns remain, with 18% of parents feeling that second-hand items did not meet their standards due to wear and tear. This underscores the need for durable uniforms that justify their cost, as parents expect high-cost items to provide lasting value (Fletcher, 2014; Niinimäki, 2010).

Quality, durability, and functional suitability are critical factors for parents when selecting school uniforms. Concerns about fabric quality were frequently voiced, with parents emphasizing the need for breathable, washable, and durable fabrics. This expectation aligns with research suggesting that consumers increasingly value longevity in apparel (Cooper et al., 2016; Goworek et al., 2023). Comfort is another important consideration, particularly in warmer climates where some materials were noted as uncomfortable. Research supports that fabric comfort and ease of maintenance significantly impact satisfaction (Fletcher, 2014). Additionally, certain styles, especially for girls, were seen as impractical for active school environments, highlighting the importance of accommodating the active lifestyles of young wearers (Rissanen & McQuillan, 2023).

Sustainability awareness and educational opportunities are also crucial. Parents advocated for greater transparency in uniform production, particularly regarding fabric composition, traceability, and sourcing. This aligns with research suggesting that transparent supply chains enhance consumer trust and promote engagement in sustainable practices (Bianchi & Birtwistle, 2011). Furthermore, parents emphasized the importance of integrating sustainability education into the curriculum. Practical activities such as upcycling projects and educational sessions on textile reuse were proposed to bridge knowledge gaps and make sustainability more tangible for students (Jones, Selby, & Sterling, 2010).

Logistical barriers and implementation challenges were also identified. Limited availability in sizes and styles of second-hand uniforms was a key obstacle, making it difficult for families to find suitable options (Bianchi & Birtwistle, 2011). Additionally, concerns over cleanliness and perceived quality of second-hand uniforms were noted, reflecting potential barriers in terms of social acceptance and quality perception (Guiot & Roux, 2010).

Community engagement and the promotion of sustainable practices were highlighted as effective strategies. Parents suggested organizing uniform swap events, competitions, and interactive campaigns to create excitement and awareness. Research indicates that structured, community-based events can effectively foster positive perceptions of eco-friendly choices (Prothero et al., 2011). These initiatives can help build a supportive community around sustainable practices and encourage broader participation in circular economy principles.

Conclusion

The study underscores the importance of addressing logistical and perceptual barriers to foster sustainable practices in school uniforms. By enhancing the availability and quality of second-hand options and engaging the

community through educational initiatives, schools can promote a circular economy model that aligns with parental expectations and environmental goals. Future research should explore the integration of digital tools and community-driven approaches to further support sustainable practices in school uniforms.

References

Abbate, S., Centobelli, P., Cerchione, R., Nadeem, S. P., & Riccio, E. (2023). Sustainability trends and gaps in the textile, apparel and fashion industries. Environment, *Development and Sustainability, 26*(2), 2837-2864. https://doi.org/10.1007/s10668-022-02887-2

Bianchi, C., & Birtwistle, G. (2011). Consumer clothing disposal behaviour: A comparative study. *International Journal of Consumer Studies, 36*(3), 335-341. https://doi.org/10.1111/j.1470-6431.2011.01011

Cooper, T., Oxborrow, L., Claxton, S., Goworek, H., Hill, H., & McLaren, A. (2016). *Strategies to improve design and testing for clothing longevity*. Nottingham Trent University. Retrieved from https://www.ntu.ac.uk/__data/assets/pdf_file/0039/906897/strategies-improve-design-testing-clothing-longevity.pdf

Fletcher, K. (2014). Sustainable fashion and textiles (2nd ed.). Earthscan. DOI: 10.4324/9781849772778

Gorokhova, T., Shpatakova, O., Toponar, O., Zolotarova, O., & Pavliuk, S. (2023). Circular Economy as an Alternative to the Traditional Linear Economy: Case Study of the EU. *Revista de Gestão Social E Ambiental, 17*(5), e03385–e03385. https://doi.org/10.24857/rgsa.v17n5-002

Goworek, H., Oxborrow, L., Claxton, S., Cooper, T. H., Hill, H., & McLaren, A. (2023). Managing sustainability in the fashion business: Challenges in product development for clothing longevity in the UK. *Journal of Business Research.* Retrieved from https://core.ac.uk/download/pdf/160274745.pdf

Guiot, D., & Roux, D. (2010). A second-hand shoppers' motivation scale: Antecedents, consequences, and implications for retailers. *Journal of Retailing*, *86*(4), 355-371. https://doi.org/10.1016/j.jretai.2010.08.002

Jones, P., Selby, D., & Sterling, S. (2010). Sustainability education: Perspectives and practice across higher education. Earthscan.

Niinimäki, K. (2010). Eco-clothing, consumer identity and ideology. *Sustainable Development*, *18*(3), 150-162. https://doi.org/10.1002/sd.455

Prothero, A., Dobscha, S., Freund, J., Kilbourne, W. E., Luchs, M. G., Ozanne, L. K., & Thøgersen, J. (2011). Sustainable consumption: Opportunities for consumer research and public policy. *Journal of Public Policy & Marketing*, *30*(1), 31-38. https://doi.org/10.1509/jppm.30.1.31

Rissanen, T., & McQuillan, H. (2023). Zero waste fashion design. Bloomsbury Publishing.

Shao, J., & Ünal, E. (2019). What do consumers value more in green purchasing? Assessing the sustainability practices from the demand side of business. *Journal of Cleaner Production*, 209, 1473-1483. https://doi.org/10.1016/j.jclepro.2018.11.022

Vincent, P. (2022, January 12). Annoyed Aussie mum is forced to spend $642 on school uniforms. Daily Mail Online. https://www.dailymail.co.uk/news/article-10392649/Australian-school-uniform-prices-outrage-costs-sending-kids-school-revealed.html

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Circular fashion and new materialities from repurposing waste: A discussion on the opportunities for the valorisation of material design from and for wearable garments.

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Keywords: circular fashion; materials; waste; upcycling; longevity.

Introduction

Despite an increasing number of regulations, such as the EU EPR (European Commission, 2022; Changing Markets Foundation, 2022), and promising circular material, product and business solutions, the fashion industry remains far from achieving a truly circular model (Circle Economy, 2024). Due to the extraction and processing of raw materials, production, use and end-of-life, this rapidly expanding global industry is one of the most polluting ones, using increasing quantities of fibers, thus exploiting finite resources beyond their regenerative capacities and exceeding planetary boundaries (Alkaya & Demirer, 2014; Hasanbeigi & Price, 2015; Instituto de Recursos Mundiales, 2021; Niinimäki, et al., 2020; Roos, et al., 2017; Shirvanimoghaddam, et al., 2020; Textile Exchange, 2024). The transition towards a circular economy in fashion holds the potential for economic profit by tapping into resources that would otherwise be wasted (Ellen MacArthur Foundation, 2017; Ellen MacArthur Foundation, 2020).

This paper offers a discussion on the benefits of eliminating the concept of waste from the perspective of material design. It considers the valorisation of fashion waste as a meaningful re-imagined secondary raw material resource by and for the industry.

Opportunities for the valorisation of material design from and for wearable garments

Although various circular solutions have been successfully integrated on a smaller scale, the fashion industry is transitioning towards a circular economy at a slow pace. Circular design emphasises the intrinsic value of a material, thus facilitating the implementation of multiple extended loops for prolonged use before recycling or regeneration. From a waste management perspective, circular design considers upcycling, recycling and downcycling as economic ways to preserve material value (Aus et al., 2021; de Aguiar Hugo, et al., 2021; Fletcher, 2014; Sandin & Peters, 2018). However, circular design addresses more than the materiality of a fashion product. It seeks to consider the whole life cycle of a garment as well as patterns of consumption and use. This holistic concept, based on systems thinking, encompasses manufacturing, production, use and end-of-life (Fletcher, 2014; Goldsworthy, 2014). Implementing circular principles from the initial design stage is a key approach to reduce the social and environmental impact of the fashion industry (Bridgens, et al., 2018; Goldsworthy, 2014; Jia, et al., 2020; Kazancoglu, et al., 2020; Zavagno, 2023).

There has been a promising increase in the production of new textile materials derived from industrial or agricultural waste, including fibres (Bananatex, 2024; Spinnova, 2023; Circular Systems, 2008), dyes (Archroma, 2025; Ignorance Bliss, 2025; MaterialDistrict, 2018; Recycrom, 2019), leather-like materials (Malai, 2025; Mycoworks, 2025; Briones & Cepeda, 2022; Boltthreads, 2022) and bioplastics (Dezeen, 2023; Designboom, 2022, VT&S, 2022). From a materials perspective, upcycling has the potential to unlock pre- and post-consumer textile waste streams for various industries, entering different design domains (Goldsworthy et al., 2018). In this sense,

upcycling transcends the boundaries of the garment industry, with applications in furniture and interior design (Fab-Brick, 2025; Fabraa, 2024; DenimX, 2025; Denimolite, n.d), art (Hug, 2024; Tiemroth, s.f.), and food (HOLOS Kombucha, 2024; Provin et al., 2021).

As the sources for upcycled materials differ, no definitive statement can be made about their performance, such as durability. Yet, especially in Western societies, the perception of upcycled materials as lower quality may hinder their scalability and industry adoption (Yusuff, 2024). Redesigning goes beyond extending its useful life, on the aesthetic and symbolic level, it consists of an intervention and a process of re-signification, it contains stories and histories, it is a way of remembering, recovering and conserving (Chapman, 2005). It enables inspirational design in which the inherent value of materials is maintained over unlimited future lives, redesigning narratives based on the creation of intrinsic material value (Goldsworthy, 2014; 2017). Upcycling links the new product with its past history through inscribed traces of use, and reflects on the passing of time by embracing signs of aging (Cassar, 2024).

In line with this concept, if the garment contains the material value, then designers become the key to ensuring that value is maintained. In the context of this article, meaningful and intelligent upcycling can be defined as a practice that involves redesign and remaking by valorisation with a focus on emotional durability and longevity. In this sense, creativity of the designer becomes a tool that leads to meaningful, inventive, novel and valuable product outcomes, not the mere purpose or result in itself. Reclaimed materials re-imagine secondary raw materials into new products, modifying their residual meaning with a meaning of value and quality (Chiais, 2022). The performative value derived from the aesthetic and symbolic dimension becomes a significant and complementary aspect to consider within circular fashion design.

This multi-perspective approach to design, encompassing the material, the garment, and their narratives, demonstrates the intricate and multifaceted nature of the fashion system. The implementation of holistic circular design principles represents a pivotal strategy for the fashion industry. The valorisation of waste presents a valuable opportunity for a beneficial socio-environmental impact, where material quality is an integral aspect of the aesthetic appeal.

Conclusions

While the circular solutions discussed above may be perceived as novel, it can be concluded that the imperative to eliminate the concept of waste from production systems can be paramount. It is more beneficial to integrate the principles of designing for circular systems and/or the concept of cradle-to-cradle design into the initial stages of the product life cycle as presented in this discussion. From a fashion perspective, it is essential to evaluate the functionality and the relationship with clothing, as well as the performative, aesthetic and symbolic aspects associated with its intended use. This perspective encourages the discourse surrounding the integration of sustainable strategies and symbolic perception in the design from fashion waste, emphasising the potential of new materials in challenging the longevity of both materials and designed garments. The contrast between new materials derived from secondary -or waste- sources and the performance sought after in fashion arises when considering product longevity and material longevity. By understanding these contrasts, designers may resolve the conflict between the application and performance of new materials designed from waste.

References

Alkaya, E., & Demirer, G. N. (2014). Sustainable textile production: a case study from a woven fabric manufacturing mill in Turkey. Journal of Cleaner Production, 65, 595-603. https://doi.org/10.1016/j.jclepro.2013.07.008

Archroma. (2025). EarthColors® by Archroma. Archroma. Retrieved February 26, 2025, from https://www.archroma.com/innovations/earth-colors-by-archroma

Aus, R., Moora, H., Vihma, M., Unt, R., Kiisa, M., Kapur, S. (2021). Designing for circular fashion: integrating upcycling into conventional garment manufacturing processes. Fash Text 8, 34. https://doi.org/10.1186/s40691-021-00262-9

Bananatex. (2024). The world's first technical fabric made from banana plants. Bananatex. Retrieved February 26, 2025, from https://www.bananatex.info/

Boltthreads. (2022). MyLoTM | Vegan, Sustainable Mycelium Leather. Recuperado 26 de

febrero de 2025, de https://boltthreads.com/technology/mylo/

Bridgens, B., Powell, M., Farmer, G., Walsh, C., Reed, E., Royapoor, M., Gosling, P., Hall, J. & Heidrich, O. (2018). Creative upcycling: Reconnecting people, materials and place through making. Journal of Cleaner Production, 189, 145-154. https://doi.org/10.1016/j.jclepro.2018.03.317

Briones, Y. & Cepeda, A. (2022). Development and exploratory design of textile based on tea, coffee, and yerba mate. Base Diseño E Innovación, 7(7), 107–122. https://doi.org/10.52611/bdi.num7.2022.80

Cassar, R. (2024). Innovative Upcycling: The Creative Potential of Collaborating with Degraded Materials. Fashion Theory, 28(7), 971–995. https://doi.org/10.1080/1362704X.2024.2402111

Chapman, J. (2005). Emotionally Durable Design: Objects, Experiences and Empathy. Routledge. DOI: 10.4324/9781849771092

Changing Markets Foundation (2022). A New Look for the Fashion Industry - EU Textile Strategy and the Crucial Role of Extended Producer Responsibility. Retrieved from https://changingmarkets.org/wp-content/uploads/2022/03/EPR-New-Look-Briefing-Online-format-layout.pdf

Chiais, E. (2022). From “Out of fashion” to Upcycling. How Art and the Fashion Industry Have Resemantized the Word “Recycling”. ZoneModa Journal, 12(1), 135–144. https://doi.org/10.6092/issn.2611-0563/14887

Circle Economy (2024). THE CIRCULARITY GAP REPORT Textiles - Closing the Circularity Gap in the textile industry. Retrieved from https://cgr-reports.s3.eu-west-1.amazonaws.com/cgr-textiles-3a1e7a73/Circularity+Gap+Report+Textiles+-+20241129.pdf

Circular Systems. (2008). Agraloop™ – Regenerative Fiber System. Circular Systems. Retrieved February 26, 2025, from https://circularsystems.com/agraloop

de Aguiar Hugo, A., de Nadae, J., & da Silva Lima, R. (2021). Can Fashion Be Circular? A Literature Review on Circular Economy Barriers, Drivers, and Practices in the Fashion Industry’s Productive Chain. Sustainability, 13(21), 12246. https://doi.org/10.3390/su132112246

Designboom. (2022). Bioplastic couture collection presents sustainable fabric options by NOT LienX. Retrieved February 26, 2025, from https://www.designboom.com/design/bioplastic-couture-collection-sustainable-fabric-options-not-lienx-11-16-2022/

DenimX. (2025). DenimX: Innovative recycled denim material. Retrieved February 26, 2025 from https://denimx.nl/

Denimolite. (n.d.). Sustainable furniture and interior solutions. Denimolite. Retrieved February 26, 2025, from https://www.denimolite.com/

Dezeen. (2023). Ten sustainable fashion designs that use biomaterials from Dezeen's Pinterest. Retrieved February 26, 2025, from https://www.dezeen.com/2023/06/26/ten-sustainable-fashion-designs-that-use-biomaterials-from-dezeens-pinterest/

Ellen MacArthur Foundation (2017). A NEW TEXTILES ECONOMY: REDESIGNING FASHION’S FUTURE. Retrieved from https://www.ellenmacarthurfoundation.org/a-new-textiles-economy?_gl=1*4gcq57*_up*MQ..*_ga*MTE3NTQxNDU2OC4xNzMzNzc4Mjg4*_ga_V32N675KJX*MTczMzc3ODI4OC4xLjEuMTczMzc3ODMzMi4wLjAuMA..

Ellen MacArthur Foundation (2020). Vision of a circular economy for fashion. Retrieved from https://www.ellenmacarthurfoundation.org/our-vision-of-a-circular-economy-for-fashion?_gl=1*4gcq57*_up*MQ..*_ga*MTE3NTQxNDU2OC4xNzMzNzc4Mjg4*_ga_V32N675KJX*MTczMzc3ODI4OC4xLjEuMTczMzc3ODMzMi4wLjAuMA..

European Comission (2022). EU Strategy for Sustainable and Circular Textiles. Retrieved from https://environment.ec.europa.eu/publications/textiles-strategy_en

Fletcher, K. (2014). Sustainable Fashion and Textiles: Design Journeys. Routledge. DOI: 10.4324/9781849772778

Fab-Brick. (2025). Eco-friendly bricks made from recycled textiles. Fab-Brick. Retrieved February 26, 2025, from https://www.fab-brick.com/

Fabraa. (2024). Fabraa: Recycled upholstery fabric. Retrieved February 26, 2025, from https://www.fabraa.com/

Goldsworthy, Kate (2014) Design for Cyclability: pro-active approaches for maximising material recovery. Making Futures, 3. Retrieved from https://ualresearchonline.arts.ac.uk/id/eprint/6871/3/goldsworthy__kate_paper.pdf

Goldsworthy, Kate (2017) The Speedcycle: a design-led framework for fast and slow circular fashion lifecycles. The Design Journal, 20. https://doi.org/10.1080/14606925.2017.1352714

Goldsworthy, K.; Earley, R. and Politowicz, K. (2018) Circular Speeds: A Review of Fast & Slow Sustainable Design Approaches for Fashion & Textile Applications. Journal of Textile Design Research & Practice, 6 (1), 42-65.

https://doi.org/10.1080/20511787.2018.1467197

Hasanbeigi, A., & Price, L. (2015). A technical review of emerging technologies for energy and water efficiency and pollution reduction in the textile industry. Journal of Cleaner Production, 95, 30-44. https://doi.org/10.1016/j.jclepro.2015.02.079

HOLOS Kombucha. (2024). How To Make A SCOBY Leather Bag From Kombucha: Eco-Chic Fashion. Recuperado 27 de febrero de 2025, de https://holoskombucha.com/blogs/home/how-to-make-a-scoby-leather-bag-from-kombucha-eco-chic-fashion

Hug, A. (2024). Alexandra Henkes. A Hug Art. Retrieved February 27, 2025, from https://www.alexhug.art/

Ignorance Bliss. (2025). Ignorance is Bliss: Waste metal pigments. Retrieved February 26, 2025, from https://ignorance-bliss.com/products

Jia, F., Yin, S., Chen, L., & Chen, X. (2020). The circular economy in the textile and apparel industry: A systematic literature review. Journal of Cleaner Production, 259, 120728. https://doi.org/10.1016/j.jclepro.2020.120728

Kazancoglu, I., Kazancoglu, Y., Yarimoglu, E., & Kahraman, A. (2020). A conceptual framework for barriers of circular supply chains for sustainability in the textile industry. Sustainable development, 28(5), 1477-1492. https://doi.org/10.1002/sd.2100

Malai. (2025). Malai Eco. Recuperado el 27 de marzo de 2025, de https://malai.eco/

MaterialDistrict. (2018). Medulla: Weed Furniture. MaterialDistrict. Retrieved February 26, 2025, from https://materialdistrict.com/article/medulla-weed-furniture/

Mycoworks. (2025). MycoWorks - Growing the Future of Materials with Fine MyceliumTM. MycoWorks. Recuperado 26 de febrero de 2025, de https://www.mycoworks.com/

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. Nature Reviews Earth & Environment, 1(4), 189-200. https://doi.org/10.1038/s43017-020-0039-9

Provin, A; de Aguiar Dutra, A.; Aguiar de Sousa, I.; Gouveia, S. & Vieira, A. (2021). Circular economy for fashion industry: Use of waste from the food industry for the production of biotextiles, Technological Forecasting and Social Change, Volume 169, ISSN 0040-1625, https://doi.org/10.1016/j.techfore.2021.120858.

Recycrom. (2019). Sustainable textile dyeing innovation. Recycrom. Retrieved February 26, 2025, from https://recycrom.com/

Sandin, G., & Peters, G. M. (2018). Environmental impact of textile reuse and recycling – A review. Journal of Cleaner Production, 184, 353–365. https://doi.org/10.1016/j.jclepro.2018.02.266

Shirvanimoghaddam, K., Motamed, B., Ramakrishna, S., & Naebe, M. (2020). Death by waste: Fashion and textile circular economy case. Science of The Total Environment, 137317. https://doi.org/10.1016/j.scitotenv.2020.137317

Spinnova. (2023). Sustainable textile innovation. Spinnova. Retrieved February 26, 2025, from https://spinnova.com/

Textile Exchange (2024). Material Market Report. Retrieved from https://textileexchange.org/app/uploads/2024/09/Materials-Market-Report-2024.pdf

Tiemroth, S. (s.f.). Obra de Sabina Tiemroth. Retrieved February 27, 2025, from https://www.sabinatiemroth.com/obra

Yusuff, M. (2024). Challenges in recycling and upcycling textiles. ResearchGate. Retrieved March 27, 2025, from https://www.researchgate.net/publication/385801248_Challenges_in_Recycling_and_Upcycling_Textiles

VT&S (2022). Von Tauben und Spatzen. Algae Leather. Retrieved February 26, 2025, from https://www.vontaubenundspatzen.com/algaeleather

Zavagno, A. (2023). Upcycling as a design strategy to innovate fashion processes and create a local value chain with the support of digital technologies : The Offbeat District case (Tesis de maestría inédita). Politecnico Milano, ARC III - School of Design, Milano, Italia. Recuperado de https://hdl.handle.net/10589/204218

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Regenerated cellulose fibers synthesized with recycled textiles: A circular bioeconomy milestone for material longevity or another fiber overproduction escalation?

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Keywords: Circular Economy; Bioeconomy; Textile; Man-Made Cellulosic Fibers (MMCF); Circular Fashion.

Introduction

Fashion is a major contributor to environmental degradation, accounting for 10% of global greenhouse gas emissions, 20% of freshwater pollution, and 35% of microplastics released into the oceans (EC, 2022). These environmental impacts have worsened due to the global expansion of textile fiber production, which has doubled since 1998. This growth has been largely driven by the rise of fast fashion, trade liberalization policies, and the decreasing lifespan of garments — now worn fewer than eight times before being discarded (EMF, 2017; Niinimäki et al., 2020). Moreover, this increase in fiber production has been largely fueled by the rise of fossil-derived fibers, which now account for over 67% of total fiber output (Textile Exchange, 2024).

In response, man-made or regenerated cellulosic fibers (MMCFs or RCFs) have emerged as a potential strategy. Their promotion fits circular economy and bioeconomy frameworks aimed at reducing dependence on fossil-based fibers. Sourced from renewable resources like forests, MMCFs also offer the potential to incorporate cotton and cellulose-based textile waste, enhancing material longevity (EC, 2018;2020;2022). Currently, most RCFs are synthesized with mechanically recycled cotton to produce lyocell (Abrishami et al., 2024); their future potential lies in chemical recycling technologies, such as ionic liquids (El Seoud et al., 2020; Haslinger et al., 2019; Ma et al., 2018). The use of recycled cellulose pulp holds significant innovation potential and is expected to grow significantly (Textile Exchange, 2024). Reusing cellulose fibers already in circulation in the market has been argued to be a this material longevity strategy and could reduce dependency on virgin raw materials like cotton and forests.

Between 2000 and 2018, global dissolving pulp production increased by 6.3%, with 85% used for MMCFs—outpacing cotton (1.3%) and synthetic fibers (5.1%) (FAOSTAT, 2024; Kallio, 2021). Growth accelerated from 2012 to 2023, with production doubling. Haemmerle identified this "cellulose gap" already in 2011, accurately forecasting the trend, with his predictions for 2015 and 2020 achieving 93% and 91% accuracy, respectively (Haemmerle, 2011; Textile Exchange, 2017, 2024).

However, despite their "sustainable" label, MMCFs face significant barriers regarding production impacts, product lifespan, recyclability, and potential rebound effects. Environmental impact and lifespan vary by fiber type—for instance, viscose, which represents 80% of MMCF production, often has a greater environmental footprint than fossil-based fibers. Meanwhile, lyocell is considered one of the most sustainable textiles due to greener chemicals in its production and more conscious forest management (Shen et al., 2010). Nevertheless, the industry faces criticism for poor forest management, particularly monocultures like eucalyptus, which threaten biodiversity and is involved in deforestation while also contributing to chemical water pollution (Changing Markets, 2020).

Recycling technologies remain limited—only 1% of textiles are downcycled. Currently, recycled content in new MMCFs barely reaches 20%, requiring the remainder to be virgin viscose or lyocell (e.g., Circulose by Renewcell, Tencel, Refibra x Lenzing, Ioncell) (Cao, 2021; Piribauer & Bartl, 2019). Furthermore, studies show that the environmental benefits of biological materials can be outweighed by the

negative impacts of reduced product durability (Hildebrandt et al., 2021).

Objectives and Methodology

This study aims to identify the drivers and barriers influencing the growth of MMCFs and assess their potential to support a circular transformation in the textile sector. It combines a comprehensive literature review with econometric ARIMAX modeling to analyze both traditional factors (e.g., forest and cotton industries) and emerging ones (e.g., recycled textiles and the cellulosic industry) affecting MMCF growth and their alignment with circular economy principles.

Given the lack of data on MMCF garment or material lifespan, the study specifically explores the potential of incorporating recycled textile waste into MMCF production as a material longevity strategy. It also examines the broader implications of this integration for transforming the textile, forest, and cellulosic sectors, assuming other factors in the current system continue their existing trajectory.

Conclusions

The potential of MMCFs lies in their technical properties and the resources used—particularly the reuse of textile waste. However, this study highlights that coupling recycling and bio-based strategies does not automatically ensure material longevity or environmental benefits. Key concerns include limited recycling technology, the need to blend recycled content with virgin MMCFs, and the environmental impacts of forestry practices and chemical use. The growing use of MMCFs in fast fashion and blended fibers, produced in high volumes with short lifespans, risks creating rebound effects. Moreover, there is a lack of research on MMCF garment longevity and little progress in improving their recyclability.

The results shows MMCFs offer economic and ecological opportunities, their ability to drive material a systemic circular transformation is limited. The findings suggest that MMCFs could improve eco-efficiency but fail to tackle core issues of overproduction, descarbonization and sustainable forest management.

Achieving meaningful change requires integrated strategies prioritizing extended product and material lifespans, with recycling as a complementary approach. Biodegradability, though marketable, is not enough. Long-term durability enabled by extended product use is crucial for environmental performance (Deckers et al., 2023).

For real circular transformation, MMCF promotion must be supported by policies that foster sustainable production and consumption, emphasizing product durability and material quality. Only through a holistic approach can the textile sector truly transition to a circular economy.

References

Cao, H. (2021). End of life clothes and their management. In R. Nayak & A. Patnaik (Eds.), *Waste Management in the Fashion and Textile Industries* (pp. 157–172). Woodhead Publishing. DOI: 10.1016/B978-0-12-818758-6.00008-9

Changing Markets. (2020). *Dirty Fashion: Crunch time. Where does the industry stand on stamping out dirty viscose?* Changing Markets Foundation.

EC. (2018). *Bioeconomy: The European way to use our natural resources: Action plan 2018* (p. 673). Unión Europea.

EC. (2020). *Estrategia de la UE sobre la biodiversidad de aquí a 2030. Reintegrar la naturaleza en nuestras vidas* (p. 667). Unión Europea.

EC. (2022). *Estrategia para la circularidad y sostenibilidad de los productos textiles*. Unión Europea.

Deckers, J., Manshoven, S., & Mortensen, L. F. (2023). *ETC/CE Report 2023/5 The role of bio-based textile fibres in a circular and sustainable textiles system*.

El Seoud, O. A., Kostag, M., Jedvert, K., & Malek, N. I. (2020). Cellulose Regeneration and Chemical Recycling: Closing the “Cellulose Gap” Using Environmentally Benign Solvents. *Macromolecular Materials and Engineering*, *305*(4), 1900832.

EMF. (2017). *Rethinking business models for a thriving fashion industry*. Ellen MacArthur Foundation.

FAOSTAT. (2024). *Forestal Producción y Comercio* [Dataset].

Haemmerle, F. M. (2011). *The cellulose gap (the future of cellulose fibres)* (89; Lenzinger Berichte, p. 10). Lenzinger AG.

Haslinger, S., Hummel, M., Anghelescu-Hakala, A., Määttänen, M., & Sixta, H. (2019). Upcycling of cotton polyester blended textile waste to new man-made cellulose fibers. *Waste Management*, *97*, 88–96. https://doi.org/10.1016/j.wasman.2019.07.040

Hildebrandt, J., Thrän, D., & Bezama, A. (2021). The circularity of potential bio-textile production

routes: Comparing life cycle impacts of bio-based materials used within the manufacturing of selected leather substitutes. *Journal of Cleaner Production*, *287*, 125470. https://doi.org/10.1016/j.jclepro.2020.125470

Kallio. (2021). Wood-based textile fibre market as part of the global forest-based bioeconomy. *Forest Policy and Economics*, *123*, 102364. https://doi.org/10.1016/j.forpol.2020.102364

Ma, Y., Hummel, M., Kontro, I., & Sixta, H. (2018). High performance man-made cellulosic fibres from recycled newsprint. *Green Chemistry*, *20*(1), 160–169. DOI: 10.1039/C7GC02896B

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, *1*(4), Article 4. DOI: 10.1038/s43017-020-0039-9

Piribauer, B., & Bartl, A. (2019). Textile recycling processes, state of the art and current developments: A mini review. *Waste Management & Research*, *37*(2), 112–119. https://doi.org/10.1177/0734242X18819277

Shen, L., Worrell, E., & Patel, M. K. (2010). Environmental impact assessment of man-made cellulose fibres. *Resources, Conservation and Recycling*, *55*(2), 260–274. http://dx.doi.org/10.1016/j.resconrec.2010.10.001

Textile Exchange. (2017). *Creating Material Change: Annual Report 2017. Textile Exchange*.

Textile Exchange. (2024). *Materials Market Report 2024*. Textile Exchange.

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Computational Circular Design of Planar Linkage Mechanisms Using Available Standard Parts

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Keywords: Circular economy; Design for circularity; Reuse; Computational kinematics; Linkages

Introduction

As a potential solution to increasing pressure on the environment and natural resources, Circular Economy has emerged as an approach that promises to close material flows, thus reducing resource use, pollution, and waste. To date, public effort has been focused on low value retention strategies like recycling, however, higher value retention solutions are still needed to better achieve a truly circular economy (Potting et al., 2017). Remanufacturing and repurposing are two high value retention strategies that focus on the reuse of existing parts of a product to create another product with the same function or a different function, respectively. These two strategies are already being explored in the building sector, where the creation of a database of available parts enables the reuse of building components (Brütting et al., 2019; Law et al., 2024).

However, for products with moving parts, like machines, current research lacks systematic circular design methods. This paper aims to address this gap by focusing on kinematics, specifically on linkage mechanisms, which are ubiquitous in modern machines across industries such as automotive, agriculture, and manufacturing. Though numerous works in kinematic analysis and synthesis have been conducted (Bächer et al., 2015; Nobari et al., 2022, 2024), these methods cannot be transferred directly into a sustainability context as they assume an unconstrained supply of parts, both in terms of the number of parts available and freedom in their geometry.

This paper presents a new computational method for synthesizing planar linkage mechanisms based on available standard parts, represented by LEGO® Technic beams. First, an adapted design representation is introduced, along with a generative design method to create mechanisms and their coupler curves based on a given inventory. Next, an optimization problem is formulated to address the inverse design task. The goal is to find combinations of reused and new parts that produce coupler curves as similar as possible to a given target curve. The resulting problem is an integer, non-linear, non-differentiable (black-box), multi-objective minimization problem.

Results

Figure 1 illustrates the two distinct parts of this work. Both the generation and optimization are implemented in Python and run on a single core of an i7-1195G7 processor.

Modeling and Generation

Mechanisms are represented with a graph with two types of nodes. Parts nodes, or LEGO® Technic beams, can connect to connector nodes, or LEGO® Technic pins. The edges in between them carry the location of the connection on the beam as an attribute. Designs are generated by randomly picking available parts from the inventory and adding them two by two to the start graph consisting of a fixed part and an actuator.

The kinematics analysis follows the arc intersection method (Bächer et al., 2015; Nobari et al., 2022). The position and orientation of the pairs of added parts is solved in the same order as they were added. Trajectories are extracted, normalized, and stored. While most designs are discarded because they are kinematically invalid, a large database of achievable mechanisms and their resulting curves is generated. The novelty of the mechanism synthesis method presented here is that it only considers the use of available parts.

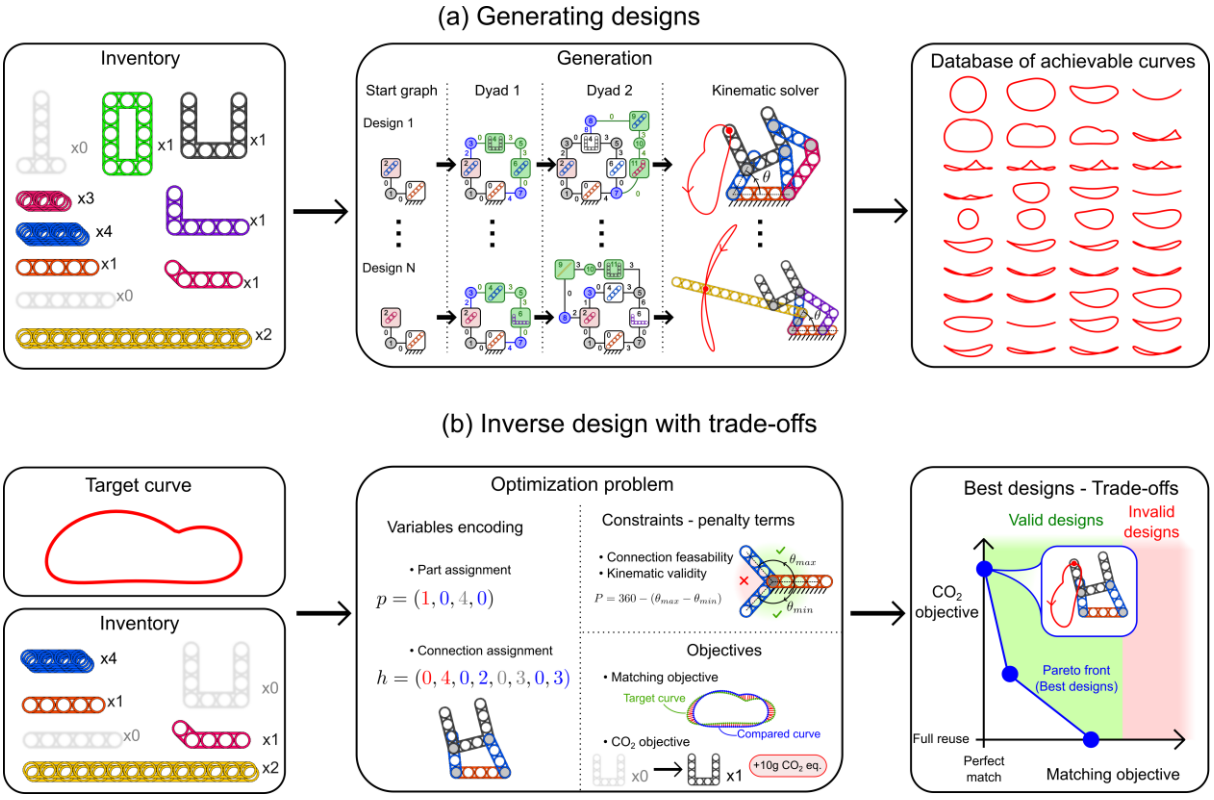


Figure 1: (a) Illustration of how designs are generated and saved to the database. (b) The inverse design method requires a target curve and a part inventory as an input. The optimization then finds a set of optimal designs based on a shape matching objective and a CO_2 objective.

Inverse Design and Trade-Offs

For the optimization problem, designs are encoded by two vectors of integers. The part assignment vector determines which part from the inventory is selected for each part node in the graph. The hole assignment vector lists the indices of the locations of all connections on their respective parts.

Constraints are modeled as penalty functions for simplified optimization. Two penalty functions ensure that the locations of all connections exist on the parts and are not redundant, in order to avoid kinematic singularities. A final penalty function penalizes designs where the actuator is not free to complete a full rotation.

The optimization model includes two objectives to minimize. The first objective, called the matching objective, calculates the degree to which the resulting curves match the target curve. The second objective, or CO_2 objective, calculates the greenhouse gas emissions caused by the fabrication of a new part, which is not available in the inventory.

An analysis of the resulting design space reveals a complex structure with a multitude of sparse local minima, most of which have significantly higher objective values than the known global minima. A genetic algorithm and a pattern search using NOMAD 4 (Audet et al., 2022) are employed to solve the defined problem.

Compared to a naive random search, both optimizers demonstrate little to no advantage in terms of convergence to designs with good matches to the target curve.

The feasible solution space and pareto front confirm the expected trade-offs between kinematic performance and environmental impact. When specific parts are missing from the inventory, designs benefit more from the addition of new parts, albeit at the expense of a CO_2 impact.

Conclusion

This work introduces a computational method to explore and select feasible designs with a given set of available standard parts represented by LEGO® Technic parts. A design representation is defined and used to generate achievable mechanisms. Black-box optimizers are used to solve the inverse design problem. Finally, this paper explores the tradeoffs between the kinematic performance and the embodied CO2.

Developing a circular design method for mechanism synthesis remains challenging due to the computational cost, the combinatorial nature of the problem, the non-linearity of the relationships between components, and the complexity of enforcing the validity of designs. New representations and solution approaches could potentially offer a substantial gain in performance and enable scenarios of reuse for more complex and industry-motivated case studies. Additionally, a more thorough life cycle assessment and the embedding of circularity metrics would improve the relevance of the designs discovered.

In the broader context, this work represents an initial step in the future development of a more holistic computational circular design method that can assist design practitioners in creating new mechanical products with reused parts.

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References

Audet, C., Le Digabel, S., Montplaisir, V. R., & Tribes, C. (2022). Algorithm 1027: NOMAD version 4: Nonlinear optimization with the MADS algorithm. *ACM Transactions on Mathematical Software (TOMS)*, *48*(3), 1–22. https://doi.org/10.48550/arXiv.2104.11627

Bächer, M., Coros, S., & Thomaszewski, B. (2015). LinkEdit: Interactive linkage editing using symbolic kinematics. *ACM Transactions on Graphics*, *34*(4), 99:1-99:8. https://doi.org/10.1145/2766985

Brütting, J., Senatore, G., & Fivet, C. (2019). Form Follows Availability – Designing Structures Through Reuse. *Journal of the International Association for Shell and Spatial Structures*, *60*(4), 257–265. https://doi.org/10.20898/j.iass.2019.202.033

Law, I., Chang, K. C., Önalan, B., Reisach, D., Griffioen, S., de Saussure, A., Dillenburger, B., & De Wolf, C. (2024). Web-Based Material Database for Circular Design. In P. Eversmann, C. Gengnagel, J. Lienhard, M. Ramsgaard Thomsen, & J. Wurm (Eds.), *Scalable Disruptors* (pp. 116–127). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-68275-9_10

Nobari, A. H., Srivastava, A., Gutfreund, D., & Ahmed, F. (2022). LINKS: A Dataset of a Hundred Million Planar Linkage Mechanisms for Data-Driven Kinematic Design. *Volume 3A: 48th Design Automation Conference (DAC)*, V03AT03A013. https://doi.org/10.1115/DETC2022-89798

Nobari, A. H., Srivastava, A., Gutfreund, D., Xu, K., & Ahmed, F. (2024). *LInK: Learning Joint Representations of Design and Performance Spaces through Contrastive Learning for Mechanism Synthesis* (No. arXiv:2405.20592). arXiv. https://doi.org/10.48550/arXiv.2405.20592

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring Innovation in the Product Chain. *Planbureau Voor de Leefomgeving*, *2544*. https://dspace.library.uu.nl/handle/1874/358310

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Minerals as Keepers of Time

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Keywords: Minerals; Materiality; Time; Linear time; Time-circles.

Introduction

Society is increasingly depending on advanced technology. Especially during the last decade, our understanding of the Anthropocene, the proposed geological time in which human activity has a significant impact on the planet's climate and ecosystems, has expanded to include the minerals needed for the production of digital devices, the storage of date, and computing infrastructures. The increasing development, testing, and use of artificial intelligence (AI) has accelerated mineral consumption. There is tension between the needs of the new wave of AI and the proponents of digital degrowth, who propose reducing technology consumption because, among others, of the unsustainable impact of mineral mining. For instance, as one of the first countries in the world, Norway has approved the deep-sea mining of minerals needed for the so-called twin transition, the digital and energy transitions. Deep sea mining will result in significant harm to marine life. How do we create awareness of the unsustainable mining of minerals? This paper proposes a focus on time to cast light on the effects of human overconsumption. Minerals cannot disappear; they may take other forms and value, but they will always remind humans of how they have (mis-)used them over time.

Linear and Circular Time

Time is a fuzzy concept, almost impossible to define, but always present. To cope with time, humans split time into moments or definite portions. The linear way of representing time, typical of Western culture, is past, present, and future (Janca & Bullen, 2003; Taylor et al., 2016). However, several alternative ways of describing time can be found both in human languages (Pamies-Bertrán & Yuan, 2020; left out for review) and in non-linguistic metaphors and mental models (Hendricks & Boroditsky, 2017). For instance, the perception of time in circles, among Australia's First Nation people (Janca & Bullen, 2003), can contribute to an additional understanding of how events are placed in time. From a 'time-circle' perspective, an event or thing is related to the center; the closer to the center, the more important the event or thing is (Janca & Bullen, 2003). At the center is the subject-person, with time understood as static. The distance from the center to any 'time-circle' is uniform, signifying that time is both static and omnipresent (see Figure 1).

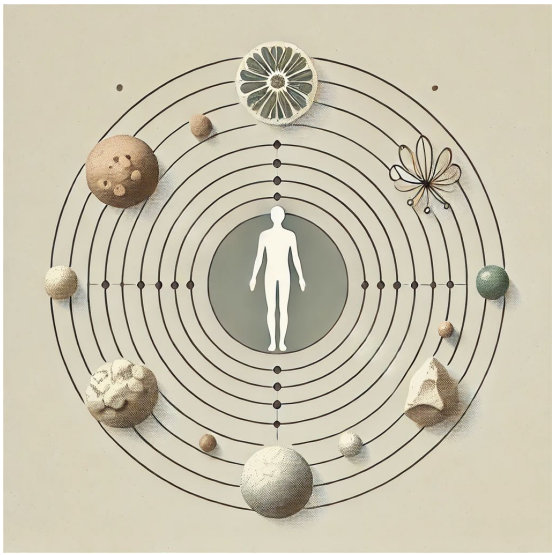


Figure 1. Time-circles and minerals. © DALL-E

Minerals and Time

Linear time can be used to explain the geological time of minerals and their relationship to humans. Minerals are stored in nature for a long time before they become part of technology. The time it takes in which the minerals are mined, sorted, displaced, transported, moved, rinsed, melted, used, repaired, recycled, and disposed of is very short in a geological and linear time perspective.

On the other hand, the conceptualization of time as static, from a 'time-circle' perspective, aligns with the nature of minerals. Minerals are

manipulated for use in the production of our digital technologies, but they will always be present in some form and keep their very long-time perspective, existing long before the Anthropocene and continuing to exist in the geological time that comes after the Anthropocene. They are keepers of time!

'Time-circles' structure the relationship between minerals, as materials of technology, and humans. They change value and meaning for humans as they are more important, closer to the center, or less important to them, distant from the center.

Overconsumption and Time-circles

Overconsumption of natural resources is a complex problem that requires a broad, comprehensive perspective to understand the role of humans in shaping the future of technology. The 'time-circles' perspective gives an additional structure to the relationship between humans and technology, highlighting their dependence on minerals.

Minerals have no value for humans as long they are in nature, however, they are part of a web of structures on Earth. Barad (2003) points out "that the boundaries and properties of the "components" of phenomena become determinate and that particular embodied concepts become meaningful" when they intra-act. This creates a tension between agencies of minerals and humans. One rhetorical question to explain this could be:

"*Is it ok that humans use all the minerals of all the planets in our solar system?"*

When humans ideate new technology, does the "concept that becomes meaningful" (Barad, 2003) allow the use of all the mineral resources available to achieve the desired result? The overconsumption of minerals is ethically questionable, especially when digital technologies are relevant and meaningful solely to humankind. Time and 'time-circles' add a new dimension to the short period humans relate to the consumption of minerals, namely when they are mined, are used in digital technologies, and discarded. 'Time-circles' are during this period closer to the center (see Figure 1). Minerals and technology have their own 'time-circles' and they are entangled with humans. This strong connection allows overconsumption by humans, where minerals are taken for granted as a commodity only humans can access.

Chronopolitics (Wallis, 1970) examines how humans' perceptions of time influence their political behavior. Chronopolitics allows reinterpretations of time, where the "true' meaning of the present is contingent upon which view" (Wallis, 1970, p. 105). The choices made in the present decide which future becomes reality. In the end, humans must reflect on their choices in relation to the creation and use of digital technologies. Chronopolitics and "time-circles" explains why there are difficulties in our society in following the optimal lifecycle of digital technology where repair is preferable over recycling or discarding. When digital technologies are discarded, minerals move to a circle away from the center, and in doing so, humans do not need to relate to them.

"*Do humans reflect on the long-term effects of using minerals in technology?"*

When recycling minerals or re-entering them into the soil as waste, minerals have changed in composition and have no chance of returning to their original form.

Conclusions

Minerals are keepers of time! They do not disappear; instead, they change forms and roles, reflecting the consequences of humanity's reckless resource consumption. The concept of 'time-circles' provides additional insight into how humans consume resources, often disregarding the natural boundaries set by Earth. Humans frequently distance themselves from technology-related issues, and 'time-circles' offer a possible explanation for this disconnection.

Acknowledgments

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References

Barad, K. (2003). Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter. *Signs: Journal of Women in Culture and Society*, *28*(3), 801–831. https://doi.org/10.1086/345321

Hendricks, R. K., & Boroditsky, L. (2017). New Space–Time Metaphors Foster New

Nonlinguistic Representations. *Topics in Cognitive Science*, *9*(3), 800–818. https://doi.org/10.1111/tops.12279

Janca, A., & Bullen, C. (2003). The Aboriginal Concept of Time and its Mental Health Implications. *Australasian Psychiatry*, *11*(1_suppl), S40–S44. https://doi.org/10.1046/j.1038-5282.2003.02009.x

Pamies-Bertrán, A., & Yuan, W. (2020). The spatial conceptualization of time in Spanish and Chinese. *Yearbook of Phraseology*, *11*(1), 107–138. https://doi.org/10.1515/phras-2020-0007

Taylor, J. L., Soro, A., Hong, A. L., Roe, P., & Brereton, M. (2016). Designing For Cross-Cultural Perspectives of Time. *Proceedings of the First African Conference on Human Computer Interaction*, 219–224. https://doi.org/10.1145/2998581.2998606

Wallis, G. W. (1970). Chronopolitics: The Impact of Time Perspectives on the Dynamics of Change. *Social Forces*, *49*(1), 102–108. https://doi.org/10.2307/2575743

Extended Abstract
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Lightfastness Natural Color Database: A tool for designing evolving effects on textile surface through sunlight exposure

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Keywords: Discoloration as surface evolution; Wear perception; Color changes Database; Textile product longevity; Evolutive design method.

Introduction

Since the onset of the 21st century, there has been a notable decline in the lifespan of textile products in the Western world, despite a twofold increase in consumption within the clothing and upholstery sectors from 2000 to 2015 (Ellen MacArthur Foundation, 2017; ZeroWaste, 2024). This trend of frequent renewal has resulted in excessive ressource waste and a threefold surge in the exportation of used textiles from Europe (Ellen MacArthur Foundation, 2017). Current initiatives aimed at reducing this waste mainly concentrate on the end-of-life phase of the product lifecycle, particularly through recycling efforts. However, it is reported that 87% of these textiles end up being incinerated or sent to landfills after their final use (Laitala and al., 2015), rendering these efforts actually ineffective.

Cosmetic obsolescence as one of the reason for end-of-life textile products

Research exploring the motivations behind the renewal of textile products has underscored factors associated with cosmetic obsolescence (Kumar and al., 2023). Consumers tend to discard one item in favor of another that is perceived more aesthetically pleasing, attractive or socially valued (Guien, 2021), even though the product remains functional.

This phenomenon emphasizes the necessity to prioritize sociological challenges over technological ones (Rogers and al., 2015) in the pursuit of reducing material production, energy consumption, and environmental degradation by over 90% by 2040 (van Ness & Cramer, 2005). In this context, a recognized approach for prolonging the lifespan and decelerating the consumption cycle of textile products, involves designing items that can adapt alongside their owners, thereby enhancing their emotional and economic value over time (Chapman, 2005; Lilley and al., 2019; Nobels and al., 2015).
Taking into account user's desires for change in the renewal of textile products, can practice-based research utilize signs of aging to suggest renewal over time, thereby extending the lifespan of these products ?

Integration of wear into textile product design as a way to build 'narrative experiences' to extend lifespan

In this regard, it is noteworthy that the perceived aging of textile product surfaces is generally deemed undesirable by both the industry and consumers, despite being a natural characteristic of most materials (Talman, 2019). Nonetheless, some forms of wear are positively perceived when associated with a patina, which is regarded as an aesthetically pleasing surface quality (Haug, 2017). Although this socio-cultural phenomenon applies to a limited range of objects (such as leather armchairs or blue-jeans), it indicates that surface wear can indeed contribute to extending product lifespans. On this point, studies on user responses to material aging show that changes that occur gradually (Manley et al., 2015) on materials of natural origin (Nobels et al., 2015) are likely to be perceived neutrally or positively.

Consequently, this article seeks to examine the extent to which surface degradation can be perceived positively as a patina, focusing specifically on the wear parameter of discoloration due to sun exposure. The chromatic reactions generated by exposure to the sun (as a photo-oxidation phenomenon) are commonly evaluated in the industry using accelerated aging machines in order to eliminate colors that would be considered non-resistant. In this research framework, we

consider them, on the contrary, as means of realizing surfaces that evolve over time. More precisely, the possibility of gradually lending behaviors to a surface that, familiarly, does not change, induces the possibility of building "narrative experiences" (Chapman, 2005) and, thus, contributing to the longevity of a product (Grimaldi, 2017).

Natural dyes lightfastness as a way to design evolutive textile products surfaces : a methodology

Utilizing the same metrological testing instrument, the colors are analyzed with the aim of predicting their behavior over the duration of use rather than employing a discriminatory control approach. A series of one hundred tests involving natural dyes applied to silk and wool yarns were subjected to artificial exposure to establish a “chromo-chronological” database (figure 1), documenting their reactions to sunlight. Subsequently, these colors were examined using a spectrophotometer to assess changes in hue, saturation, and luminance for each reference sample. With this data, a chromo-chronological color chart was developed in the form of both 3D and 2D models for use by textile designers. In this regard, it is interesting to note that the students who tested this design method relied only on the database samples, excluding the 2D printed reproductions.



Figure 2 Extract from the Chromo-chronological database, silk threads on paperboards exposed to artificial sunlight during 50, 40, 30, 20, 10 and 0 hours. ©Ramage

Through practice-based research in textile design, the database has facilitated color exploration aimed at creating textiles that exhibit both appearance and disappearance effects over time exposure. The intention to create a monochrome surface capable of revealing a pattern or design has modified the conventional approach to color reproduction. Traditionally, the goal is to reproduce the shade of a sample through successive adjustments in a linear process. In our case, the research focuses on achieving the same perceived shade from two coloring resources (hues on the same fiber) that react differently to prolonged exposure to sunlight. The search for the same color thus occurs through successive adjustments on the two colors, in order to increasingly restrict a chromatic perimeter. When these two threads present the same perceived color, we can therefore create a monochrome textile surface. Over the period of sunlight exposure, the contrast between these two colors will increase, allowing the predetermined design to emerge (figure 2).



Figure 1. Evolutive rug Green law square, wool threads before (left side) and after (right) exposure to natural sunlight during 6 months, Chateauroux. ©Ramage

Conclusion

This paradigm shift, which reinterprets the phenomenon of discoloration as a means to design evolving textile surfaces in their ability to reveal patterns or images over time. The chromo-chronological data base has enabled the development of textile prototypes (weavings and carpets) demonstrating this concept. While current research on integrating wear parameters into design for extended product

lifespan lacks concrete methods — even if a lot of studies attempt to have a better understanding of consumer's responds to patina and surface degradation (Lilley & al., 2019; Manley & al., 2015) — this study highlights the potential of storytelling within product experiences to foster user attachment and extend product longevity (Grimaldi, 2017). By incorporating evolving and surprising visual changes into textile surfaces, we aim to capture user attention and create a more memorable experience (ibid.). This evolving surface behavior can establish a narrative, imbuing the textile with emotional significance and potentially mitigating factors that contribute to textile product remplacement, as consumer boredom and weariness (Zouaghi, 2017). However, further research is needed to understand how users perceive discoloration within a design contexte, building upon existing perception studies (Lilley & al., 2019; Manley & al., 2015).

Although the research methodology focused on understanding and subsequently predicting the surface reactions of materials — so that these can be integrated into the manufacturing process for the creation of evolving objects — highlights the significance of developing predictive tools, as guarantee for graceful aging throughout the lifespan of products.

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References

Chapman J., (2005). *Emotionally durable design: Objects, experiences and empathy*. Routledge, London: Earthscan.

Ellen MacArthur Fondation, (2017). *A new textile economy : Re-designing fashion's future*.

Grimaldi, S., & Chapman, J. (2017). Surprising longevity. In *Routledge Handbook of Sustainable Product Design* (1st ed., pp. 298–315). Routledge.

Guien, J. (2021). *Le consumérisme à travers ses objets. Gobelets, vitrines, mouchoirs, smartphones et déodorants*. Editions Divergentes, Paris.

Haug, A. (2017). Defining 'Resilient Design' in the Context of Consumer Products. *The Design Journal*, *21*(1), 15–36. https://doi.org/10.1080/14606925.2018.1395265

Kumar V., Hernandez N., Jensen M., Pal R., (2023). *Deep learning based system for garment visual degradation prediction for longevity*. Computers in Industry, Volume 144. https://doi.org/10.1016/j.compind.2022.103779

Laitala K., Boks, C., Klepp, I.G., (2015). *Making clothing last : A design approach for reducing the environmental impacts*, Int. J. Des, 9, p. 93-107. Retrieved from: https://ijdesign.org/index.php/IJDesign/article/view/1613/696

Lilley D., Bridgens B., Davies A., Holstov A., (2019) *Ageing (dis)gracefully: Enabling designers to understand material change*. Journal of Cleaner Production 220, p. 417-430. https://doi.org/10.1016/j.jclepro.2019.01.304

Nobels E., Ostuzzi F., Levi M. Rognoli V., Detand J., (2015) *Materials, Time and Emotion: how materials change in time ?* Conference paper, Tangible means, EKSIG, Denmark. http://hdl.handle.net/1854/LU-6985094

Rogers J. G., Cooper S. J.G., Cooper S., Densley T., Braithwaite D., Moreno N., Rodrigues M., Salvia A., (2015). *Product longevity and shared ownership: sustainable routes to satisfying the world's growing demand for goods*. Aims Energy 3 (4), p. 547–561. https://doi.org/10.3934/energy.2015.4.547

Talman, R. (2018). Designing for Multiple Expressions: Questioning Permanence as a Sign of Quality in Textiles. *Journal of Textile Design Research and Practice*, *6*(2), 201–221. https://doi.org/10.1080/20511787.2018.1514697

van Nes N., Cramer J., (2005). *Influencing product lifetime through product design*. Bus. Strat. Env. 14, p. 286-299. https://doi.org/10.1002/bse.491

Zouaghi S., (2017). *Implication des femmes dans le cycle de changement des produits d'ameublement domestique: manifestations du désir de changement, pratiques de consommation divergentes et contribution au design écologique*. Art et Histoire de l'art. Université Panthéon-Sorbonne, Paris 1.

ZeroWaste France, (2024). *Tendances Maison. L'envers du décor*.

Clothing, Footwear, and Accessories Longevity



Research paper
6th PLATE 2025 Conference
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A Shared Vision: The importance of Knowledge Exchange through Co-design in Scaling Circular Strategies for Fashion Remanufacture – Case studies from global perspectives

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Keywords: Remanufacturing; Circularity; Scaling; Co-Design; Knowledge Exchange.

Abstract: Overproduction in the fashion industry poses a significant challenge, leading to excessive resource use and rapidly growing textile waste before garments reach consumers. The Circular Economy (CE) is gaining recognition as a means to reduce resource consumption through various strategies integrated into product lifecycles. However, effectively scaling these strategies to achieve tangible impacts remains underdeveloped. This paper draws on research projects that collaborate with industry partners to incorporate remanufacturing into existing supply chains. It highlights the essential knowledge exchange required for implementing circular production methods, aiming to identify strategies necessary for scaling. The paper enhances understanding of how remanufacturing pre-consumer textiles can be integrated into large-scale fashion business settings. Through two practice-based research projects, one with a major fashion brand and the other with a large garment factory, the research investigates how co-designing pilot projects as a form of knowledge exchange can facilitate the scaling of circular strategies in fashion production. These projects are designed to build capacity, enabling the industry partner to develop systems that can expand the implementation of remanufacturing excess stock.

While extensive research exists on circular strategies, there is limited understanding of practical implementation and how collaborations between research and industry can foster a knowledge exchange that supports the transition to circularity. The implementation of remanufacturing, like other circular strategies, depends on adapting processes contextually with a clear understanding of the industry's existing parameters and developing design responses that can effectively maintain value and recirculate garment stock.

Introduction

Overproduction has become normalised, with brands padding sales forecasts (Pucker, 2023), while on the production line, it is used to mitigate any faults found during quality control. Overproduction also accommodates possible design re-runs that the brands may request later in the season, allowing for time-efficient lean production strategies. In addition to the overproduction generated by factories, estimated to be between 25% and 47% above the orders placed by brands (Runnel et al., 2017), it is also estimated that up to 30% of garments produced by brands are never sold (*Global Fashion Agenda: Prosperity vs. Growth*, 2021). While the actual figures on pre-consumer textile waste are difficult to ascertain due to lack of transparency, it is well documented that much of this whole product (WP) fallout is ending up in waste streams of landfill and incineration (Child, 2020). Currently, less than 1% of the material used to produce clothing is recycled into new clothing (Anguelov, 2021; Ellen MacArthur Foundation, 2021). This reflects a loss of resources and inherent value in this material, as brands primarily offload excess stock through discounting—often below profit margins or leaving it with the manufacturer to dispose of.
While many micro-businesses are utilizing upcycling on a small scale, the impact on the overall resource wastage is minimal (Ellen MacArthur Foundation, 2017; KeBler et al., 2021), perhaps due to the challenges of embedding remanufacturing within existing supply chains. Finding pathways for large-scale fashion businesses to implement remanufacturing is critical for reharnessing the resources in pre-consumer waste. For now, traditional linear production using virgin

materials remains cheaper since raw materials often have low value to begin with (Shephard and Pookulangara, 2023), challenging the incentive to remanufacture. However, Walter Stahel notes, wasted material is also wasted money (Stahel, 2019), meaning that increasingly industry stakeholders are looking to exploit the potential economic benefit of 'remanufacture' or 'upcycling'. This presents an opportunity to leverage these economic factors for the environmental benefits of circular economy strategies such as remanufacturing.

This research examines remanufacturing as a strategy that can revalorise pre-consumer waste by making new products that have the potential to offset new production. Remanufacturing is framed as an emerging approach to production, using a series of linked processes that use a degree of process-level industrialization to attain scale (Dissanayake & Sinha, 2015; Wen-hui et al., 2011). Using collaboration as a strategy, this research calls for co-design and co-development in response to issues of shared concern. Johnson (2020) highlights Knowledge Exchange (KE), or Knowledge Transfer, as a key output of academic research, which can offer greater insights into the viability of remanufacture as a design strategy in a scalable setting. While there is extensive research on the value and potential of circular initiatives in fashion production, there is limited literature on what the implementation of these initiatives looks like and how they can be successfully scaled. This paper unpacks some of the opportunities that arise through an increased focus on circularity while highlighting how KE can offer a step change towards embedded change.

Methodology

To explore scalable solutions, each designer/researcher, referred to as a re-designer, collaborated with an industry partner to reintegrate pre-consumer waste, such as excess stock and product fallout, into the production line. Both pilot projects used action research methodology, allowing the re-designers to work from within the process through iterative cycles of testing, reflecting, and refining (Somekh, 2003). This paper examines these projects using qualitative data gathered from notes, observations, interviews and questionnaires, to compare, divide them into phases and identify characteristics that can facilitate remanufacturing in large-scale industry settings.

The case studies presented clarify tactics and key skills necessary to implement remanufacturing within the context of a large fashion brand and a garment factory. They highlight strategies for moving circularity from theory to practice and underline the importance of collaboration and knowledge exchange in advancing and replicating these efforts. Developing circular products requires rethinking business models from design through remanufacturing to supply chain and marketing (Charter, 2019).

Industry Collaborators

The research projects are collaborations between large industry partners and the authors/re-designers who bring their dual experiences in SME fashion businesses and academic research. The re-designers are positioned as the coordinators of the remanufacturing process within the industry collaboration and facilitators of knowledge exchange that can build capacity within the stakeholder teams (Dan & Østergaard, 2021). It frames remanufacturing as a series of processes that include the redesigning of garments as well as the coordination of material selection and production. This requires a foundational understanding of the fashion production system, through the SME fashion sector, that spans the product development, manufacturing and retail phase of garments. The redesign process aimed to develop garments suitable for resale without undermining the brand's or manufacturer's existing product lines (Dissanayake & Sinha, 2015).

Case study 1 is a collaboration between Borcherdt's research project and the co-located brand Country Road (CR), a well-established mid-market lifestyle brand with an Australian retail network of 150 stores (Payne, 2021). The collaboration inserted Borcherdt as the re-designer into the CR organisation, with the aim of building capacity within the brand for future replication.

Through the collaboration, a series of garments were selected from previous season stock, redesigned and then recirculated back into CR's stores. This project pilots remanufacturing

within the brand's supply chain and leverages CR's Corporate Social Responsibility (CSR) policy that includes circularity as one of its pillars. The objectives of the project were co-designed with the support of a core team at CR, setting out to explore a range of remanufacturing processes across diverse garment types. The outcomes formed a capsule collection of six styles, across 550 units, that range from minimal interventions such as overdyeing and placement printing, to high-cost processes such as dis/reassembly and laser cutting leather garments. The stock was selected from the brand's outlet store, requiring the development of stock flow overviews to facilitate knowledge sharing between the brand's outlet, technical and design teams with the re-designer. The outlet store represents the end of the line in CR's linear supply chain, where excess stock is channelled following various cycles of discounting in their primary retail stores. The selection criteria that were established included identifiable barriers preventing sell-through, high discount rates of >50%, and potential alignment to other products that would be in CR's retail stores contemporaneously.

Since the brand relies primarily on an extensive offshore manufacturing network, the project required establishing new onshore supplier relationships. This posed the challenge of finding manufacturers that are large enough to accommodate their commercial requirements while also having the flexibility to handle the complexity of new production processes. During this process, a large-scale factory that did have experience with remanufacturing withdrew since their set-up as a knitwear manufacturer made them unable to accommodate structured woven garments. A smaller factory was recruited, that had the skillset for handling the complexity of dis/reassembly. The approach undertaken by the re-designer focused on the individual garment's qualities, addressing barriers that prevented sell-through during the retail phase, including colour, functionality and fit (see examples in Figures 1, 2 and 3). This process involved the re-designer developing core ideas through prototypes and the brand's design team making adjustments. This ensured the aesthetic integrity of the brand and developed technical remanufacturing processes that would align with available manufacturing options. This close collaboration positions the re-designer as a facilitator between these parameters.



Figure 1: Case Study 1 remanufacturing outcomes. © Country Road.



Figure 2: Case Study 1 remanufacturing outcomes. © Country Road.



Figure 3: Case Study 1 remanufacturing outcomes. © Country Road.

Products developed

The six garments were redesigned and placed back into stores as a capsule collection with an additional two accessories produced from the fringe offcuts. The prices test a range of strategies, from just recuperating the remanufacturing costs (Figure 1), to adding a small profit margin (Figure 2) or reverting to the original full retail price (Figure 3). The close collaboration with the manufacturers allowed for insights into each remanufacturing process in terms of planning and costing. The knowledge exchange with the manufacturers took place via in-person meetings at the factory that focused on identifying steps that create complications during production and co-designing solutions that can simplify the process. These solutions included slightly amending the garment design and making allowances for minor variations between garments. The product launch was accompanied by a marketing campaign that highlighted the remanufacturing process and featured the local manufacturers involved in the project, linking it to other circular initiatives and the brand's CSR policy. Sales data revealed that the remanufactured products met benchmarks in line with conventionally produced garments, suggesting that the identified barriers had been addressed through the interventions. A key deliverable of this pilot project is a summary report for CR, making recommendations for future implementation, such as upstream planning for dyeing, providing pricing templates and a 'costing menu' for a range of remanufacturing interventions.

Case study 2 is a collaborative project with a Sri Lankan Garment Manufacturer and author/re-designer Child, consisting of five factories specialising in different mid-market product ranges, with 90% of its sales being in Europe (Hameed, 2020). Identifying a suitable manufacturing facility took up much of the early negotiations with this pilot test. An initial factory in Sri Lanka was identified and agreed to support the project, however, due to the scale of production, it became clear that they were unable to offer the flexibility required to reintroduce the product back into the facility. Subsequently, a smaller facility was located through contacts with the first facility, offering a scale of production that produced volumes of fallout or overproduction, with greater flexibility to respond to the complexity of working with product for dis/reassembly. Through initial discussions with the manufacturing facility, a range of whole product fallout was identified. This consisted of both, A & B grade with the addition of overproduction. It was clear from early discussions that the manufacturing facility had not engaged with this product resource before. McQuillan (2019) states that the lack of information about waste reduction through design interventions in the industry is primarily due to the scarcity of attempts and the opacity of the industry (p.200), and this could highlight why manufacturers are unsure how to proceed with this resource.

The pilot aimed to understand the opportunities to reutilize this product for re-sale through re-design strategies. The re-designer took on an initial design leadership role but adopted a co-design philosophy by encouraging the facility's expertise in manufacturing and the products to feed into the design development process. The aim was to produce 100 units consisting of T-shirts suitable for re-sale in the UK market. The main collaborative exercise involved proposing methods to de-label and remanufacture while demonstrating enough change in the design to allow for rebranding and re-sale. Once usable products were identified, a technical sheet was developed to outline the proposed designs. This was coupled with a two-way dialogue to reassure the manufacturers that changes could take place to the design and process, as flexibility is one of the key drivers of this project. Ensuring that the manufacturing facility had the autonomy to inform design decisions was

crucial to the success of this pilot test. Throughout, this close collaboration strategy required high levels of two-way communication with the production manager to enable a flexible and responsive design strategy.

Products developed

The t-shirts were made using WP factory fallout in their entirety (Figures 4 and 5). This was the first time the manufacturing facility had engaged with this product resource, so both the re-designer and manufacturer had to respond to challenges as they arose. This meant that the insights gained from this pilot test would highlight the barriers that other brands or manufacturers would be likely to face if this was systemically embedded into the supply chain. For this pilot test, the outcomes were developed to understand and evidence the proof-of-concept, while the end consumer was outside the scope of this project. Waste was produced in the remanufacturing process, however, the volume of overall waste was reduced while offering opportunities to develop novel product lines. If items are going to be produced that have a resale value, more interventions and frameworks may be needed to ensure the balance around proof-of-concept and commercial appeal while aligning with a specified customer market.



Figure 4: Case Study 2 remanufacturing outcomes. © Child.



Figure 5: Case Study 2 remanufacturing outcomes. © Child.

Analysis & Insights

The live pilot tests conducted for this research allowed for inferences to be drawn from the specific brand or manufacturer, while collectively pooling this information and highlighting shared parameters outside the design sphere that evidence the complex nature of design in this field. Figure 6 synthesizes the phases of the remanufacturing process across the two Case Studies, highlighting the scaling tactics and the key knowledge areas that stakeholders bring to effective remanufacturing collaborations.

Overall, these collaborative pilot tests have established that to engage with methods of scale for remanufacture, the following parameters need to be considered alongside the design interventions:

- **Key skills and stakeholder alignment** need to be identified in collaborations between brands, factories and re-designers, including areas of expertise and scale. As the framework of the circular economy as a connected system has been brought to the fore by organisations such as the Ellen MacArthur Foundation, designers are increasingly understanding the need to consider the whole lifecycle while acknowledging business models, services and systems (Hall and Earley, 2019). In this instance using designers/researchers with an SME background brings a skill set that has a broader understanding of the whole supply chain, allowing for systems thinking and frameworks beyond design

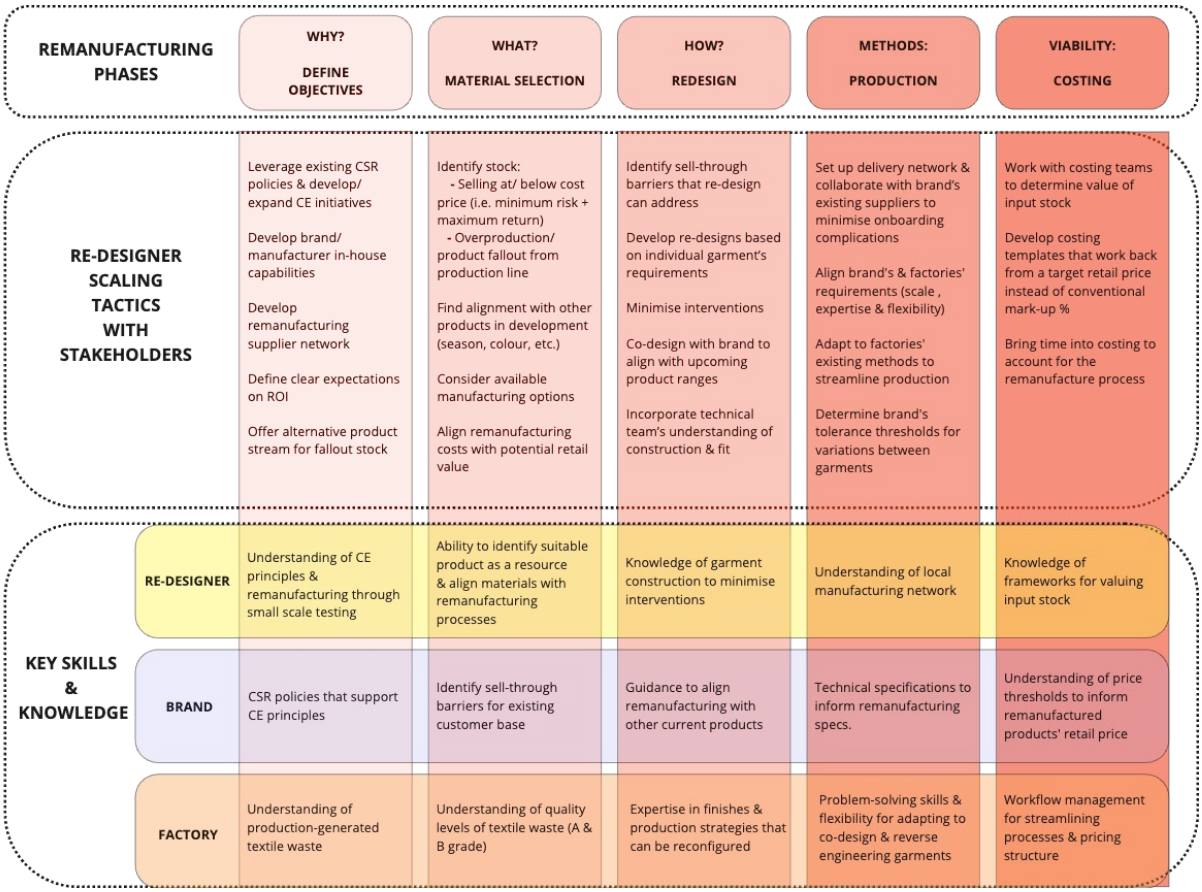


Figure 6: Scaling tactics by stakeholders within remanufacturing phases

interventions that facilitate working with remanufacture at scale.

- **Defining clear objectives** shapes all later stages of the remanufacturing process through risk tolerance, the scope of investment and expected returns, along with any design parameters necessary within the re-designed product range.

- **Material selection** requires criteria that are aligned to the brand's context and manufacturers' capabilities to help identify stock suitable to be recirculated.

- **New information flows**, such as for stock flow management, are required for the tracking of stock in real-time, identifying why it may not be selling and determining how to intervene through remanufacturing. This requires new reverse logistics and information flows, including input from retail and outlet staff back to the design and technical teams. In the manufacturing facility, reverse logistics is less necessary as the product is held on-site, but information flows are needed to ensure designers have access to the volumes of whole products available for re-design.

- **Flexibility** is required from the re-designer, the brands and the manufacturers to adapt to new processes. Manufacturers need to have the flexibility to adapt conventional factory workflows to accommodate the disassembly process. The re-designer needs to adapt to a range of brand and manufacturer parameters by developing responsive solutions that draw from fashion design practice while thinking about scalability. This role is characterised by the fluid shifting between external consultant, facilitator between entities and co-designing alongside existing teams.

- **Context-specific redesign** solutions are required for aligning remanufactured with conventionally produced garments, not

only for each brand but for each garment. This allows for the remanufactured products to be recirculated via the existing retail channels of a brand or novel ranges, which potentially offsets new production.

- **Costing** of remanufactured garments differs from conventional production as the valuation of existing garments is more subjective than raw materials. This requires new costing frameworks that depart from conventional markups, such as working back from target retail prices. This also needs to factor increased time into the costing framework to account for the deconstruction and remanufacture time.

- **Effective communication** is critical for the knowledge/information flows between the brand and manufacturers and is also foundational to the role of the re-designer as facilitator. These projects used a wide range of methods, including in-person and online meetings, summary emails with detailed instructions, questionnaires, interviews, technical sheets, mood boards, and WhatsApp to facilitate the two-way process involved in KE (Ahmed et al. 2022). Other examples of these are increasingly seen in the sphere across academia and industry, such as BFFT and the European Commission Horizon 2020, evidencing collaborative approaches of research with impact.

Despite design outputs, market levels and industry collaborators being from different global contexts, the shared insights highlight the potential frameworks that could support wider uptake and serve as a reminder of the importance of industry collaborations in scaling methods of remanufacture.

Conclusions

This study has demonstrated how strategic knowledge exchange through co-designing pilot projects with industry can increase capabilities for remanufacturing. It draws from dual perspectives in methods of remanufacture to understand the interventions needed to support scale through fostering knowledge exchange with the partnering companies.
The pilot tests looked to facilitate KE in a 'live' industry setting, understanding that close collaboration and co-designing build capacity within industry partners and are critical for both scaling and working towards remanufacture as a transition strategy for the circular economy. Insights from this enable a greater understanding of the parameters outside of design to support the success of remanufacture as a design strategy. This work is the first endeavour to bring together dual perspectives to support designers and researchers navigating this complex design space where re-designers are becoming facilitators within brands and manufacturers. This paper highlights the importance of KE in developing systems that can be scaled. To this end, we provide a series of tactics drawn from industry collaborations, serving as examples of actionable knowledge for those wanting to engage in scalable solutions for remanufacture. We envision future efforts to expand on this scale, leading to further integration of remanufacturing by brands and manufacturers as a transition strategy to the CE, whilst remembering that offsetting new production with remanufactured garments is critical for this process to have impact instead of being an add-on (Cooper & Gutowski, 2017; Fortuna & Diyamandoglu, 2017; Woolridge et al., 2006).

References

Agrawal, S, Singh, RK & Murtaza, Q. (2015). A literature review and perspectives in reverse logistics, Resources, Conservation and Recycling, vol. 97, pp. 76–92. https://doi.org/10.1016/j.resconrec.2015.02.009

Ahmed, F., Muhammad., T., Ali, S., & Enam, R. (2022). Strengthening the Bridge Between Academic and the Industry Through the Academia-Industry Collaboration Plan Design Model. Frontiers in Psychology. 13. 875940. [online] https://doi.org/10.3389/fpsyg.2022.875940

Anguelov, N. (2021). The sustainable fashion quest innovations in business and policy. Productivity Press. https://doi.org/10.4324/9781003153344

Charter, M. (2018). Designing for the circular economy. Routledge.

Child, E. (2020). What is Fallout Fashion? In: Research Circles; A collection of essays and interviews by researchers at Centre for Circular Design, Ed. Earley, R. (2020), University of Arts London.

Cooper, D. R. & Gutowski, T. G. (2017). The Environmental Impacts of Reuse: A Review. Journal of Industrial Ecology, 21(1), 38–56. https://doi.org/10.1111/jiec.12388

Dan, M. C. & Østergaard, T. (2021). Circular fashion: the new roles of designers in organizations rransitioning to a Circular Economy. The Design Journal, 24(6), 1001–1021. https://doi.org/10.1080/14606925.2021.1936748

Dissanayake, G. & Sinha, P. (2015). An examination of the product development process for fashion remanufacturing. Resources, Conservation and Recycling, 104, 94–102. https://doi.org/10.1016/j.resconrec.2015.09.008

Ellen MacArthur Foundation. (2017). A new textiles economy: redesigning fashion's future. Ellen MacArthur Foundation [Online]. Available at: https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept

Ellen Macarthur foundation. (2021). Circular Design for fashion. Ellen Macarthur Foundation Publishing.

Fortuna, L. M. & Diyamandoglu, V. (2017). Optimization of greenhouse gas emissions in second-hand consumer product recovery through reuse platforms. Waste Management, 66, 178–189. https://doi.org/10.1016/j.wasman.2017.04.032

Hall C. & Earley, R. (2019) Divide, Switch, Blend. Exploring two hats for industry entrepreneurship and academic practice-based textile design research, The Design Journal, 22:sup1, 19-35, DOI: 10.1080/14606925.2019.1595848

Hameed, S. (2020). Interview with Emjayi Manufacturing. Interview by Emmeline Child.

Johnson, M. T. (2020). The knowledge exchange framework: understanding parameters and the capacity for transformative engagement. Studies in Higher Education, 1–18. https://doi.org/10.1080/03075079.2020.1735333

Keßler, L., Matlin, S. A., & Kümmerer, K. (2021). The Contribution of Material Circularity to Sustainability – Recycling & Re-Use of Textiles. Current Opinion in Green and Sustainable Chemistry, 32, 100535. https://doi.org/10.1016/j.cogsc.2021.100535

McQuillan, H. (2019). Zero Waste Design Thinking. Licentiate Thesis. University of Borås. Available at: http://hb.diva-portal.org/smash/get/diva2:1478307/FULLTEXT01.pdf

Global Fashion Agenda: prosperity vs. growth. (2021). Https://Globalfashionagenda.Org/Resources-News/Video-Library/. https://youtu.be/vlj2cw2nq78

Payne, A. (2021). Designing fashion's future: Present practice and tactics for sustainable change (Payne, Ed.). Bloomsbury Publishing USA. https://doi.org/10.5040/9781350092495.ch-003

Pucker, K. (2023, 20. December). How Fashion's Business Model Is Wasteful by Design | BoF. Business of Fashion. https://www.businessoffashion.com/opinions/sustainability/fashion-waste-business-model-design/?utm_source=newsletter_sustainability&utm_medium=email&utm_campaign=Sustainability_221223&utm_content=intro

Runnel, A., Raihan, K., Castle, N., Oja, D. & Bhuiya., H. (2017). White paper: Digitally enhanced circular economy within global fashion supply chains - reverse resources. https://reverseresources.net/white-paper-digitally-enhanced-circular-economy-within-global-fashion-supply-chains/

Somekh, B. (2003). Theory and Passion in Action Research. Educational Action Research, 11(2), 247–264. https://doi.org/10.1080/09650790300200220

Stahel, W. R. (2019). The circular economy : a user's guide. Routledge, Taylor & Francis Group. https://doi.org/10.4324/9780429259203

Wen-hui, X., Dian-yan, J. & Yu-ying, H. (2011). The remanufacturing reverse logistics management based on Closed-loop supply chain management processes. Procedia Environmental Sciences, 11, 351–354. https://doi.org/10.1016/j.proenv.2011.12.056

Woolridge, A. C., Ward, G. D., Phillips, P. S., Collins, M. & Gandy, S. (2006). Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: An UK energy saving perspective. Resources, Conservation and Recycling, 46(1), 94–103. https://doi.org/10.1016/j.resconrec.2005.06.006

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Testing methods of remanufacture of pre-consumer textiles in scalable environments

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Keywords: Textiles; Remanufacture; Upscaling; Pre-consumer; Circular Economy.

Abstract: Despite a growing response by multiple stakeholders to address waste issues in the industry, the consumer appetite for newness and the speed and agility of the mass manufacturing system encourages overconsumption Currently, less than 1% of the material used to produce clothing is recycled into new clothing.

As Walter Stahel notes, wasted material is also wasted money, meaning that increasingly industry stakeholders are looking to exploit the potential economic benefit of 'remanufacture' or 'upcycling'. While many micro-businesses are utilising upcycling on a small scale, the impact on the overall resource wastage is minimal.

This paper explores how working in a factory environment can give greater insight into the challenges of working with remanufacture for scale. It will support a greater understanding of the barriers that are impeding the widespread adoption of working with Whole Product (WP) fallout on a production line, while helping to identify the frameworks needed to support methods of WP Remanufacture (WPRem) within the linear commercial environment.

Introduction

To date, many upcycling/remanufacturing strategies have been led by small-scale designers. Understanding how working with WP fallout, (garments that fail quality control and overproduction) within a scaled manufacturing environment is theoretical; According to Kerr and Landry (2017), the next step is to examine systems of scale to have a greater influence in the sector. To comprehend the obstacles to working towards scale, it is crucial to test these concepts in a modern industrial setting.

Stahel (2019) confirms that unless a practical solution is identified within the circular economy, the science will be ignored, underscoring what he describes as an "honest quest for holistic solutions" (Stahel, 2019, p.87). Developing effective frameworks and identify practical solutions will be key in gaining industry and consumer take-up. This fallout field test will identify the current barriers in place that hinder the development of remanufacturing in the textile supply chain. It will support a greater understanding of the shift manufacturers will have to take to embed this "new economy" (Stahel, 2019). The aim is to evidence the possibilities of remanufacturing for Whole Product Remanufacture (WPRem).

Product-level upcycling/remanufacture utilises product already in the system with some academics suggesting that it eliminates the need for a new product (Szaky, 2014), reducing the use of raw materials (material efficiency) and industrial energy for production, ultimately reducing greenhouse gas emissions (Sung et al., 2017). The potential social, economic, and environmental benefits of remanufacture have led some authors to describe this as a triple win (All-Party Parliamentary Sustainable Resource Group 2014; Sinha et al., 2016). This validates the reason to explore remanufacture as a method in fashion.

Using design and remanufacture offers a way for brands to rework WPs consisting of overproduction and A and B-grade garments (fallout). This product was identified in discussions with the manufacturer, with the potential for high-priced remarketing for commercial re-sale (Stahel, 2019).

This paper seeks to produce a run of remanufactured garments utilising WP fallout from the production line while testing out in a scalable setting to understand the potential to scale these techniques for commercial production.

Methodology

The methods in this research are grounded from insights by previous small-scale tests by the researcher (Child, 2021) using making as the primary method to surface insights. This research goes beyond making as a singular activity and uses a bricolage of methods, described as a multi-methodological approach to inquiry (Rogers, 2012; Hall, 2021). This approach looks to draw from both the commercialisation of industry and the intellectual tradition of academia (Fallman, 2008), to seek solutions from both perspectives. Many designers have used this method in textile design, noting this approach allows the flexibility to draw on the methods needed at a particular point, as Hall (2020) states in an active response to the needs of the designer.

The aim of this project was to ensure that the manufacturing facility has agency to feed in, and input in decision-making, to ensure that their expert perspective is considered. LIFE ECAP (2019) highlights how industry co-operation is key, as experts hold knowledge along the supply chain. Working collaboratively combines that knowledge to achieve the best solutions under the current constraints and allows for greater Knowledge Exchange (KE) to take place.

This test focused on t-shirts as a material source. By focusing on a specific garment, the analysis of the method can be developed without a focus on other external design constraints that might arise when mixing garment types. The aim is to utilise as much of the existing products as possible, with little to no virgin material.

The Commercial Facility

Emjay International manufacturing facility in Sri Lanka was selected to carry out the tests. It consists of five factories specialising in different product ranges, with 90% of its market being in Europe (Hameed, 2020).

The garment industry is Sri Lanka's biggest manufacturing sector, mainly producing western fashion (Evans and Park, 2017). Despite this, there are no textile recycling facilities in the country to deal with the waste industry generates (Ibid, p. 8) meaning that high quantities of fallout are finding themselves in waste streams.

Process

Early discussions highlighted that the manufacturing facility had not engaged with this product resource before. McQuillan (2019) states that the lack of information about waste reduction through design interventions in the industry is primarily due to the scarcity of attempts and the opacity of industry (p.200), and this could highlight why manufacturers are unsure how to proceed.

The WP garments, destined for remanufacture followed the existing production line as the virgin garment production. Payne (2015) highlights that production lines have the potential to offer flexibility due to manual automation, suggesting that new systems may not hinder progression. This field test will enable an understanding of whether WPRem can work within the existing production line, offering a step change towards greater circularity in the linear fashion supply chain. If a viable product line can be achieved, then it could make a case for industry uptake.

The first stage was to have discussions with the manufactures and identify WP Fallout on their production line (Figure 1&2). Once this was identified a process of design could take place, utilising the design strategy for remanufacture developed in earlier small-scale tests (Figure 3).



Figure 1: Fallout t-shirts from the manufacturing line (white).



Figure 2: Fallout t-shirts from the manufacturing line (black).

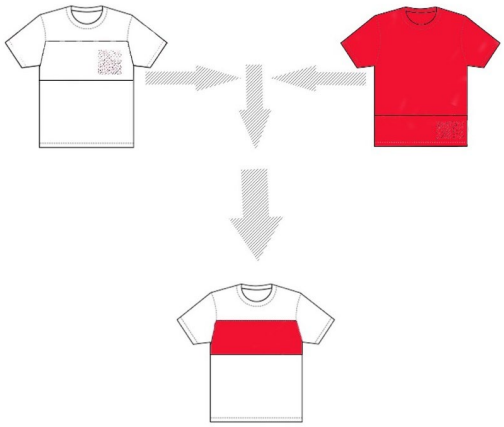


Figure 3: Design strategy for remanufacture.

A technical sheet was developed to outline the proposed designs (Figure 4). This was coupled with a two-way dialogue to reassure the manufacturers that changes could take place. Ensuring that the manufacturing facility had the autonomy to inform design decisions was crucial to the success of this field test as Smyth and Holian (2008) highlight, an insider understands how things work in reality. The designs were kept simple to allow genuine barriers to arise without additional design complications to consider.

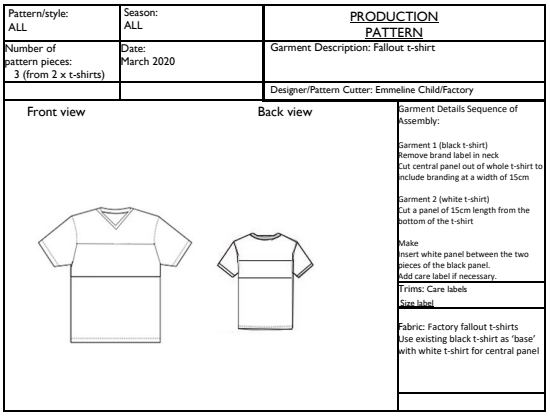


Figure 4: Technical sheet outlining product to remanufacture.

The test took place on location at the manufacturing facility in Sri Lanka, while the designer/researcher was in the UK. When conducting research inside the factory there are many advantages, including the "speed at which breakthroughs can take place" (McQuillan, 2019, p.74). However, in reality, the industry relies on distanced negotiations between the designer and the brand. The project and process were in line with the realities of how the fashion industry operates, whereby agents work in isolation. This gave greater insight into some of the issues and challenges faced when communication is from different perspectives, while helping to gain an understanding of the realities of WPRem in this context. However, drawbacks included nuances and challenges that could be worked through when face-to-face but could not be observed or referenced from a distance. Subtle understandings and communications could be misinterpreted. This reinforces why the industry relies on technical sheets and suggests why rigid boundaries are put in place.

Barriers

Getting the manufacturer to return the fallout product to the linear production line rather than constructing smaller loops outside of the current supply chain was an early obstacle to overcome. This evidences the challenges of working with this product in the existing set up where LP strategies hinder the flexibility of shifts on the production line.

Skills Relied on for Success

Communication, and positive reinforcement throughout the product development stage was vital. Throughout the development of the

product samples, constant communication occurred via WhatsApp chat and email. Communication was also crucial in embedding the philosophy of remanufacture. Initial samples developed by the manufactures were more cost-effective (Figure 5) yet lacked the finished design aesthetic for commercial appeal. This highlighted that flexibility was important to allow methods to surface that would work in the factory context, however it reinforces the need for a designer in the process.



Figure 5: Initial sample remanufactured.

Changing Mindsets

It was difficult to get the manufacturers to think beyond their typical standardised approach. Once accomplished, though, they were open with suggestions. At every stage, two-way discussions took place around the relevant process, while alternative options were explored. This was positive experience, as this relationship allowed this research to flex in response to the findings. Reed *et al.* (2014) reinforce that engagement is key and that, by respecting local knowledge, greater KE can take place. McQuillan highlights that when hierarchies are broken down, greater design success can be achieved (2019, p.155), reinforcing the need to democratise the relationships. Ahmed *et al.* (2022) (Figure 6) outline the structures to ensure good relationships between the two parties, underscoring the need for this to be a two-way knowledge transfer.

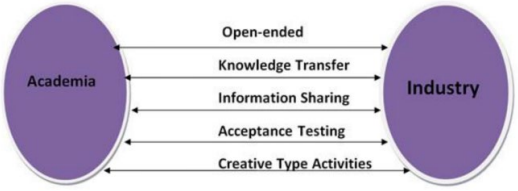


Figure 6: Strategic planning structure for communicating between academia and industry (Ahmed et al., 2022).

The WPRem Products

The developed t-shirts were made using WP factory fallout in their entirety (Figure 7&8). Evidencing proof of concept for this product resource in a factory setting.



Figure 7: Remanufactured t-shirt developed from fallout fashion.



Figure 8: Flexible t-shirt design from fallout fashion.

To capture the decisions made, a Process Diagram for Whole Product Fallout (Figure 9) was developed in response to insights while working with the manufacturing facility, through interviews and the samples developed at each stage. By allowing two-way dialogues to take place, a greater understanding of the resource and its destination routes was achieved, while gaining a handle on the systems in the manufacturer has enabled clarification on textile finishes that could further complement and diversify the range. Clear infographics were developed so that manufacturing facilities and designers could work together to reutilise this product resource.

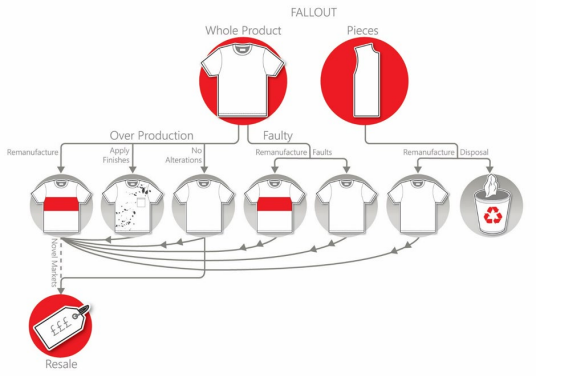


Figure 9: Process diagram for whole product fallout.

Reflection on the Process

The Industry Perspective

Factories measure their productivity by time, and the re-design process more than doubles with the deconstruction process (Hameed, 2020). This makes it challenging to make the process financially viable. Hameed states that products usually take 6-7 minutes to go through the production line, but this remanufacture method takes 20-30 minutes (Ibid). Hameed highlights that this increase in time would be the biggest challenge to overcome and states that manufacturers would need to view remanufacture as a separate business opportunity. If viewed on productivity alone, the remanufacture process does not work. This observation underscores the importance of engaging all parties in this process to highlight barriers outside the design practice of the researcher. A revised pricing structure above the usual tight margins would be needed to make this product line financially viable.

Hameed also observes that he was concerned about the variations and, therefore, quality control of the product range. He states that "the t-shirts produced for you were closely monitored" but goes on to state that quality could be an issue if working on a large scale due to the shade and measurement differences (Hameed, 2020). This comment points again to the ingrained mindsets of all agents along the supply chain and the need for greater flexibility and less standardisation in product lines while ensuring that the overall quality of make is maintained.

The Academic Perspective

There are inherent beliefs held by the manufacturers and dictated by the brands about what defines a successful product. Traditionally, garments that fall outside of this standardisation ultimately end up as fallout. A shift in both user and industry understanding of what successful products are, is important. This does not mean having lower standards, but a move away from standardisation and uniformity would help to achieve greater efficiency on the production line.

By paying a realistic price for the product, the manufacturers have the time to create more flexible strategies. Despite this remanufactured product being inefficient, if the correct (and realistic) pricing structure is put in place with a realistic overhead cost for this product line, then there is potential for this product range to work commercially. However, the impact and challenges around the marketing of this at a higher price point are to be explored.

It is worth noting that the variables and flexibility, without strong communication or frameworks, could create products with little resale value. This could be further complicated with products outside of a basic t-shirt. If not managed correctly, this has the potential to add to the issues of waste in the supply chain and highlights the need for specialised training or designers overseeing this novel product range.

The industry is notoriously known for its linear (and fast) business model (Pedersen *et al.,* 2019). In contrast, this novel system slows the flow of material through the facility compared to the usual linear efficiency goals. This has wider cost (and therefore uptake) implications, which could explain why investment in disassembly areas has not become common

practice. The systems in place and the emerging new systems continue to conflict with each other. The scale of the systems and complexity in the industry intimidates those trying to change it. Despite working with a flexible manufacturing facility, there were concerns about how this pilot could be scaled up further with the current time pressures (Hameed, 2020), highlighting that these mindsets take precedence over the utilisation of this product resource.
An integrated system is always better and more cost-effective than non-integrated (Xiong *et al.,* 2013), yet there are challenges to how this is embedded to keep it commercially viable. Collaborative take-up will be essential in gaining momentum and ensuring that this product can be re-utilised, as embedding systems will require both the brands and the manufacturers engaged to seek meaningful solutions. Having an integrated disassembly area within the CMT facility would enable greater material flows across all areas within the facility, creating opportunities to remanufacture with this fallout resource (Figure 10).

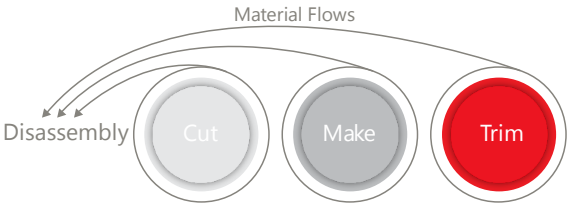


Figure 10: Material flows across the CMT facility.

A shift needs to take place, from a myopic view where speed and efficiency rates are directly linked to one where volumes of material processed and resource efficiency are connected. When this systemic viewpoint shifts, then greater developments can become more widespread. As the theory of resource efficiency WPRem works, it is the practical application and investment that has slowed its adoption.

Conclusions

The purpose of this study was to test out the capacity of working with WP fallout in a factory setting working towards scalable solutions. This pilot test delivered t-shirts that utilised 100% factory fallout (overproduction or A&B Grade fallout). This evidenced the proof-of-concept for WPRem.
The pilot test and reflections from both the industry and academic perspectives highlighted the complexities faced when a product slows down the production line. While the tests evidenced that products can be made in scalable environments, the interviews highlighted logistics barriers and time pressures that made this less viable. To successfully design for WPRem in scalable settings, further collaborative buy-in needs to take place.

Identifying and profiling the hidden value in this waste resource has enabled further discourse with the manufacturing facility around other possible opportunities with this resource. By giving the manufacturer agency and flexibility over the product, deeper collaborative partnership ensued. There was a turning point in this process from the more usual client/customer relationship to a connection where two-way dialogue in the decision-making process took place. This shift meant that brainstorming and problem-solving took place together, rather than being locked in by the designer or brand. Each agent along the supply chain needs to be able to feed information back and forth to enable greater streamlining. The expertise and knowledge held by each agent have value in creating greater resource efficiency. This field test has demonstrated that this free-flow discussion can still be achieved remotely. The test evidences the need to slow down and allow discussion and solutions to be found, pooling expertise from the different parties.
The aim was not to test the commerciality of the product but to explore the realities of working with the product in a scalable setting. This pilot study has enabled the development of two process diagrams that bring further illumination to the process of WPRem in a manufacturing facility.

Acknowledgments

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References

Ahmed, F., Fattani, M. T., Ali, S. R., & Enam, R. N. (2022). Strengthening the Bridge Between Academic and the Industry Through the Academia-Industry Collaboration Plan

Design Model. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.875940

All-Party Parliamentary Sustainable Resource Group (2014) *Triple win: the economic, social and environmental case for remanufacturing* [online]. Available at: https://www.policyconnect.org.uk/apsrg/sites/site_apsrg/files/report/535/fieldreportdownload/triplewin-thesocialeconomicandenvironmentalcaseforremanufacturing.pdf .

Anguelov, N. (2021) *The Sustainable Fashion Quest*; *Innovations in Business and Policy*. Oxford: Routledge.

Child, (2020) What is Fallout Fashion? In: *Research Circles*; *A collection of essays and interviews by researchers at Centre for Circular Design*, Ed. Earley, R. (2020), University of Arts London.

Ellen MacArthur Foundation (2017) A new textiles economy: redesigning fashion's future. *Ellen MacArthur Foundation* [Online]. Available at: https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept.

Ellen Macarthur Foundation. (2021) *Circular Design for Fashion*. Ellen Macarthur Foundation Publishing: Cowes.

Evans, S, Park, C (2017) The Trans Textile Project Report. Centre for Industrial Sustainability [online]. Available at: https://www.ifm.eng.cam.ac.uk/uploads/Resources/TransTextile_Report.pdf

Fallman, D. (2008) 'The Interaction Design Research Triangle of Design Practice, Design Studies, and Design Exploration', *Design Issues*, 24(3), pp. 4–18. doi: 10.1162/desi.2008.24.3.4.

Hall, C. (2021) Design for Recycling Knitwear: a framework for sorting, blending and cascading in the mechanical textile recycling industry. Ph.D. Thesis. University of the Arts London. Available at: https://www.cathrynannekahall.co.uk/_files/ugd/eb22a2_ee68275805c64f718fe2cde4d9526b39.pdf

Hameed, S. (2020) Interview with Emjayi Manufacturing. Interview by Emmeline Child.

Han, S., Tyler, D. and Apeagyei, P. (2015) Upcycling as a Design Strategy for Product Lifetime Optimisation and Societal Change. *In: PLATE (Product Lifetimes And The Environment) Conference, 2015.* Nottingham. https://www.researchgate.net/publication/293487790_Upcycling_as_a_design_strategy_for_product_lifetime_optimisation_and_societal_change

Hirscher, A-L., Niinimäki, K. and Armstrong, C. (2018) Social Manufacturing in the Fashion sector: New value creation through alternative design strategies? *Journal of Cleaner Production*. 172, pp.4544-4554. https://doi.org/10.1016/j.jclepro.2017.11.020

Keßler, L. Matlin, S. Kümmerer, K, (2021) The contribution of material circularity to sustainability—Recycling and reuse of textiles. *In: Current Opinion in Green and Sustainable Chemistry*. Volume 32. [online] Available at: https://doi.org/10.1016/j.cogsc.2021.100535.

Kerr, J. and Landry, J. (2017) Pulse of the Fashion Industry, 2017. *Global Fashion Agenda: Boston* [online]. Available at: https://www.globalfashionagenda.com/publications-and-policy/pulse-of-the-industry/

LIFE ECAP (2019) European Sustainable Clothing Action Plan LIFE14 ENV/UK/000257, [online] Available at: http://www.ecap.eu.com/

Mazzarella, F (2022) We must co-create to decolonise fashion. UAL [Online] Available at: https://ualresearchonline.arts.ac.uk/id/eprint/18955/1/we-must-co-create-to-decolonise-fashion.pdf

McQuillan, H. (2019) Zero Waste Design Thinking. Licentiate Thesis. University of Borås. Available at: http://hb.diva-portal.org/smash/get/diva2:1478307/FULLTEXT01.pdf

Payne, A. (2015) Open- and Closed-loop Recycling of Textile and Apparel Products. In Muthu, S. (ed.) *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*. United Kingdom: Woodhead Publishing, pp.103-123. https://doi.org/10.1016/B978-0-08-100169-1.00006-X

Pedersen, E.R.G., Earley, R. and Andersen K.R. (2019) From singular to plural: exploring organisational complexities and circular business model design. *Journal of Fashion Marketing and Management.* 23 (3), pp.308-326. https://doi.org/10.1108/JFMM-04-2018-0062

Reed, M.S., Stringer, L.C., Fazey, L. Evely, A.C., Kruijsen, J.H.J. (2014) Five principles for the practice of knowledge exchange in environmental management, *Journal of Environmental Management*. Volume 146, pp.337-345, Available at: https://doi.org/10.1016/j.jenvman.2014.07.021.

Rogers, M. (2012) 'Contextualizing Theories and Practices of Bricolage Research', *The Qualitative Report*, 17(48), pp. 1–17. https://doi.org/10.46743/2160-3715/2012.1704

Sinha, P., Muthu, S. S. and Dissanayake, G. (2016) *Remanufactured Fashion*. Singapore: Springer. DOI:10.1007/978-981-10-0297-7

Smyth, A and Holian, R (2008) Credibility issues in research from within organisations. in. *Researching Education from the Inside*. Routledge. ISBN 9780203932353

Stahel, W.R. (2019) *The Circular Economy: A User's Guide*. Abingdon: Routledge.

Sung, K., Cooper, T., Painter-Morland, M., Oxborrow, L., Ramanathan, U. and Singh, J. (2017) Multi-stakeholder perspectives on the challenges and success factors for scaling-up upcycling businesses in fashion industry in the UK. *In: The 18th European Roundtable on Sustainable Consumption and Production Towards a Greener Challenge & Evolution in the Framework of the Circular Economy Conference, 2017*. Greece. Available at: https://www.researchgate.net/publication/320702213_Multi-stakeholder_perspectives_on_the_challenges_and_success_factors_for_scaling_up_upcycling_businesses_in_fashion_industry_in_the_UK

Szaky, T. (2014) *Outsmart Waste: The Modern Idea of Garbage and How to Think Our Way Out of It.* San Francisco: Berrett Koehler Publishing.

Vuletich, C. (2014) 'Sustainable Textile Design as bricolage', in Proceedings of In a Reverse Fashion: A Critical Agenda for Sustainable Fashion, Centre for Fashion Studies, Stockholm University, Stockholm, Sweden. Available at: https://www.academia.edu/7707960/Sustainable_Textile_Design_as_bricolage

Xiong, Y., Zhou, Y., Li, G., Chan, H.K. and Xiong, Z. (2013) Don't forget your supplier when remanufacturing. *European Journal of Operational Research*. 230 (1), pp.15-25. https://doi.org/10.1016/j.ejor.2013.03.034

Young, C., Jirousek, C. and Ashdown, S. (2004) Undesigned: a study in sustainable design of apparel using post-consumer recycled clothing. *Clothing and Textiles Research Journal*. 22 (1-2), pp.61-68. https://www.researchgate.net/publication/247783734_Undesigned_A_Study_in_Sustainable_Design_of_Apparel_Using_Post-Consumer_Recycled_Clothing

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Categorising Remaking Methods for Fashion Practitioners

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Keywords: Remake practices; reuse methods; fashion remanufacturing; upcycled garments and accessories; textile waste.

Abstract: Within fashion and textiles, practices which transform existing textile waste materials are discussed using various terms, for example upcycling, remanufacturing, or redesign, however, this study will collectively refer to these as remaking practices. Through the examination of 38 cases of remake collaborations occurring within the Australian community between November 2019 to July 2023, this study explores how the fashion remake outcomes can be classified to more effectively support the development of different remaking practices. As a result, the paper proposes a remaking lexicon to encompass eight different methods which can be employed individually or in combination: over-dye, over-print, embellish, alter, splice, piece, patchwork and refabricate. This proposed categorisation draws parallels to traditional fashion production processes, yet also recognises that end-to-end production skills are not required for remaking, instead showcasing that the methods may use different skillsets. In identifying different types of skills, rather than different *levels* of skills, this paper highlights an opportunity for remaking practices to engage a wider range of actors and encourage a broader range of specialisations than has been previously suggested. The eight methods provide a clear categorisation to enable more critical comparison and evaluation of remaking practices, encouraging discussion into how the fashion industry might build a diverse ecosystem of remake practitioners.

Introduction

The volume of textile waste currently produced poses a significant challenge for the fashion system, whether this is in Australia where charities are currently overwhelmed with the volume of textiles (Heinrich et al., 2024), or internationally, as global exports of clothing to countries such as Ghana can have significant environmental and social impacts (McClymont, 2021). Moreover, for businesses producing fashion products, pre-consumer waste streams (deadstock) also pose a challenge for disposal, particularly when brands are unwilling to distribute them for reuse as-is (Roberts et al., 2023). Principles for retaining material value advocate for reuse over recycling, with approaches such as repair, refurbish, remanufacture and repurpose proposed as alternatives when direct reuse is not an option (Reike et al., 2018). Small-scale making with unwanted waste products has been recognized as a way to build more resilient economies and have positive environmental and social impacts (Bridgens et al., 2018).

These types of practices which transform existing waste materials can be described through language such as: remanufacturing, upcycling, redesign, repurpose and more. When applied within fashion and textile contexts, these different terms often attempt to focus on a particular approach to transforming textile waste materials, such as at scale (remanufacturing) (Pal et al., 2021; Sinha et al., 2016), or as a means to increase material value (upcycling) (Dares, 2021; Sung et al., 2020), or turning materials to a different purpose (repurposing) (Eike et al., 2020). As a means of encompassing all these different terms, this study uses the term remaking, to avoid connotations of scale, value or purpose, instead placing the emphasis on the common process of transforming the material via making it again.

Background

Within the fashion industry, remaking practices which produce fashion outcomes (referring here to garments or accessories which are created by the fashion system), can be undertaken in a range of ways. However, across studies examining remake, the ways remake is described may not be consistent or clear. These descriptions sometimes use terms in conflicting ways, for example “patchwork” has been used to describe different remake processes (Han et al., 2017; Pal et al., 2018,

2021). One idea of patchworking referred to applying patches (Pal et al., 2021), while another was focused on cutting pattern pieces from garments and sewing into three-dimensional form (Han et al., 2017), whereas a third appeared to use it to represent creating a flat fabric from multiple fabric scraps (Pal et al., 2018). These methods are not the same, as one addresses minor issues in garments, while another cuts pattern pieces which must then fit within garment sections, whereas the third creates a length of fabric which can then be processed similarly to traditional production and may not face the same pattern piece size limitations. The other limitation is when studies do not actively recognised that there are multiple ways actors may engage in remake and therefore fail to describe or contextualise their specific processes. One example which cut pattern pieces from existing garments explored how this might be part of a zero waste approach, yet failed to acknowledge that other remaking methods might be more suitable or produce less waste (Lewis et al., 2017). Another discussed the potential of algorithms for streamlining processes yet did not describe how these interacted with practical construction processes and remake methods (Paras et al., 2022). Another study which evaluated the feasibility of different cases have did include different methods, yet did not explicitly draw links between the different methods and their feasibility despite them having different labour intensity, instead focusing on business approaches (Pal et al., 2018).

One proposed typology suggest that designers may make choices to either disguise or elevate waste (Payne & Binotto, 2017), while other studies focus on methods for approaching designing with garments (Bigolin et al., 2022; Lidström, 2023). These studies highlight how designers might approach remake via storytelling or specific techniques; however, they focus on transformation, limiting them as tools for discussing the requirements associated with the physical processes of remake. One more useful categorisation focused on repurposing, suggesting four methods: restyle, subtractive, additive and intentional patternmaking (Eike et al., 2020). Restyle to repurpose describes how remaking can involve using a fashion object in a different way than intended, while subtractive focuses on taking material away from a larger textile like a quilt or sheet, whereas additive brings together multiple material sources into one outcome, with intentional patternmaking drawing on patternmaking techniques in order to create a new outcome (Eike et al., 2020). The boundaries around how these methods might be used together is unclear, for example, the intentional patternmaking appears to potentially also overlap with the other methods, whereas subtractive and additive appear to be oppositional. This categorisation is also attributed to different levels of skills, where restyling has the lowest, while intentional patternmaking the highest (Eike et al., 2020). Levels of skill seems to be a common theme, with categorisations of remaking methods as representing skills which move from “basic” to “advanced” (Lapolla & Sanders, 2015, p. 185), or “minor-value adding”, “Cut, add and put-together” and “sewn from scratch” methods being attributed as involving skills which increase from “low” to “moderate” to “high” (Pal et al., 2021, p. 8). While Pal, Samie and Chizaryfard (2021) offered the clearest description of different remaking processes, these categorises also did not capture examples where pattern pieces are cut directly from garments, demonstrating opportunity for further expansion and refinement.

Methodology

This study draws on the author’s PhD research which examined remaking practices in Australia. Research methods include object analysis of products produced within 38 cases of remake collaborations between fashion businesses, and six semi-structured interviews with actors who were involved in remaking as part of these collaborations. Object analysis has been recognised as a useful method for understanding the knowledge embodied in fashion objects (Finn, 2014), and this method has been used for understanding historical garments which were remade (Aspinall, 2019). Object analysis is viewed as a likely method for future evaluation of remade outcomes and may therefore support a categorisation which can be more easily applied to both existing and future remaking examples. The research also draws on semi-structured interviews with actors involved in remaking to understand their experiences.

Findings

In evaluating the 38 different cases of remake collaborations, it became clear that the processes involved had some similarities to traditional fashion production processes, and

that the skills employed for remaking were varied.

Remaking Production Processes

The remaking processes were discerned by the researcher via object analysis and examination of information provided with the collaborations. Comparison of these processes to traditional fashion production steps, demonstrated that remaking methods facilitated similar material transformations to traditional steps, excluding raw fibre processing which aligns with recycling rather than remake. Examples of these comparisons are summarised in Table 1. Two cases showed that the remake process used the unwanted textile waste materials as 'yarn' to remake with, whether this was by crocheting post-industrial yarn waste, or the cutting of material into strips for weaving into a bag, with other examples in the literature weaving and felting luxury scraps (Keith & Silies, 2015), while amongst practitioners a well-known example is *Victor and Rolf*'s "Vagabond" collection (2016). This use of the unwanted textile material as a 'yarn' which is remade with is proposed as being classified as the method: *refabricate*. The next method: *patchwork*, was used either in isolation or combination with other methods in eight cases, with this process having involved large sections of material being created by actors joining together smaller sections to create a flat length of fabric, which was then processed similarly to regular fabric, evident in how the design lines were positioned differently across repeats of the products. The *piece* method cuts pattern pieces directly from the garments or textiles, allowing for strategic placement of existing details, for example the specific placement of logos, or textile details such as whiskering on jeans (Dares, 2021). Once the pattern pieces have been cut, these pieces can then move through traditional garment construction processes, with this method being the most common amongst the cases and used in isolation or combination 15 times. The *splice* method has been referred to as "cut, add and put-together" (Pal et al., 2021), yet has been simplified in this study as the term *splice,* and involves cutting and joining together partial garments, potentially retaining existing features, trims and three-dimensional form, used by 11 cases in isolation or combination. By comparison, *alter* focuses on only one item which is adjusted in its form, and was primarily evident in one case, although another six used *alter* for some styles within their project. *Embellish*, *over-print* and *over-dye* each demonstrate alignment with traditional value add services, or whole garment finishes within the fashion industry. *Overdye* was used alone for four cases, but also used in combination with other methods for another six. *Over-print* and *embellish* were only used in isolation for one case each but were used in conjunction with other methods across eight and nine cases respectively.

Similarity to Traditional Processes	**Example from this study**	**Remaking Method**
Yarn production: Creating a yarn from fibres for use in fashion production process.	Post-industrial waste such as fabric offcuts and denim leg tests were cut into strips and woven as the weft yarn on a loom, resulting in bags.	Refabricate
Fabric production: Creating a length of flat fabric.	Different black linen garments were cut into panels, joined together into a length of fabric, from which oversized bat wing sleeve dresses were cut and sewn.	Patchwork
Pattern cutting: Cutting pattern pieces from a length of fabric.	A series of garments were created by cutting pattern pieces from post-consumer jeans and sewing them into jackets, skirts and dresses.	Piece
Garment construction: Joining together specific pieces of fabric into a three-dimensional form.	T-shirts were cut into two or three sections, which were mix and matched, then overlocked together to create new hybrid t-shirts.	Splice

	A wrap dress had the back neckline lowered and fullness added to the sleeves.	Alter
Trim: Adding trims or other components to specific areas of the garment.	Ruffles made from production offcuts were gathered and handsewn onto base garments.	Embellish
Placement prints: Applying a print to a specific part of a garment.	Unsold skirts and pants had organic shapes hand-painted all over them.	Over-print
Whole garment finishes: Treatments applied to the finished garment.	A range of garments including t-shirts and wool coats were tie -dyed or ombre dyed.	Over-dye

Table 1. Adapted from Author's own thesis. © Julia English

Remaking Skills

While these methods demonstrate production parallels, unlike traditional production, not all remake processes involve material moving through the whole system. For example, not all cases involved pattern-cutting or even garment construction as part of the remaking. Across the methods, the two which had the closest parallels to traditional garment production processes were patchwork and piece, with alter having similarities to tailoring and needing greater knowledge of garment construction. The actors who had training in traditional fashion production were more likely to use these methods, as three of the six interviewees drew on the methods of patchwork, piece or alter, and had cut, make, trim (CMT) training such as through formal university education or experience manufacturing for their own brand. In contrast, the three interviewees who did not have formal CMT training either used methods which did not involve patternmaking such as splice or overdye, or brought in partners with CMT skills as needed, or only used piece and patchwork methods to make accessories which have lower technical, functional and fit requirements. Based on extant data, it was identified that of the 22 different actors were primarily responsible for remaking across the 38 cases, 13 actors were either trained in technical fashion production or had extensive experience in fashion production. Of these, 11 used methods including patchwork, piece, and/or alter, with the remaining two employing refabricate and over-dye. Four other actors were trained in fashion business, and they primarily used methods of splicing and over-dyeing, which they could gain skills in through informal learning, or employ other partners. Five actors had experience across a range of other fields such as art, product design, textile design and craft and costuming, and they generally drew on these skills in their choice of methods, the artist and textile designer both using over-print, the product designers creating accessories, while the creative craft and costuming actor employed the embellish method.

Remaking Specialisation

It has been previously suggested that there are parallels between the intensity of the remaking process and the level of skills involved. Yet the fashion production process is not a series of low to high skill roles, but rather a combination of different skills, which are used together to create fashion products, and this is mirrored in remaking practices. Within traditional fashion production, actors involved in developing patterns are not always skilled at creating markers and cutting materials, while skilled machinists are not necessarily experienced patternmakers. Similarly, actors who can provide value add services may not know how to produce a garment end to end, and they do not need to. This pattern was also evident within the remaking context, as actors demonstrated specific skills which were associated with their methods. For example, one overdyeing service focused on dyeing cellulose materials black, which requires a level of skill to get consistent and even colour. An arguably higher and more specialised skill was evident in another actor who over-dyed leather and wool coats across two different examples, as these materials are more challenging to dye whilst maintaining desired textile properties (like not shrinking or maintaining malleability). Other actors who had existing specialised skills applied these into a remake context, for example, two actors used their existing art style and over-printed in this style for their remaking process. While these cases demonstrate more skilled applications of these methods, low skill equivalents are often

evident in DIY books and guides, whether this is t-shirt yarn projects or taking up a hem (Fulop, 2020). In contrast to previous studies which have drawn parallels between remaking methods as offering low to high skill options, this study instead demonstrates that remaking methods involve different skillsets and acknowledges that there may be subsets of low to high skill levels within each.

Discussion

This study suggests that remaking methods can be differentiated based on the production processes and associated skills, proposing eight different remake methods, summarised in Table 2.

Remaking method	Icon	Description
Over-dye		Material has been altered at the fibre level, most commonly by dyeing, to change the colour and/or properties of the material.
Over-print		Specific areas of the material's surface are altered through self-adhering mediums, leaving the surface intact. May include single or multiple placement prints, ink, paint or other printable medium.
Embellish		Sections of material surface are added to or removed with perforation, with additions needing mechanisms for attachment such as fusing or stitching. This may include embroidery, beading, felting, patching.
Alter		Individual garment or fashion object has components removed or adjusted, commonly through cutting and/or sewing, to change form, retaining some existing three dimensionality.
Splice		Unwanted material is separated into sections which retain three dimensionality, these are then joined with other three-dimensional sections from other material.
Piece		Piecing uses material as fabric from which pattern pieces are cut, these pattern pieces are then joined together to create a three-dimensional fashion outcome.
Patchwork		Patchwork uses material as fabric from which sections are cut and sewn together into a flat fabric, from this new fabric pattern pieces are cut and sewn into fashion outcomes.
Refabricate		Material is made into a yarn which is then interlocked together using methods like weaving, knitting or crochet, this yarn could be strips of fabric or garment, an unravelled garment, or leftover ends-of-yarns.

Table 2. Overview of eight remaking methods, adapted from Author's thesis. © Julia English. Note: Icons available via https://doi.org/10.25439/rmt.27323901.v2 under CC-BY.

Eight Remaking Methods

These eight proposed methods of remaking demonstrate clear links between actor's skillsets and the production processes involved in remaking. These eight methods are not exhaustive, but they do capture a wide range of remaking processes which may be used alone or in combination for fashion outcomes. Other researchers may benefit from contextualising their research amongst these methods, to support more critical evaluation of their cases.

The relevance of a method-specific focus is evident in an historical example which shows how overdyeing was a widespread practice in Japan until the mid-twentieth century (Sugiura, 2019). Where that example demonstrates how one method has been established in the past, contemporary practices might use the methods to more specifically evaluate the potential applications of their findings around approaches like using computer-aided design (Lewis et al., 2017) or garment pairing

algorithms (Paras et al., 2022). Clearly situating research in relation to methods might encourage more nuanced evaluation of the different remaking methods potential and the development of focused research areas.

Diversification of Remaking

Previous studies have classified some remaking approaches as low skill, which may have limited investigation into the potential diversity of specialisation within remake and the opportunities this provides. The case studies showed how some actors from outside traditional fashion can participate in remake, when their skills are recognised and applied within a remake context. Recognising the opportunity for participation from those within arts, crafts, textiles and wider creatives fields, might then both support the growth of these practices and offer opportunities for these actors to specialise and develop remaking practices.

Conclusions

This paper has proposed that a categorisation of remaking methods based on processes and associated skills offers greater opportunity for remaking practices to look beyond traditional fashion systems, and invite participation from other creative fields, opening the door for a highly diverse range of remake specialisations. The eight remaking methods, which are closely tied to skills and processes, provide a tool for describing, comparing and evaluating remake outcomes. These methods may be applied across a range of fashion and textile remake practices, whether these deemed remanufacturing, upcycling, repurposing, repair or remake, providing a clearly defined and consistent baseline for future examinations of practices which transform textile waste materials.

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References

Aspinall, M. (2019). *Back to the Future of Fashion Past: Re-fashioning Future Garment Making* [PhD Thesis, University of the Arts London]. University of the Arts London. DOI: 10.1007/978-3-031-06886-7_4

Bigolin, R., Blomgren, E., Lidström, A., Malmgren de Oliveira, S., & Thornquist, C. (2022). Material Inventories and Garment Ontologies: Advancing Upcycling Methods in Fashion Practice. *Sustainability*, 14(5), Article 5. https://doi.org/10.3390/su14052906

Bridgens, B., Powell, M., Farmer, G., Walsh, C., Reed, E., Royapoor, M., Gosling, P., Hall, J., & Heidrich, O. (2018). Creative upcycling: Reconnecting people, materials and place through making. *Journal of Cleaner Production*, 189, 145–154. https://doi.org/10.1016/j.jclepro.2018.03.317

Dares, J. L. (2021). Fashion Upcycling: A Canadian Perspective. In S. S. Muthu (Ed.), *Circular Economy: Assessment and Case Studies* (pp. 19–75). Springer. https://doi.org/10.1007/978-981-16-3698-1_2

Eike, R., Irick, E., McKinney, E., Zhang, L., & Sanders, E. (2020). Repurposing Design Process. In S. S. Muthu & M. A. Gardetti (Eds.), *Sustainability in the Textile and Apparel Industries: Sustainable Textiles, Clothing Design and Repurposing* (pp. 189–239). Springer International Publishing. https://doi.org/10.1007/978-3-030-37929-2_9

Finn, A. L. (2014). *Designing fashion: An exploration of practitioner research within the university environment* [PhD, Queensland University of Technology]. https://eprints.qut.edu.au/77850/

Fulop, L. (2020). *Wear, repair, repurpose: A maker's guide to mending and upcycling clothes* (First edition.). The Countryman Press, a division of W. W. Norton & Company.

Han, S. L. C., Chan, P. Y. L., Venkatraman, P., Apeagyei, P., Cassidy, T., & Tyler, D. J. (2017). Standard vs. Upcycled Fashion Design and Production. *Fashion Practice*, 9(1), 69–94. https://doi.org/10.1080/17569370.2016.1227146

Heinrich, K., Garis, L. D., & Rawson, M. (2024). *Measuring Reuse Activity and Impacts in NSW: Executive Report* (pp. 1–19) [Report]. Charitable Reuse Australia and NSW Environment Protection Authority.

Keith, S., & Silies, M. (2015). New life luxury: Upcycled Scottish heritage textiles.

International Journal of Retail & Distribution Management, 43(10/11), 1051–1064. https://doi.org/10.1108/IJRDM-07-2014-0095

Lapolla, K., & Sanders, E. B.-N. (2015). Using Cocreation to Engage Everyday Creativity in Reusing and Repairing Apparel. *Clothing and Textiles Research Journal*, 33(3), 183–198. https://doi.org/10.1177/0887302X15572877

Lewis, T. L., Park, H., Netravali, A. N., & Trejo, H. X. (2017). Closing the loop: A scalable zero-waste model for apparel reuse and recycling. *International Journal of Fashion Design, Technology and Education*, 10(3), 353–362. https://doi.org/10.1080/17543266.2016.1263364

Lidström, A. (2023). *Redesign Foundations.* https://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-29579

McClymont, A. (Producer). (2021, August 12). The Environmental Disaster that is Fuelled by Used Clothes and Fast Fashion | Foreign Correspondent [Broadcast]. In *Foreign Correspondent.* Australian Broadcasting Corporation. https://iview.abc.net.au/show/foreign-correspondent/series/2021/video/NC2110H019S00

Pal, R., Larsson, J., Torstensson, H., & Scott, M. (2018). *Feasibility of Fashion Remanufacturing: Organizing fashion value chains for circularity through remanufacturing (including redesign)* (Report 3; Retextile Series Report, pp. 1–95). University of Borås. https://doi.org/10.13140/RG.2.2.15416.98561

Pal, R., Samie, Y., & Chizaryfard, A. (2021). Demystifying process-level scalability challenges in fashion remanufacturing: An interdependence perspective. *Journal of Cleaner Production*, 286, 1–12. https://doi.org/10.1016/j.jclepro.2020.125498

Paras, M. K., Wang, L., Pal, R., & Ekwall, D. (2022). A sustainable model based on genetic algorithm for garment redesign process. *Journal of Fashion Marketing and Management*, 1–18. https://doi.org/10.1108/JFMM-04-2022-0096

Payne, A., & Binotto, C. (2017). Towards a typology of waste in fashion practice: An Australian perspective. In R. Mugge & C. A. Bakker (Eds.), *PLATE: Product Lifetimes and the Environment 2017—Conference Proceedings: Vol. 9.* (pp. 340–346). Product Lifetime and the Environment (PLATE) Conference, The Netherlands. IOS Press. DOI: 10.3233/978-1-61499-820-4-340

Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation and Recycling*, 135, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Roberts, H., Milios, L., Mont, O., & Dalhammar, C. (2023). Product destruction: Exploring unsustainable production-consumption systems and appropriate policy responses. *Sustainable Production and Consumption*, 35, 300–312. https://doi.org/10.1016/j.spc.2022.11.009

Sinha, P., Muthu, S. S., & Dissanayake, G. (2016). *Remanufactured Fashion.* Springer Singapore Pte. Limited.

Sugiura, M. (2019). The mass consumption of refashioned clothes: Re-dyed kimono in post war Japan. *Business History*, 61(1), 106–121. https://doi.org/10.1080/00076791.2018.1494730

Sung, K., Cooper, T., Oehlmann, J., Singh, J., & Mont, O. (2020). Multi-Stakeholder Perspectives on Scaling up UK Fashion Upcycling Businesses. *Fashion Practice*, 12(3), 331–350. https://doi.org/10.1080/17569370.2019.1701398

Victor & Rolf. (2016). *Haute Couture Lookbook AW16.* Viktor&Rolf. https://www.viktor-rolf.com/pages/haute-couture-lookbook-aw16

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Defining Worn Out Workwear: exploring how to assess garments for reuse within a laundry system

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Keywords: Workwear; Assessment Criteria; Reuse; Longevity.

Abstract: This paper explores how to create an objective assessment criterion for 'worn out' workwear within an industrial laundry system. Undertaken during the ReSuit project, the research used Elis (laundry service provider) as a case study. Four styles of light workwear (2x t-shirts and 2x trousers) were selected because they represented the products with highest numbers of discards. During a field study, the researchers visually analysed a week's worth of these discarded garments for a variety of types of wear and tear. The research found that wear and tear could be categorised across four themes: holes, stains, pilling and colour. A traffic light system was created in which garments were assessed as Green: Reusable. Yellow: Normal wear and tear with the potential for reuse. Red: Worn out (discard for recycling). From this assessment guides were created, both digital (to be printed) and physical (exemplars). Working within the limitations of the research, these guides did not provide definitive definitions of worn-out workwear, rather were to 'start the conversation' of where the line is drawn between reuse and discard within the workwear sector. This research concludes that there is a huge potential for the workwear sector to reuse clothing and extend the lives of the products and further research should seek to streamline and test this worn out workwear assessment criteria.

Introduction

According to European Commission (2024) textiles have the fourth highest negative environmental impact after food, housing and mobility. To combat this the Commission is actioning its strategy for Sustainable and Circular Textiles which will, amongst many other focus areas, ensure durable textiles and reverse overconsumption. Therefore, this area has become the focus of many research projects.

This study was conducted as part of the ReSuit project (Recycling Technologies and Sustainable Textile Product Design) between design research at Kolding School of Design and industrial laundry service company Elis. The focus of the work was to explore how to increase the longevity of workwear within Elis' laundry system.

Workwear

Textiles is a large sector that encompasses fashion, interior, architecture etc… This research focuses on textiles produced for workwear. The workwear consumption in 2015 in Europe was 93,000 tones (Malinverno *et al.*, 2023). It is estimated by WRAP, in their report in 2012 (cited in Nerup, 2022), that employees who wear work clothes replace 3.25 pieces of clothing per year (based on UK data). This demonstrates the potentially vast volumes that will also be discarded. Concerningly up to 90% of discarded workwear could be sent to landfill (Business in the Community, 2021), although this maybe an overestimation, as research concerning workwear in Switzerland suggest incineration could stand at 41%. However, this is still a significant figure that could be diverted into reuse of recycling (Malinverno *et al.*, 2023). What is clear, supported by Malinverno *et al.* (2023), is the data is lacking in this area and much improvements could be made.

Workwear, is defined by ECAP (2017, p.17) as:

> "Garments of simple and typically very durable construction usually in poly/cotton fabrics, including boiler suits and coveralls, bib and brace, coats, jackets and trousers"

As Bundgaard-Nielsen (2025) explains, there is a range of workwear practices. Employees may be given the specific workwear 'uniform' they must wear, while others could be given an

allowance to purchase their own. Furthermore, while some companies own/manage their own workwear, others may choose to 'lease' it from professional laundries (Malinverno *et al.*, 2023). In this case the garments are selected by companies from catalogues that are suitable for the laundry system (Bundgaard-Nielsen, 2025). Then, across their lives, the laundries are responsible to supply, wash, repair (if necessary) and discard the garments.

Even within a rental system there are different setups. The workwear could be part of a central pool where employees are sent garments each week but not necessarily the exact same ones. Alternatively they could be personalised to an employee (with a visible/external or invisible/internal name tag), and/or as ECAP (2017) points out can be branded with logos. Importantly, visible personalisation has an impact on whether the garment can be reused. Solutions such as changeable name tags with Velcro have been tested but unfortunately where not fit for purpose (Business in the Community, 2021). However, research is underway to explore how to remove printed brandings/name tags which could offer a solution (Bjørn Thorsen, 2024).

Design for Longevity

Designing for longevity and avoiding textiles being discarded at their current pace is widely explored topic. Cooper *et al.*, (2013) explain that garments are mostly discarded because they no longer look good or no longer fit the user. Furthermore, they clarify that users have different expectations for wear and tear that affect longevity, and discard occurs because colours/shapes go out of style or caring for the garments is done inappropriately. To avoid discarding an garment early, Lerpiniere and Davies (2023) suggest that customers should be given more technical information about the longevity of their garments, such as number of expected washes and the expected appearance across time (i.e. colour fastness and shrinkage) as well as life expectancy (how long the garment is designed to last for). However, in the world of professional work wear for use within a laundry system many (but not all) of these elements are already considered and incorporated.

Longevity and Reuse of Workwear

From a longevity perspective, workwear that is produced for laundry systems is designed with durability in mind. For example, ID® Identity's (2024) pro-wear range, they explain, has reinforced details that will withstand daily wear and tear and are designed to keep their shape and colour wash after wash. In addition, laundry companies can offer repair services to keep the garments in use for longer, however, as Bundgaard-Nielsen (2025), points out this can be limited as the price of a new item might be less expensive than the cost of repair.

The lifetime of a piece of workwear, Nerup (2022) clarifies, depends on the type and situation of use. To truly extend the life of the garment it would need to be used by several different people. However, as the Business in the Community (2021, p.10) report describes:

> "a perceived barrier is that employees do not want to be issued with 'someone else's clothing'"

This is supported by Nerup (2022), who illuminates, t-shirts and shirts are only passed on if they are relatively new.

One of the issues is the lack of data collected on how the garments get worn out, why it is discarded and how long the lifespan of product is. Thus, workwear that could be reused is being discarded. For example, when an employee leaves (especially when garments are personally assigned and externally named) or at the end of the textile laundry service contract the textiles have to be discarded *(GPP in Practice, 2016).* However, by changing these practices there is potential for environmental and financial gains if the clothes could be reused and lifespans extended (Nerup, 2022).

Worn Out Textiles

According to the Cambridge Dictionary (2024) the word worn out is defined as something that:

> "can no longer be used because it is so old or because it has been damaged by continued use"

In Denmark (the location of this study) textile waste has started to be separately collected. Textile waste is defined by Miljø og Ligestillingsministeriet (2024) as "textiles that others cannot benefit from, e.g. damaged,

holed or stained clothes and textiles" (Google Translate, 02.12.2024). However, while these definitions offer an indication of what 'worn out' garments might look like the reality is more of a spectrum. For example, Sunde *et al.* (2023) created five grades of clothing in their picking analyse method for of textiles. This started with Grade 1 where the clothing was not useable at all. Grade 2 was similar to Grade 1, but had the possibility to be saved even though it is "on the brink of ruin" (p.44). Grade 3 has noticeable changes; it is still worn but has only small holes/stains and some discolouration. Grade 4 has minor changes, such as a missing button or fabric thinning. Finally Grade 5 clothing is in perfect condition.

The complexity of assessing textiles has also be explored by Nørup *et al.* (2018). In their research, they produced an assessment criterion for a sorting plant of post-consumer clothing. Here they considered: stitching defects, wear and tear, holes, stains faded/discoloured, paint, over-washed, zipper defect, solo item (previously paired, such as a sock). While they don't explain what 'wear and tear' specifically is, they point out that to properly establish the condition of a textile it is essential to understand:

> "which product type it is, where the defect is and how extensive it is and whether the product has more than one defect" (p.12)

In workwear, Nerup (2022) enlightens, clothing is discarded "when it is worn or is no longer presentable" (p.15). Nerup's study also found, that companies often don't have any specific guidelines for these conditions (worn out or no longer presentable). Assessments were assumed to be based on experience even though this is very subjective. Thus, she argues:

> "It would therefore make sense for the individual company to set up criteria for when a uniform is 'non-rewearable', 'rewearable' or 'repair for rewearable'" (p.19).

This is the focus of the paper, using Elis as a case study, the research explores how an assessment criterion can be created to encourage reuse of workwear.

Elis Case Study

Within Elis' laundry system used workwear is delivered to the laundry and washed, dried and folded before returning to the customers. Products can be flagged by either the customer or laundry staff when attention is required, such as when an item is damaged; an employee requires a different size; or an employee stops working and the item is not needed anymore. These products will either be repaired (if possible) before re-entering the system or sent to the warehouse for re-assessment. Here the workwear is either discarded for recycling or reused, depending on condition (wear and tear) and suitability (such as, if it has a logo it could only be used for another employee within the same company, but if it has no logo it could be used for another customer entirely). A reason code is assigned to all discarded garments which enables data analysis (please note that the reason code is often broad and therefore there could be many reasons for discarded garments within a single code).

The re-assessment of items is conducted by trained staff at the warehouse. The product range is very wide, from outerwear to t-shirts, and the condition varies greatly due to different types of use. In this role there is limited time to assess each product and often an assessment is subjective as there is no specific guidelines (currently) for the different product categories making it very challenging. Therefore, the research objective was to help Elis define 'worn out' workwear vs. workwear with an 'acceptable level of wear and tear' that could be sent back into the system for the customers to reuse.

Methods

The research consisted of multiple field visits (Burgess, 1984) to Elis Taastrup facility, where the system was first mapped visually to establish waste hotspots (Barthel *et al.*, 2014) and choose a specific focus area. The enquiry was narrowed by centring on the discard code "almindelig slid" which translates to "normal wear and tear" (Google Translate, 17.10.24). Using one year of data of discarded products ELIS identified light workwear as the category with the most discards in which t-shirts and trousers formed the two largest product groups. This was narrowed down to 4 specific styles, 2 t-shirts and 2 trousers, for analysis.

The warehouse sorted out and collected approximately one week's discarded products according to their current method. From this, two of the researchers sorted out the specified t-shirts and trousers. The samples discarded using the code "normal wear and tear" were taken by the design researchers for their study (Table 1).

Table 1. Numbers of 4 specific styles collected, and numbers assessed.

Garment Type	Numbers Collected	Numbers of discarded as "normal wear and tear"
2 styles T-shirts	91	56
2 styles Trousers	310	196

Each t-shirt and pair of trousers was visually assessed, and cuttings were taken of specific 'wear and tear' (see details in the next section). This data was reviewed; common themes were established and used to develop a spectrum (traffic light system) of 'wear and tear'. The findings were used to establish a more objective tool (first draft) with the aim of increasing the levels of reuse in workwear.

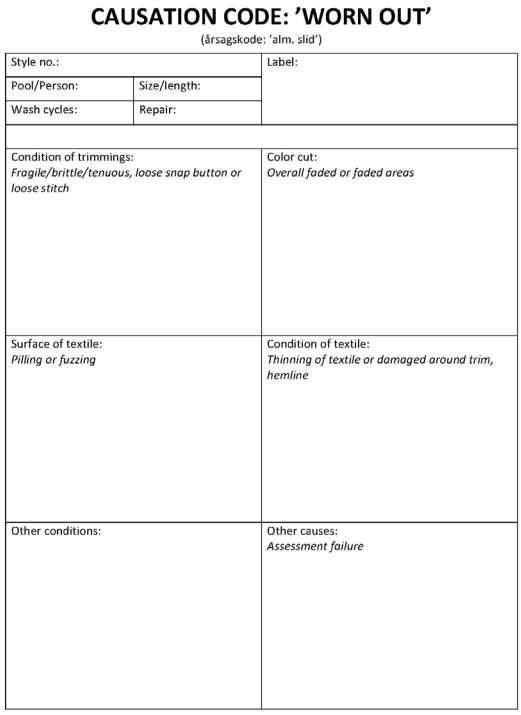
Procedure and Findings

The procedure used to assess the workwear was developed by the two researchers that conducted the assessment. First, they listed the four main types of wear and tear they were looking for (Table 2).

Table 2. Four areas for assessment

Types of wear	**Detail**
Trims & stitching	Is the zipper fragile or brittle? Is the snap button loose? Are the Leg straps loose? Loose stitching?
Colour	Faded overall? Specific areas faded?
Surface	Pilling or fuzziness?
Textile	Thinning of the textile? Condition of textile around trims?

After the researchers had conducted a first, visual assessment, the list was transformed into a worksheet (Figure 1) which was used to systematically assess each garment and cuttings were taken and attached for reference (Figure 2).



CAUSATION CODE: 'WORN OUT'

(årsagskode: 'alm. slid')

Style no.:		Label:
Pool/Person:	Size/length:	
Wash cycles:	Repair:	
Condition of trimmings: *Fragile/brittle/tenuous, loose snap button or loose stitch*		Color cut: *Overall faded or faded areas*
Surface of textile: *Pilling or fuzzing*		Condition of textile: *Thinning of textile or damaged around trim, hemline*
Other conditions:		Other causes: *Assessment failure*

Figure 1. Blank Assessment Worksheet

Each researcher assessed half of the samples. While this way of working has limitations, namely two different subjective assessment results, the researchers overcame this by establishing the criteria together and meeting to discuss throughout the process as well as reviewing the findings together at the end. Once the physical data had been collected, the next stage was to review all the textile cuttings (of all 252 garments). From this, four specific 'wear and tear' themes materialised: holes, stains, pilling and colour. For holes, stains and pilling the size and placement was noted. For colour and pilling the level of 'wear and tear' was discussed. To establish the spectrum of wear and tear, the researchers looked for both the



Figure 2. Assessment of Garments

lowest and highest levels across all four categories, such as the smallest and the largest holes and stains. For these two categories (holes and stains) commonalities in location were also noted. The same was established with colour fading and surface pilling. In addition, other attributes were noted, such as broken and missing trims. For example, specifically on the trousers, the leg straps were often cut out by the customer which would need to be repaired if the trousers were reused.

Based on this review the researchers created their own criterion using a traffic light system.

- **Green:** Reusable (good enough to go back into the system and customer should not notice)
- **Yellow:** Normal wear and tear with the potential for reuse (would require customer buy-in and mind shift)
- **Red:** Worn out (discard for recycling)

The results from this assessment can be seen in Figure 3 and 4 in which 13% t-shirts and 26% trousers could be directly used (5% of these trousers would require a small repair, which is a service that is set up within the laundry system). 50% t-shirts and 35% trousers were assessed as 'yellow' which had some 'wear & tear' but were considered within an acceptable level (9% of these trousers would require a small repair). Finally, 37% t-shirts and 39% trousers were assessed as 'worn out' and ready for recycling (please note: 14% t-shirts and 20% trousers of these numbers were assessed as "should be discarded" but for other reasons not due to "normal wear and tear").

This assessment was materialised as a 'kassationsguide' (Google translated as cassation guide – 02.12.2024). This was defined by the researchers as an assessment guide to assess wear and tear on products with the aim of increasing reuse. The guide was presented in both a digital (that was printed and laminated) and physical (exemplars) form; intended to be used by staff at their workstations (see figure 5, 6 and 7 overleaf). The digital guide indicated the parameters for garments to be sorted into the three traffic light categories. The physical guide used examples of the unacceptable and acceptable levels of wear & tear, such as colour fade and pilling. Furthermore, a plastic disc with four holes sizes was provided to measure holes and stains to assess if they were within the thresholds.

Discussion and Conclusions

Defining when a textile is 'worn out' is subjective. While there could be clear physical markers, such as holes and stains (the focus of this study), these physical traits might not stop a person from wearing an item for an extended period. However, within a system where a quality control has been put in place, defining what 'worn out' is and creating criteria for assessment that encourages reuse is vital.

The assessment guides created were not meant as a definitive definition of what acceptable wear & tear is (the nature of the study conducted by two researchers was subjective in its design). Rather, they were created as a 'conversation starter' to help Elis determine for themselves and on behalf of their customers where the line between reuse and discard lies.

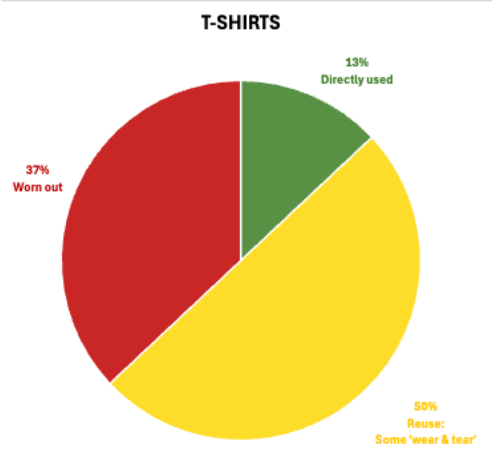


Figure 3. Results of the researcher's assessment – T-shirts.

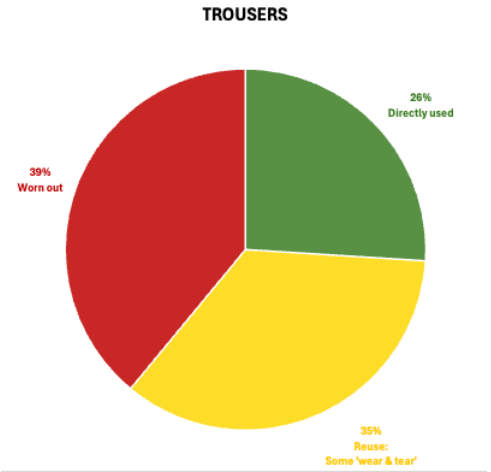


Figure 4. Results of the researcher's assessment – Trousers

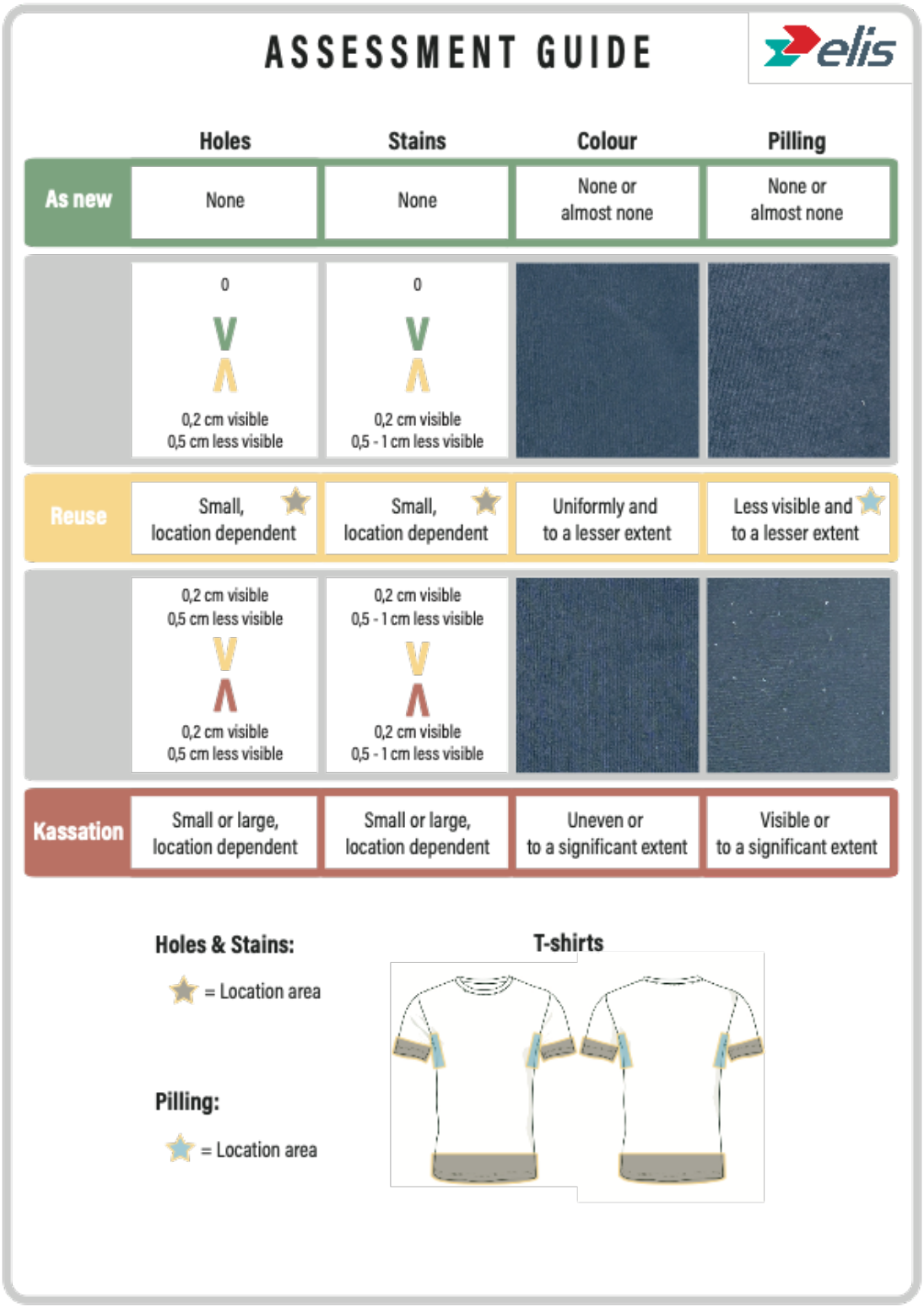


Figure 5. Assessment Guide for worn out workwear t-shirts

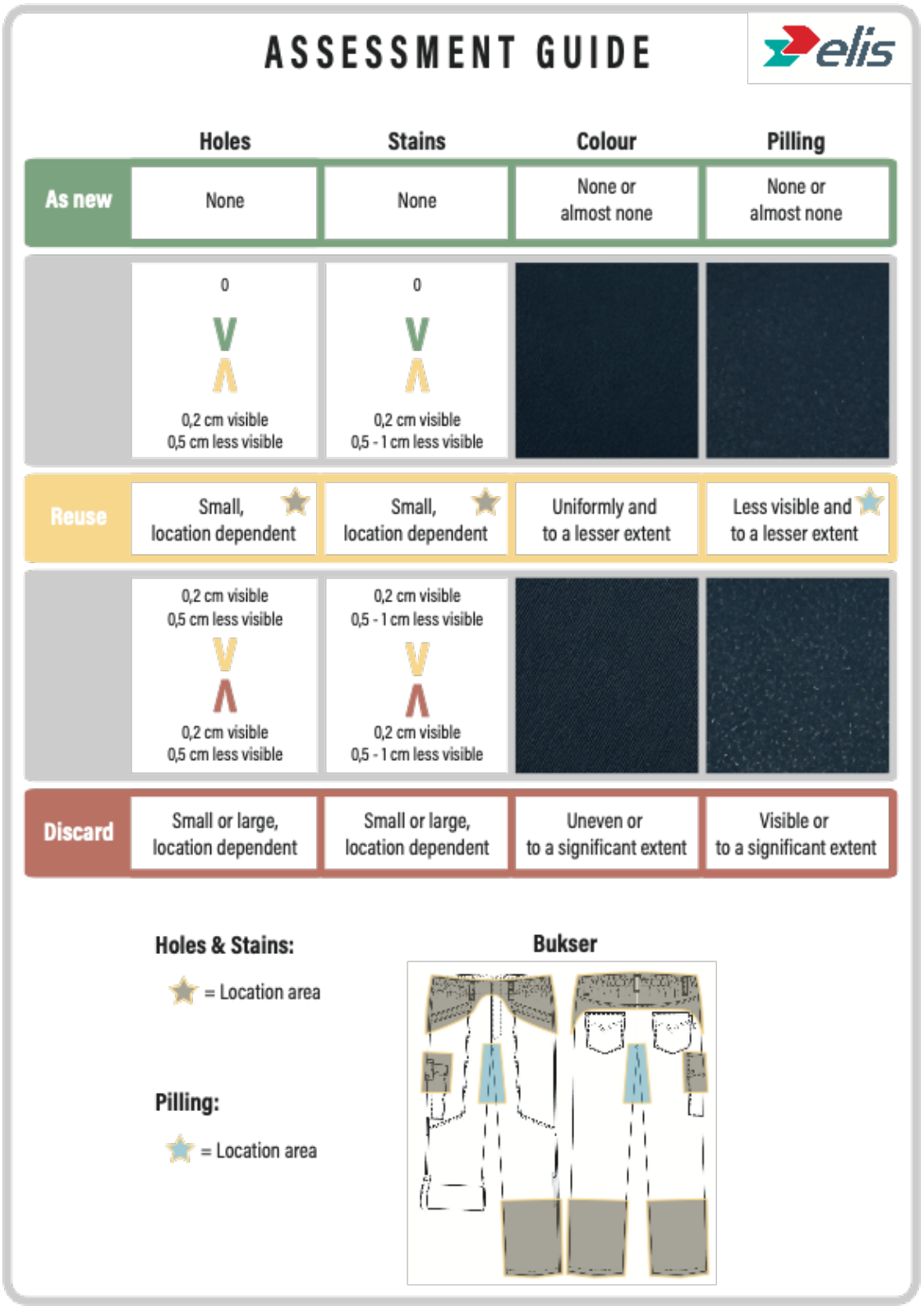


Figure 6. Assessment Guide for worn out workwear trousers



Figure 7. Physical assessment guide

Following in Nørup *et al's.* (2018) suggestion, the sorting guides were specific to garment type and considered the location of acceptable holes, stains and pilling. However, it did not go as far as to consider the number of holes/stains within the guide itself, rather this was assumed know-how that the assessor already possesses. Further research might look to include and or study how the different wear (holes, stains, colour and pilling) interplay with each other and how this effects the assessment.

While the sample used in this study is relatively small (it could be repeated to provide more robust data), it does demonstrate the potential for reuse. If both the 'green' and 'yellow' assessed garments were to re-enter the system, then 63% t-shirts and 61% trousers could avoid being discarded and would prevent the production of new garments thereby reducing environmental impacts and lowering economical costs. However, it should be noted that in order for the garments in the 'yellow' category to be reused a dialogue with the customers would need to take place to help them shift their mindsets to accept more signs of wear. Business in the Community (2021) report suggests that this could be combatted, in part, by the repackaging of the workwear to appear 'new'. However, if the industry is to transition to a circular economy and become more sustainable, then the mindset shift should be bigger and bolder and asking customers to reuse garments that are not new looking, such as with stains. Could this be a badge of honour in this future rather than a mark of bad quality?

The combination of a digital (printed and laminated) and physical (exemplars) guides was considered a successful outcome for assessment to help staff change their currently very subjective assessment to a more objective one. However, while this study focused on the creation of the guide it didn't go as far as testing it. This will take place in the next stages of the research.

While this guide only focused on t-shirts and trousers that were navy, further research could consider other product categories and colours. We also acknowledge that this guide was created specifically for Elis and while other laundry companies work in similar ways, exploring if this guide is transferable across the industry would expand its impact. Furthermore, future research might consider if this assessment could be translated and/or used as a starting point for assessing discarded clothing/textiles more generally.

Overall, this research concludes that there is a huge potential for the workwear sector to reuse clothing and extend the lives of the products. This study has started a conversation about what 'worn out' is, what levels of use are accepted and provides the groundwork for establishing a practical objective assessment method that encourages the reuse of workwear in the transition to a circular economy.

Acknowledgments

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References

Barthel, M., James, K., Guinness, J., Barker, C., Fava, J., Harnanan, C., Smerek, A., Adibi, N., Valdivia, S. and Khan, S. (2014) *Hotspots Analysis: mapping of existing methodologies, tools and guidance and initial recommendations for the development of global guidance*. Available at: http://lifecycleinitiative.org/wp-content/uploads/2014/10/Flagship3a-Hotspots-Mapping.pdf (Accessed: 18 September 2018).

Bjørn Thorsen (2024) *Enhancing textile recycling with removable logos*, *Bjørn Thorsen A/S*. Available at: https://www.bjorn-thorsen.com/enhancing-textile-recycling-

with-removable-logos/ (Accessed: 2 December 2024).

Bundgaard-Nielsen, M.J. (2025) *Uniform Report*. Kolding, Denmark: Kolding School of Design and Lifestyle and Design Cluster. Available at: https://webpagefilestorage.blob.core.windows.net/webpagefilecontainer/Andre%20publikationer/Uniform_report.pdf?utm_source=Nyhedsbrevstilmeldinger&utm_campaign=7dbc77a9dd-EMAIL_CAMPAIGN_2024_11_05_01_55_COPY_01&utm_medium=email&utm_term=0_-17ff54a98a-431853828 (Accessed: 18 February 2025).

Burgess, R.G. (1984) *In the field: an introduction to field research*. London: Allen & Unwin (Contemporary social research series, 8).

Business in the Community (2021) *A UNIFORM APPROACH: Defining procurement principles for sustainable professional clothing*. UK: The Prince's Responsible Business Network. Available at: https://www.bitc.org.uk/report/improving-the-sustainability-of-professional-clothing/ (Accessed: 11 July 2022).

Cambridge Dictionary (2024) *worn out*. Available at: https://dictionary.cambridge.org/dictionary/english/worn-out (Accessed: 2 December 2024).

Cooper, T., Hill, H., Kinmouth, J., Townsend, K. and Hughes, M. (2013) *Design for Longevity: Guidance on Increasing the Active Life of Clothing*. UK: WRAP. Available at: https://refashion.fr/eco-design/sites/default/files/fichiers/Design%20for%20Longevity.pdf (Accessed: 4 July 2024).

ECAP (2017) *European Textiles & Workwear Market: The role of Public Procurement in making textiles circular*. Netherlands: Rijkswaterstaat. Available at: http://www.ecap.eu.com/wp-content/uploads/2016/09/ECAP-Workwear-Report-Pt-1-def-final.pdf (Accessed: 19 November 2024).

European Commission (2024) *Textiles strategy - European Commission*. Available at: https://environment.ec.europa.eu/strategy/textiles-strategy_en (Accessed: 19 November 2024).

GPP in Practice (2016) *Reusing workwear in Herning - Denmark*. 65. Herning Denmark: European Commission. Available at: https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/a98253a8-511e-463c-b471-5693a018f654/details (Accessed: 2 December 2024).

ID® Identity (2024) *Tøj til produktion og industri - Translated into English: Clothing for production and industry*. Available at: https://id.dk/dk/shop/brancher/produktion-og-industri?PageNum=2&SortBy=Created&SortOrder=DESC&PageSize=8&fg=Category&fg=Certificate&fg=Gender&fg=Size&fg=Color.facets&fg=StyleFit&fg=Composition&fg=Washing&StyleNumber=0302%2c0510%2c0511%2c0322%2c0320%2c0321%2c0362%2c0360%2c0311%2c0383%2c0382%2c0336%2c0326%2c0747%2c0746%2c0745%2c0744%2c0851%2c0850%2c0856%2c0854%2c0913%2c0912%2c0911%2c0910%2c0902%2c0903%2c0385%2c0384%2c0381%2c0600%2c0896%2c0897 (Accessed: 29 November 2024).

Lerpiniere, C. and Davies, A. (2023) 'Using textile testing information to ensure garment quality, longevity and transparency', in M. Charter, B. Pan, and S. Black, *Accelerating Sustainability in Fashion, Clothing and Textiles*. 1st edn. London: Routledge, pp. 88–102. Available at: https://doi.org/10.4324/9781003272878-8.

Malinverno, N., Schmutz, M., Nowack, B. and Som, C. (2023) 'Identifying the needs for a circular workwear textile management – A material flow analysis of workwear textile waste within Swiss Companies', *Resources, Conservation and Recycling*, 189, p. 106728. Available at: https://doi.org/10.1016/j.resconrec.2022.106728.

Miljø og Ligestillingsministriet (2024) *Sortering af tekstiler - Translated into English: Sorting of Textiles*, *Miljøstyrelsen*. Available at: https://mst.dk/erhverv/groen-produktion-og-affald/affald-og-genanvendelse/affaldshaandtering/affaldsfraktioner/de-ti-affaldsfraktioner/sortering-af-tekstiler (Accessed: 2 December 2024).

Nerup, L. (2022) *Uniformer: Muligheder og Udfordringer i et Genanvendelsesperspektiv - Translated into English: Uniforms: Opportunioties and challanges of a recycling perspective*. Copenhagen, Denmark: KEA and Lifestyle and Design Cluster. Available at: https://ldcluster.com/search?q=uniformer.

Nørup, N., Pihl, K., Damgaard, A. and Scheutz, C. (2018) 'Development and testing of a sorting and quality assessment method for textile waste', *Waste Management*, 79, pp. 8–21. Available at: https://doi.org/10.1016/j.wasman.2018.07.008.

Sunde, C., Hovda, E.V., Sheikhi, S. and Vestengen, S. (2023) *Method for Picking Analyses of Textiles - REdu Wasted Textiles Project*. Norway. Available at: https://s3-eu-west-1.amazonaws.com/avfall-norge-no/dokumenter/WT-REdu-final-report-Aug11-2023-revised-Aug17.pdf (Accessed: 13 May 2024).

Research paper
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Exploring spirituality's location in sustainable clothing consumption through "Black Swan" narratives

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Keywords: clothing; spirituality; sustainability; consumption practice.

Abstract: "Black swan" events (e.g., pandemics, natural disasters, war) often prompt individuals to clarify their self-concept and boost self-esteem with consumptive activities when their mortality is threatened. Research about the Covid-19 pandemic's effects on clothing consumption indicates that some consumers shifted toward more conscious clothing consumption habits, which may be associated with a desire for self-transcendence (e.g., spirituality). The purpose of this study was to locate spirituality's role in consumption practice that strengthens clothing's longevity. Narrative inquiry methodology was used to engage individuals who reported a spiritual experience relevant to their consumption during the pandemic. The study explores the nature of narrators' spiritual experiences, insights, and the clothing consumption practices and ideals that are informed by each narrator's spiritual framework, which is idiosyncratic and deeply personal. The pandemic is described by narrators in this study as an opportunity for personal growth and insight into the value of time and relationships. Narrators describe an increased spiritual consciousness, leading to a sense of interconnectedness and responsibility, beyond their own survival. Their empathy for others expands. Materiality is reevaluated in their spiritual sense of what makes a "good life." Most importantly, narrators squarely negotiate their identity through contemplative spiritual practices and reduce their need for external approval. This allows them to deepen their commitment to reduce or restrain their clothing consumption habits. The narrators illustrate how sustainable clothing consumption is itself a spiritual practice that results in greater freedom of expression and a more meaningful and satisfying experience with clothing.

Introduction

"Black swan" events like the Covid-19 pandemic often prompt individuals to clarify their self-concept and boost self-esteem with consumptive activities when one's mortality is threatened (Pyszczynski et al., 2021). Surprisingly, studies show that this event prompted some consumers to adopt more conscious clothing habits (see Degli Esposti et al. 2021; Vladimirova, et al., 2022), focusing on simplicity (Penz & Drewes, 2022) and even spirituality (Iran et al., 2022). Chakraborty and Sadachar (2023) demonstrated that amid pandemic stress, people turned to self-transcendence and developed positive attitudes towards slow fashion principles.

As fashion consumption drives climate change and diminishes human well-being (Coscieme et al., 2022), there is a critical need for consumers to be more conscious of their habits. Joyner Armstrong (2020) argues that spiritual motivations have the potential to transform clothing consumption and promote sustainability. Spirituality has been linked to advanced levels of consciousness and is recognized as an important factor in human development and attitudes (Combs & Krippner, 2003; Stillman, et al., 2012). However, the role of spirituality in disrupting unsustainable consumerism is still being explored.

While some research suggests that spiritual motivations play a role in simplifying lifestyles and transforming identities (Cherrier & Murray, 2007; Sandlin & Walther, 2009), few have fully explored the relationship between spirituality and consumption, particularly in the context of clothing. Clothing is one of the most common products used to express identity (Kaiser, 1997), making it a relevant product to examine from a spiritual perspective due to its impact on personal and planetary well-being.

The purpose of this study was to locate spirituality's role in consumption practice that strengthens clothing's longevity. A primary research question guided inquiry: How

do individuals integrate their spirituality into sustainable clothing consumption in real practice? Narrative inquiry methodology was conducted with seven individuals who reported having a spiritual experience during the pandemic that was relevant to their clothing consumption. This inquiry was conducted towards the conclusion of the global pandemic, an ideal period to observe spirituality's activation for coping, allowing clear descriptions from storytellers.

Background

Spirituality, an internal search

Transpersonal psychology studies the impact of spirituality on identity and behavior, acknowledging that human development goes beyond the body or ego to increase awareness and decrease selfish tendencies (Davis 2003; Walsh & Vaughan, 2018). Previous research has shown that voluntary simplifiers detach consumption from their sense of self by finding inner fulfillment (Cherrier & Murray, 2002; Elgin, 1977; Zavestoski, 2002). Spiritual experiences can shift perspective, leading to more realistic views of identity (Grof & Grof, 1989; Sinclair, 2016). This transformation is often triggered by a turning point or awakening when current consumption habits become undesirable (Sandlin & Walther, 2009; Uggla, 2019). Changiz (2024) argues that because spiritual transformation diminishes the egoic self, when the freedom to individuate decreased during the onset of COVID-19, a process of spiritual individuation was made more possible.

Fashion, an external identification

Clothing users play a crucial role in the fashion industry's externalities by deciding what to buy, use, and discard at what pace (Klepp et al. 2020). Their awareness and agency are key in pursuing sustainable consumption. Clothing fulfills basic needs like warmth, but it especially satisfies socio-psychological needs like identity expression. The latter markedly hinder sustainable consumption efforts (McNeill & Venter, 2018). Immersion in consumerist culture replaces one's true self with a consumer-based ego over time (Kaza, 2000). Alternatively, spirituality shifts this focus from ego satisfaction towards greater sensitivity about the consequences of one's consumption (Ulvoas-Moal, 2010; Walsh & Vaughan, 2018). This study examines this potential.

Methods

Narrative inquiry methodology is particularly attentive to the rich context that surrounds experiences, including one's personal history (e.g., temporality), personal relationships (e.g., social interaction), and their situatedness in a place (Clandinin & Connelly, 2000). Rather than reducing the data, storytelling is used to capture nuance to reveal the outer bounds of phenomena (Clandinin & Murphy, 2009). This approach permitted the characterization of the complex interplay between spiritual experience and consumptive ideals and practices to fully locate spirituality within clothing consumption.

This study received exempt status from the university's institutional review board. A mass email was sent to 5,000 faculty, staff, and students across three campuses of a large U.S. university to recruit for the study. The call sought participants who had a spiritual experience during the pandemic and found it relevant to their consumption. A screening survey was used to collect demographic data (e.g., age, gender, ethnicity) and contained two open-ended questions asking the respondent to briefly describe their spiritual experience that occurred during the pandemic that they found relevant to sustainable consumption practices regarding clothing. As this study required a large time commitment and the revealing of intimate details of one's life, seven narrators agreed to participate.

A semi-structured conversation guide was used to prompt narrators to share several types of stories: their circumstances and spiritual encounters during the Covid-19 pandemic, consumptive history, and a spiritual biography. Occasional follow-up prompts were used by the researcher to ensure these stories were complete and helped identity the spiritual levers being engaged in consumptive lifestyle choices. The narrators provided their verbal consent and a preferred pseudonym during the interviews. Fourteen in-depth individual interviews were conducted with seven narrators over two separate meetings of 1.5 - 2 hours in length. Upon the conclusion of their final interview, narrators were provided a $25 cash incentive. Interviews were audio recorded and transcribed for analysis. Data collection was concluded within 12 months.

Analysis began during data collection. Field texts were co-created with narrators during the interviews. After transcription, the researcher

worked with large sections of the narratives, grouping them first by the intensity of the spiritual experience, and then by the impact of spiritual experience on consumption. Short stories were developed to characterize each narrator's experiences, including how identity was being negotiated. Special attention was paid to synergies and divergences to develop a detailed research text that captured unique perspectives and experiences around identity. Additional content analysis was conducted to categorize each narrator's spiritual identity, the nature of their spiritual experiences, spiritual insights, and clothing consumption practices that were spiritually motivated. The narrators provided feedback about the researcher's characterizations and interpretations during two instances of member checking, one including review of the researcher's short stories.

Findings

The narrators, aged 32-68, mostly identified as White females, with two exceptions (see Table 1). Most worked or studied from home during the pandemic, most experiencing ample social isolation. Two participants experienced spiritual crises during this time, one a near-death experience and another a "traumatic emotional event". Though most narrators began their spiritual or religious understanding in a Christian tradition (e.g., Southern Baptist, Methodist), most were now drawing upon diverse spiritual or religious frameworks to shape unique spiritual identities (e.g., "believer," not ritualistic; Soka Gakkai Buddhist; anarchist) (see Table 2).

Narrator pseudonym	Gender identity	Ethnicity	Age
Ellen	Female	White	68
Rosa Maria	Female	White	59
Faye	Female	White	37
Leah	Female	White	34
Jeannette	Female	White	44
Epicurus	Male	Prefer not to answer	32
Maya	Female	Asian or Pacific Islander	Prefer not to answer

Table 1. Narrator attributes.

The narrators provided vivid details about their commitment to sustainable clothing consumption habits and the deeply personal, idiosyncratic spiritual underpinnings of their practice. According to narrators, enacting new or continuing to live more sustainably is a spiritual way of being in the material world that is punctuated by highly varied spiritual practices that are inherently contemplative (e.g., prayer, exercise, chanting, gratitude, journaling, bird watching). Narrators describe feeling the emotional "pull" of the marketplace and engaging spiritual reflexivity to weigh the potential spiritual consequences of various consumption choices. These choices fortify the spiritual self.

Table 2 highlights each narrator's spiritual identity, the nature of their spiritual experience during the pandemic, their spiritual insights, and their clothing consumption practices and ideals to make relationships more visible.

The accounts noticeably nuanced, though some important commonalities are discernible. All narrators describe some form of heightened spiritual consciousness to others and the planet, conjuring a feeling of interconnectedness that strengthened their sense of responsibility, beyond their own survival or happiness. Most narrators discuss awakening to a better understanding and acceptance of others' experiences and perspectives that increases their empathy and compassion. Intense emotional responses are evident, including grief, gratitude, awe, anger, loneliness. Narrators view the pandemic as an opportunity to deepen their spiritual understanding about themselves, others, and the world. Most describe insights that include clarity about the value of time and relationships. They become attuned to what is most meaningful and satisfying in life. They seek to spiritually intuit how much materiality is required for a "good life" through reflexive practice.

Devoting a spiritual reflexivity about the potential harm of consumptive choices enriches their spiritual growth and deepens the meaning they attribute to their choices. The narrators describe a breadth of practices and ideals for their clothing consumption practice that spans all clothing consumption phases, including acquisition, use, and disposal (indicated in Table 2 as "A", "U", "D"). These practices are idiosyncratic to each narrator, though they share some common intentions. Most narrators emphasize restraint and purchasing, not purchasing new, acquiring only secondhand, and imposing definitive constraints on

acquisition generally. All of the narrators describe their use practice (e.g., wearing, caring, repairing clothes) to be focused by an exploration of their personal style and expression, which requires negotiation of external influences, approval, or reference points; influences on the appearance they have become aware of. Most describe a significant reduction in preening behaviors, wearing less makeup, being more accepting of or compassionate about aging or the appearance of it (e.g., skin changes, graying hair) or the body's natural condition or shape. Most narrators actively engage in practices that reduce disposal to landfill by donating; some thoughtfully considering how their underutilized items could find joyful use among others. Notably, choices are perceived to have spiritual consequences.

Importantly, narrators describe their identity negotiation as a contemplative practice during which they regularly explore how their self becomes enmeshed with others' perceptions and evaluations. Spirituality pushes them beyond the body to recognize their ego's involvement in potentially fruitless consumptive activity, and they are more able to cultivate a sense of authentic sufficiency. They experience great freedom of expression and have satisfying experiences with clothing. Their consumption practice is made more durable over time because the practice is deeply rooted in their spiritual values.

Discussion and Conclusion

Each narrator's experience provides a richly nuanced view of how the Covid-19 pandemic activated a spiritual experience that catalysed significant clothing consumption changes for some and deepened the consumptive practices and ideals of others. Previous authors have highlighted how resolute one must be to simplify one's lifestyle. It requires more than a desire for happiness and more leisure time; both motivation and discipline are requisite to sustain such a path (Alexander & Ussher, 2012; Etzioni, 1998). These narratives depict the complexity of the motivational foundation for sustainable consumption, emphasizing why spirituality and spiritual practice should be considered as key contextual variables in sustainable lifestyles. Integrated under supportive conditions and a willingness to endure the discomfort associated with personal growth, these transpersonal experiences provide powerful and long-lasting motivation for sustainable consumption.

Narrators describe the process of making wiser consumptive choices as a spiritual experience itself; choices that verify the self. Sustainable consumption is, therefore, a spiritual experience and a host of practices with spiritual consequences. The narrators approached their spiritual emergence as a learning experience, an opportunity to see things another way, even themselves. Intense emotional responses are evident in these cases, including grief, gratitude, awe, anger, loneliness; all of which spark spiritual introspection that propel the narrators toward deeper commitments to reduce or restrain their clothing consumption habits.

Sinclair (2016) argues that as individuals often embark on the spiritual search for the real self, transformational ideas about identity realistically emerge. Consumption is considered a channel to transcend and self-actualize, to attain one's ideal self (Hunting & Conroy, 2018), so it is easy to understand why consumption of clothing can move into excess as one changes and grows over time. Alternatively, these narrators were inclined to consider the potential harm of their choices for others, to focus on their own sufficiency, being more intentional about how much clothing was needed to achieve their desired expression. The narrators highlight how transpersonal processes often move the personal identity or the ego, to fewer selfish impulses, to wholeness, to higher awareness (Davis 2003; Walsh & Vaughan, 2018). These experiences demonstrate another way to be with clothing, a material tool that is often used to portray an identity; here, the process of clothing consumption is itself a spiritual experience.

These narratives are instructive, showing a far more holistic and complex view of the motivational foundation for deep and sustained commitment to sustainable consumption.

Narrator Pseudonym & spiritual identity	**Nature of spiritual experience**	**Spiritual insights**	**Clothing consumption practices & ideals**
Faye *Spiritual, a "believer," not ritualistic*	Near-death experience Navigates ambivalence about God with prayer Grief from other Covid deaths Observes influence of others' approval Desire to make world better	Recognizes stress level Reflects on life satisfaction Galvanizes sense of belief in and feeling of connection to something bigger Perceives others' spirituality as having something to offer Increased comfort/acceptance of uncertainty Clearer sense of purpose Prioritizes quality of relationships Reduced concern of others' judgment about appearance; body acceptance Feeling of freedom comes with decluttering Household decluttering is method to connect with others Meaning of material things changes	*Declutters entire household; 75% reduction in wardrobe* Needs-focused shopping [A] Conducts research on large corporations [A] Buys locally, secondhand, fair-trade [A] Supports small businesses [A] Acquire nothing brand new [A] Gratitude of what she has [U] Dress for what makes you feel good (e.g., self-love focused styling) [U] Explores/develops unique personal style; become more brazen in expression [U] Reduced preening; less makeup; less hair care [U] Routine closet maintenance (e.g., 6-month wear rule; satisfaction-focused) [U] Careful wear to preserve [U] Clothing life extension (e.g., fixed shirt, owns sewing machine) [U] Clothing swaps with friends (e.g., let someone else enjoy what you have) [D] Donates "where it matters"; give to friends who will enjoy [D]
Epicurus *"Anarchist"; free from any system of belief*	"Traumatic emotional event"; isolation Pandemic triggers memories of war and ISIS Confronts Islamic ideas and faith Experiences "unified" sense of "soul and mind" Releases belief system	Human suffering occurs in every culture = competition; desire for competition is "illusion of ego" Alignment of "soul and mind" Perceives divine as manifest in all Discovers anarchy; abandons good-and-evil system of belief Seeks spiritual meaning inwardly, rather than outwardly Desire to moderate consumption via reduced competition and social comparison that influences appearance Increased meaning assigned to consumption (e.g., focus on experiences, using money to help others) Clarity in dress and consumptive ideals –what is truly meaningful in life Seeks wisdom in consumptive decision-making Fosters contentment	*Deepening of existing consumptive ideals; no decluttering; newfound contentment* More "realistic" or "reasonable" consumption; reflexive about materiality required for life [A] Renounces excess without asceticism [A] Needs-focused shopping, not just on what's available [A] Increased value placed on material [U] Explores personal style; what brings comfort and peace; dress for myself; comfort in who I am [U] Dressing "more classical," "less modern" (e.g., stylish, flashy); new reference points for dress [U] Less use of appearance to compete with others (e.g., dressing for ego); dress for environment I'm in; less worrying about the symbolism (trendiness) associated with clothing [U] Self-confidence in appearance [U] Less impulsive, ego-induced acquisition means no need to declutter [D]

Rosa Maria *Non-denominational Christian*	Search to understand what is to be learn from this crisis; Loving God is a way to learn Search for self-trust Values clarification Observes burdens of pandemic shouldered by society's most vulnerable	Pandemic as growth opportunity; not "crappy deck of cards" Attunement to and concern for others' experiences during pandemic "Values clarification" Shift in the meaning of work, family, relationships, and things Release of others' judgement Increase desire to work in the service of others Longing for and prioritization of community	*Declutters entire household; 50% reduction in wardrobe* Needs-focused shopping [A] Defines cap on amount of clothing to own [A] Stopped buying new; thrifting more (higher quality) [A] Focused on buying less [A] Focused on using more [U] Explores/develops personal style that yields self-confidence [U] Preference for comfort and neutral colors [U] Comfort in/with body/age and clothing choices [U] Reduced concern for others' opinions/approval [U] Shops own closet [U] Reworks old clothing to new needs/roles [U] Values/considers material quality of wardrobe; finds beauty in garment itself [U] Stopped dry-cleaning [U] Regular sorting/organizing of wardrobe to maintain prescribed quantity [U]
Jeannette *Episcopal, seeking more ritual*	Pandemic = spiritual learning opportunity Search for role in greater good Sense of God as "protective blanket" Deepens commitment to spiritual/religious ritual	Pandemic viewed as "next human rotation" Contemplates personal responsibility for global challenges Attunement to others' needs Appreciation and acceptance of others' experiences and perspectives Increased comfort/acceptance of uncertainty Crystallization of personal values	*Deepening of existing consumptive ideals; no decluttering* Acquires/buys primarily secondhand [A] Considers potential garment use and longevity, impact post-life, and production [A] No new pants, despite pandemic weight gain [A] Conducts research about material make-up of clothing [A] Focuses on utilization [U] Reduced preening; cuts her own hair; allows hair to gray; less make-up [U] Comfort in own skin/appearance, even with pandemic weigh gain [U] Explores/develops personal style that yields self-confidence and comfort (e.g., feel my best); autonomy in appearance (e.g., Doc Martins go with anything); less concern for "matchiness" [U] Reworks old clothing to new needs/roles [U] Anticipates life changes, clothing need changes (e.g., retirement) [U] Hand dries clothing [U] Refuses to declutter [D]

Ellen *Quaker*	Grief for fragility of planet Insomnia Feeling abandoned by God Awe Sense of interconnectedness Empathy	Increased sense of connection to herself, others Explores unseen powerful force or spirit that endures through life's complicated and deeply troubled nature Realization of beauty in world, despite devastation Finding action, the "gesture", beyond the self	*Deepening of existing consumptive ideals; "ruthless" household decluttering; continuation of small wardrobe* Only buys second-hand, except for under garments or white clothes [A] Considers potential for clothing waste; considers end-of-life [A] Prioritizes utility over fashion [A] Focus on utilization; reduce waste in wardrobe [U] Willingness to wear damaged clothing (e.g., missing button) [U] Works to extend garment lifespan; repairs garments and shoes with professional help; [U] Appreciates clothing as art rather than trend [U] Attentive to bright color preference [U] Donates to secondhand; donate more than I purchase [D]
Leah *Christian*	Sense of love for the land; being in relationship to Earth Cultivation of faith Sense of gratitude Learning what pandemic will show us Search to be of service	Views and accepts pandemic; "all things have a reason and a season" Reconsiders the value of time Becomes closer to nature Turns inward Enhanced faith in something larger than oneself Transformation in meaning of things, quantity of things, a good life Reflexivity of others' influence in appearance expands	*Begins to declutter; plans for future decluttering* Needs-focused shopping; consistent reevaluation of needs [A] Reduced acquisition [A] Replaces damaged items [A] Increased secondhand; develops preference for used (e.g., clothes for new baby) [A] Buys for quality and longevity [A] Considers utilization level of purchases [A] Preserves items for future; organization, careful storage, making clothes last; keep clothes out of landfill [U] Retain clothes until they look bad or damaged [U] Works to resolve waste around spouse's clothing use/damage [U] Organizes closet [U] Donates unused items; do not throw away what others will find joy in [D]
Maya *Soka Gakkai International (SGI)Buddhist*	A planted seed finds fruition Expansion of personal universe Sense of interconnectedness Gratitude Experiences mystical faith Curiosity, inquisitiveness; engages with mystery	View of pandemic as "message from nature" Connection to a source/mystery that is unknowable as source of hope Expansion of personal universe "Connected the dots" between Hinduism, Buddhism, science, and philosophy Acknowledgement of wisdom of limits	*Deepening of existing consumptive ideals; no decluttering* Buys for quality, sustainability; consider environmental impact [A] Buys only items washable; no dry-cleaning [A] Informed consumer; reads about brands, garment care; research about styles [A] Spends ample time during acquisition process [A] Prioritizes utility over fashion [A] Less accumulation [A] Explores personal style; dressing for mood [U] Regular sorting/organizing of wardrobe [U]

			High levels of reuse; use clothes to their limit [U] Preserve clothing by limiting washing [U] Air dry items to refresh [U] Line dries clothes [U] No buying means no donating [D]
[A]= acquisition-related [U]= use-related [D]= disposal-related			

Table 2. Characterizations of narrator spiritual experiences, insights, and consumptive outcomes.

References

Alexander, S., & Ussher, S. (2012). The voluntary simplicity movement: A multi-national survey analysis in theoretical context. *Journal of Consumer Culture*, *12*(1), 66–86. https://doi.org/10.1177/1469540512444019

Chakraborty, S., & Sadachar, A. (2023). Spirituality bestowing self-transcendence amid covid-19 through slow fashion. *Journal of Global Fashion Marketing, 14*(3), 350–368. https://doi.org/10.1080/20932685.2023.2197920

Changiz, M., Mohammadi-Shirmahaleh, F., Mardani-Hamooleh, M., & Seirafi, M. (2024). Crystallization of spiritual awakening in patients with Covid-19: A hermeneutic study. *Novelty in Biomedicine*, *12*(2), 61–67. https://doi.org/10.22037/nbm.v12i2.44125

Cherrier, H., & Murray, J.B. (2002). Drifting away from excessive consumption: A new social movement based on identity construction. *Advances in Consumer Research, 29*, 245-247.

Clandinin, D.J., & Connelly, F.M. (2000). *Narrative inquiry: Experience and story in qualitative research*. San Francisco: Jossey-Bass.

Clandinin, D.J., & Rosiek, J. (2007). Mapping a Landscape of Narrative Inquiry: Borderland Spaces and Tensions. In D.J. Clandinin (Ed.), *Handbook of narrative inquiry: Mapping a methodology* (pp. 35–75). Sage Publications, Inc.

Combs, A., & Krippner, S. (2003). Process, structure, and form: An evolutionary transpersonal psychology of consciousness. *International Journal of Transpersonal Studies, 22*(1), 47–60. https://doi.org/10.24972/ijts.2003.22.1.47

Coscieme, L., Akenji, L., Latva-Hakuni, E., Vladimirova, K., Niinimäki, K., Henninger, C., Joyner Martinez, C., Nielsen, K., Iran, S., & D´Itria, E. (2022). *Unfit, Unfair, Unfashionable: Resizing Fashion for a Fair Consumption Space*. Hot or Cool Institute, Berlin, Germany.

Davis, J. (2003). An overview of transpersonal psychology. *The Humanistic Psychologist, 31*(2-3), 6-21. https://doi.org/10.1080/08873267.2003.9986924

Elgin, D. (1981). *Voluntary simplicity: Toward a way of life that is outwardly simple, inwardly rich*. William Morrow.

Esposti, P., Mortara, A., & Roberti, G. (2021). Sharing and sustainable consumption in the era of COVID-19. *Sustainability, 13*(4), 1903. https://doi.org/10.3390/su13041903

Etzioni, A. (1998). Voluntary simplicity: characterization, select psychological implications, and societal consequences. Journal of Economic Psychology, 19, 619–643. https://doi.org/10.1007/978-3-662-03900-7_1

Hunting, A., & Conroy, D. (2018). Spirituality, stewardship and consumption: New ways of living in a material world. *Social Responsibility Journal*, *14*(2), 255–273 https://doi.org/10.1108/srj-06-2016-0097

Iran, S., Joyner Martinez, C.M., Vladimirova, K., Wallaschkowski, S., Diddi, S., Henninger, C. E., McCormick, H., Matus, K., Niinimäki, K., Sauerwein, M., Singh, R., & Tiedke, L. (2022). When mortality knocks: Pandemic-inspired attitude shifts towards sustainable clothing consumption in six countries. International *Journal of Sustainable Fashion & Textiles, 1*(1), 9–39. https://doi.org/10.1386/sft/0002_1

Grof, C., & Grof, S. (1989). *Spiritual emergency: When personal transformation becomes a crisis*. New York, NY: Putnam's Sons.

Joyner Armstrong, C.M. (2021). Fashion and the Buddha: What Buddhist economics and mindfulness have to offer sustainable consumption. *Clothing and Textiles Research Journal, 39*(2), 91–105. https://doi.org/10.1177/0887302x20917457

Kaiser, S. B. (1997). *The Social Psychology of Clothing: Symbolic appearances in context*. Fairchild Publications.

Kaza, S. (2000). Overcoming the grip of consumerism. *Buddhist-Christian Studies*, *20*(1), 23–42.

https://doi.org/10.1353/bcs.2000.0013
Klepp, I., Laitala, K., & Wiedemann, S. (2020). Clothing lifespans: What should be measured and how. *Sustainability, 12*(15), 6219. https://doi.org/10.3390/su12156219
Penz, E., & Drewes, K.L. (2022). What shapes pro-environmental attitudes and intention for sustainable fashion consumption during a stressful time event? *Sustainability, 14*(22), 15331. https://doi.org/10.3390/su142215331
Pyszczynski, T., Lockett, M., Greenberg, J., & Solomon, S. (2021). Terror management theory and the COVID-19 pandemic. *Journal of Humanistic Psychology*, *61*(2), 173–189. https://doi.org/10.1177/0022167820959488
Sandlin, J.A., & Walther, C.S. (2009). Complicated simplicity. *Adult Education Quarterly*, *59*(4), 298–317. https://doi.org/10.1177/0741713609334137
Sinclair, C. (2016). Transformation and subjectivity in spiritual emergence and emergency: A discourse analytic study. *Journal Of Transpersonal Psychology*, *48*(1), 34-56.
Stillman, T.F., Fincham, F.D., Vohs, K.D., Lambert, N.M., & Phillips, C.A. (2012). The material and immaterial in conflict: Spirituality reduces conspicuous consumption. *Journal of Economic Psychology*, *33*(1), 1–7. https://doi.org/10.1016/j.joep.2011.08.012
Uggla, Y. (2019). Taking back control: Minimalism as a reaction to high speed and overload in contemporary society. *Sociologisk Forskning*, *56*(3–4), 233–252. https://doi.org/10.37062/sf.56.18811
Ulvoas-Moal, G. (2010), "Exploring the influence of spirituality: a new perspective on senior consumers' behavior", in Campbell, M.C., Inman, J. and Pieters, R. (Eds), *Advances in Consumer Research, 37*, Association for Consumer Research, Duluth, MN, 917-919.
Vladimirova, K., Henninger, C.E., Joyner-Martinez, C., Iran, S., Diddi, S., Durrani, M., Iyer, K., Jestratijevic, I., McCormick, H., Niinimäki, K., Thangavelu, P., Sauerwein, M., Singh, R., Simek, P., & Wallaschkowski, S. (2022). Fashion consumption during COVID-19: Comparative analysis of changing acquisition practices across nine countries and implications for Sustainability. *Cleaner and Responsible Consumption, 5*, 100056. https://doi.org/10.1016/j.clrc.2022.100056
Walsh, R.N., & Vaughan, F. (1980). Beyond the ego: toward transpersonal models of the person and psychotherapy. *Journal of Humanistic Psychology, 20*(1), 5-28

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Consumers' interest in using clothing repair services in Finland

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Keywords: Clothing; Repair; Service; Circular economy; Consumption.

Abstract: Sustainable consumption practices, including garment repair, are vital in transition to a circular economy. Engaging in garment repair through professional repair services is, however, not as widely adopted practice as one might hope. This paper focuses on clothing repairs in the Finnish context, aiming to understand how consumers perceive the use of clothing repair services and what might be the reasons for not using these services. An online survey was conducted in 2021 to address this topic as part of a collaboration between the FINIX research project and the Finnish retail and service network S Group. Based on 1,903 survey responses, consumers generally express interest in the sustainable aspects of clothing and recognize themselves playing an important role in extending garment lifetimes. The use of clothing repair services remains yet relatively moderate among Finnish consumers. Many are competent in repairing garments themselves and do not require professional help. Price and availability are other critical factors that discourage consumers from using such services. Establishing a viable repair business may be challenging, given the price levels consumers are willing to pay for garment repairs.

Introduction

The textile and fashion sector is strongly aiming to transition towards a circular economy. The European Commission's vision of sustainable and circular textiles has led towards a policy work where several new regulations are under construction, and which will increasingly push the industry to implement more sustainable practices in doing fashion business (European Commission, n.d.).

Consumers play also an important role in this transition from a linear to a circular production and consumption model. Instead of constantly purchasing new fashion items and using them for a very short time, it is important to take care of the existing garments, to use them actively and to repair them when needed.

The importance of extending the use time of clothing is a recognized goal in the sustainable consumption research (e.g. Niinimäki et al., 2020). Citizen engagement in clothing repair practices and interest in using clothing repair services are increasingly studied (e.g. Qwilt 2014, Cerulli-Harms et al., 2018; Laitala & Klepp, 2018; Durrani, 2019; Jain, 2021; Laitala et al., 2021; Potdar, McNeill & McQueen, 2023). Earlier research shows that older generations seem more likely to engage in paid clothing repair services than younger ones (e.g. McQueen, et al., 2023), and men more likely than women (McQueen et al., 2022; Potdar et al., 2023, ibid.). Motivations behind garment repairs also seem to be linked to emotional connection to a garment, high price and/or good quality (e.g. Laitala et al., 2021; Jain, 2023). Especially quality conscious consumers seem more likely to use professional repair service, if they do not consider the cost of repair to be too high (Jain, 2023). Repair services for expensive garments or alterations done for special events can provide good value for money (Maguire & Fahy, 2022) but this can also be the case when garments require more challenging repairs (McQueen et al., 2023).

By contrast, low-priced and low-quality garments are not perceived to be worth repairing (e.g. Laitala et al., 2021; McQueen et al., 2023). The lack of access to repair services (ibid.) and the effort that is required to arrange the repair (Cerulli-Harms et al., 2018) can also be reasons for not getting clothes repaired. In some countries, many consumers are also competent in repairing clothes themselves, which implies less need for repair services. Private clothing repairs, for example in Norway, are at least three times more common than using professional repair service (Laitala et al.,

2021). However, the most referred barrier for using clothing repair services seems to be the price, which is often compared to the price of a new garment.

The price issue is also visible in the Finnish context (Berninger et al., 2024). Repairing garments and using services for making, fashioning and repairing clothes were common practices in Finnish households until the 1960's and 70's (Frisk, 2023). With the rise of ready-made clothes, the price of clothing related services increased compared to purchasing a new item, and the use of repair and modification services started to decline (Frisk, 2023). Today, another challenge for Finnish clothing repair businesses is that garments are not designed to be repaired (Berninger et al., 2024).

The aim of this paper is to delve deeper into the Finnish context of clothing repairs and provide a better understanding of how consumers view the use of clothing repair services today. The specific research questions are the following:

- How common is the use of clothing repair services?
- How much are consumers willing to pay for clothing repairs?
- What prevents consumers from using clothing repair services?

Currently, the Finnish repair sector is small, consisting mostly of micro-enterprises, in which repair services are mainly used for shoes, leather products, bicycles and mobile phones – self-repair being more common in the context of clothing (Berninger et al., 2024). Despite the above it is important to study consumers' readiness to use garment repair services since the new textile regulations of the European Union push companies to consider garment repairability as part of their business.

Methods

This research was conducted in collaboration with the FINIX research project and S Group. The FINIX project focuses on transition towards sustainable textile system through several themes such as new materials, digital solutions and circular economy management (FINIX, n.d.). S Group is a large customer-owned Finnish retail and service network, which consists of department stores, various specialty stores and hospitality services (e.g. hotels and restaurants) (S Group, n.d.). S Group also has a major role in the Finnish fashion business; even 37% of Finnish consumers are estimated to purchase garments from S Group's biggest supermarket chain 'Prisma' (Finnish Commerce Federation, 2024).

The data collection of this study was carried out through an online survey between April 8–15, 2021. The target group of the survey consisted of adult co-op members of S Group. An email invitation to participate in the survey was sent to 35 000 individuals, who also received one reminder email during the survey period.

The survey questions broadly addressed aspects related to sustainability of clothing, consumers' interest in different kinds of clothing services and use practices. On this basis, we were able to the get an idea of the respondents' general attitudes towards sustainable consumption. The deeper analysis, however, focused on the data that links specifically to clothing repairs; respondents' interest in clothing repair (services); readiness to pay for such services; and barriers to using them. The cross-analysis was applied to find out possible differences in responses in terms of respondents' age, gender or region. Content analysis was applied to identify the most significant reasons for not using clothing repair services.

Findings

A total of 1,903 adult S Group co-op members from various age groups and regions of Finland participated in the survey (Figure 1). Of the respondents, 39% were men, 61% women, and the majority 45 years old or older (71%). 26% lived in the capital region where population density is higher than in other parts of Finland.

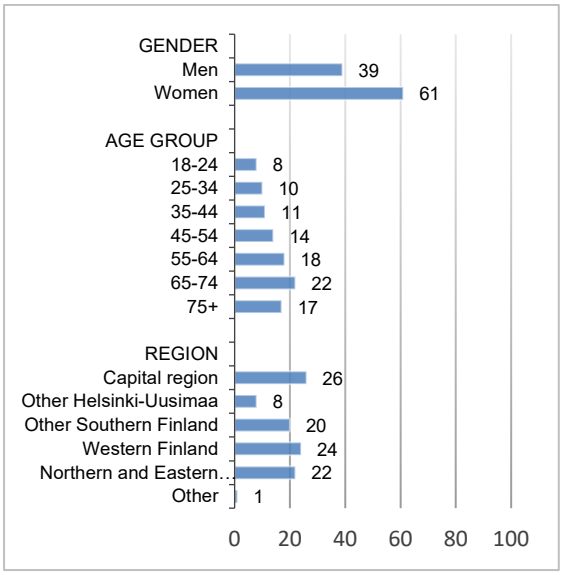


Figure 1. Number of survey respondents by gender, age group and region (% of respondents, N=1903).

General attitudes towards sustainable consumption

70% of the survey respondents show interest in the environmental impact of clothing. 74% think that information about environmental aspects should be more easily available, and more than half of respondents (58%) would like to receive information about the human rights issues of clothing production.

Regarding clothing reuse, the data indicates that many respondents engage in different reuse activities *at least sometimes*: 89% of the respondents donate and 54% sell their own old clothes; and 66% buy second-hand clothes. Correspondingly, 9% of the respondents never donate their clothes; 45% never sell their old clothes; 33% never buy second-hand clothes.

Considering clothing quality and the use phase more generally, most respondents (90%) think they would be willing to pay more for a good quality product if they could trust its quality. A high number of respondents also see that the best way to extend the garment lifetime is to use it carefully (94%) and to maintain it properly (91%). 83% express interest in extending the lifespan of clothing through their own actions, for example by repairing or otherwise taking good care of their garments. This indicates that respondents are quite confident that they themselves are the best actors to extend the use time of their garments.

Current use of clothing repair services

28% of the respondents do use clothing repair services. The number of users by gender, age group and region are illustrated in Figure 2. Among male respondents, 30% reported using services, while for women, the figure was 26%. Those aged 45-54 seem to use clothing repair services the most (35%). Contrarily, the youngest age group reported using repair services the least (16%).

Here it is important to note that the highest total earnings in Finland are among those aged 45–49, whereas the youngest age group has lower income levels compared to other age groups (Statistics Finland, 2022). This can partly explain why older age groups use repair services more. The use of repair services seems to be almost equally popular in all regions (26-32%), except for the other Helsinki-Uusimaa (17%).

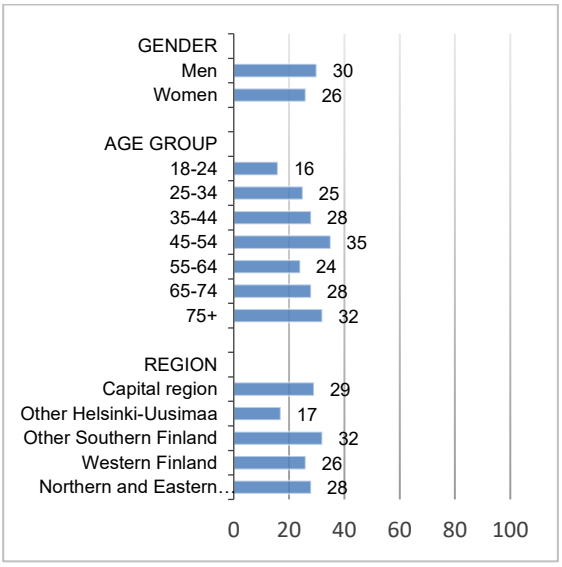


Figure 2. Number of respondents already using clothing repair service(s) by gender, age group and region (% of respondents, N=1903).

Interest to use clothing repair services

Generally, 56% of respondents are *somewhat* (35%) or *very* (21%) interested in using clothing repair services, whereas 23% of respondents are *not very* or *not at all* interested. Regarding gender, age group or region, there were no significant differences in the responses.

When asked if one was interested specifically *in extending the lifespan of a garment by using paid services*, approximately half expressed

their interest (51%). The responses were fairly similar among men and women and in different regions. Those under 24 and between 65-74 were slightly less interested in this particular practice than other age groups, even if still showing moderate interest.

Regarding the relation between repair services and the resale value of clothing, only 26% of respondents are *somewhat (*19%) or very (7%) interested in repair service *if it can increase the resale value of the clothing*. This is quite interesting because the second-hand fashion has become a trendy business in many countries. While 54% of the survey respondents sell their old garments, they apparently have not thought that using repair services might even increase the resale value of their garments and thus make the potential resale activity more profitable for them. The younger age groups (18-44) showed slightly more interest here than older age groups (45+), and women slightly more than men.

Pricing of specific repairs

The purchase price of the clothes has a clear impact on how much respondents are willing to pay for repairs. This was investigated in the survey through *two exemplary products*, which typically might be quite difficult for an average consumer to repair by themselves:

- a winter coat with a broken zipper
- a pair of ripped jeans/trousers

Figure 3 illustrates the amount respondents are most likely to spend on their next winter coat purchase. Figure 4 shows how much the respondents would be willing to pay to repair the winter coat in the price category they chose, if the zipper was to break after some time, but the coat was otherwise in good condition. 75% of the respondents reported they could pay 10-30 euros for repairing a broken zipper of a winter coat, but 8% of the respondents would not pay anything for such a repair.

From the data, it was also possible to observe that the younger age groups (18-34) would more likely purchase a winter coat with under 100 euros than older age groups. In contrast, a coat over 300 euros would most likely be bought by someone over 75. Older age groups and those living in the capital region if Finland seem more willing to buy more expensive winter coats and pay higher repair prices.

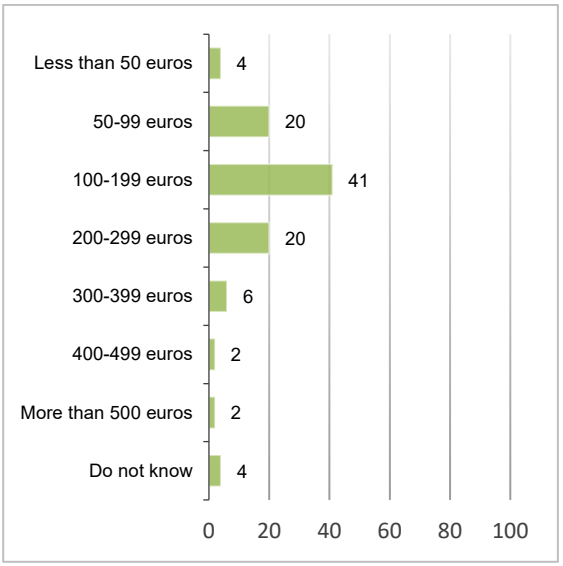


Figure 3. Respondents' estimates of the price category of their next winter coat purchase (% of respondents, N=1903).

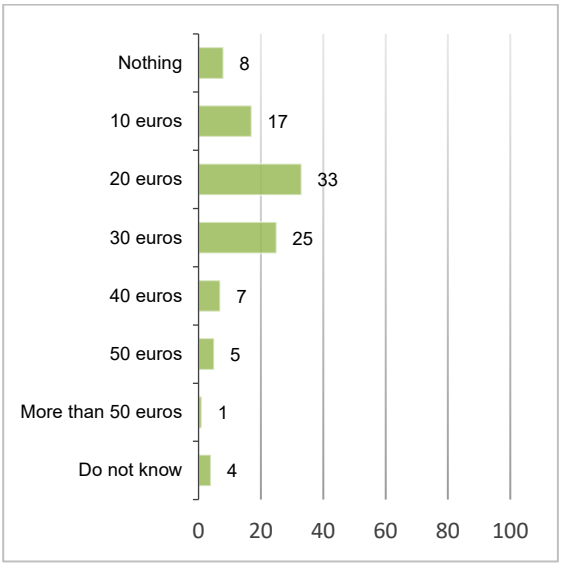


Figure 4. Acceptable repair price for a broken zipper of a winter coat (% of respondents, N=1903).

Figure 5 illustrates the amount respondents are most likely to pay for their next jeans/trousers. Figure 6 shows what could be an acceptable repair price for a pair of ripped jeans/trousers if it was otherwise in good condition. 53% would be ready to spend 10-20 euros on repairing such a product, whereas 25% would not pay anything.

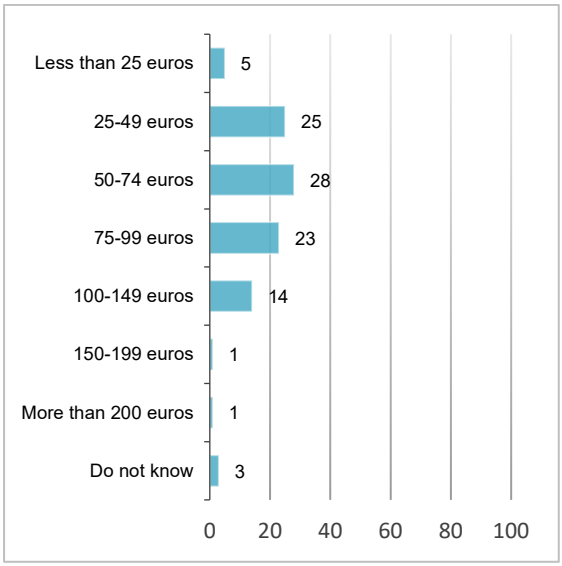


Figure 5. Respondents' estimates of the price category of their next jeans/trousers (% of respondents, N=1903).

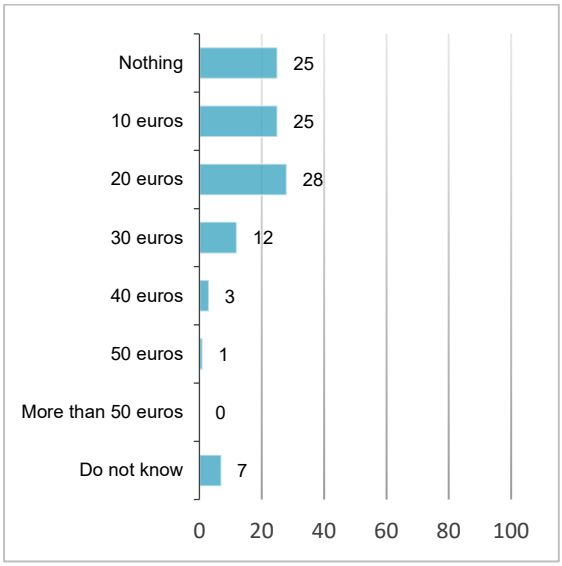


Figure 6. Acceptable repair price for ripped jeans/trousers (% of respondents, N=1903).

Generally, the cheaper the product, the less the respondents are willing to pay for repair services in euros. This applied to both exemplary products. However, the acceptable repair price of more expensive products, in relation to the original purchase price, seems to be percentage-wise lower than for cheaper products.

Reasons for not using clothing repair services

A significant number of respondents (23%) reported not being particularly interested in extending the lifespan of their clothing through repair service. The question of what currently prevents consumers from using clothing repair services was approached through an open-ended question, which got 1645 answers (86% of all survey respondents). The main reasons for not using clothing repair services are illustrated in Table 1. It shows how many respondents mentioned the specific reason. The percentage indicates the proportion of those who answered this open-ended question.

Across all age groups the main reason was that consumers have the skills to repair clothes themselves or they have "someone close" who can. 83% of respondents who reported having repair skills were women. Regarding age, repair skills seemed to be equally common in both younger and older age groups. For men, "someone close" is often the spouse, whereas for women, a mother, a close relative or a friend is usually the one repairing for them. The response "I could probably repair the garment myself" also shows confidence in a respondent who apparently is not an active "repairer", but still believes in their own abilities to repair.

Price was the second biggest reason for not using clothing repair services. Responses not only mentioned "high price" but also expressed concerns that such services are not profitable for consumers compared to "just buying a new garment". Price seemed to be a critical factor equally for men and women, but more for younger than older age groups.

Availability and accessibility were further factors for not using clothing repair services and almost equally significant in all regions. From the data, it was also possible to observe that 67% of all survey respondents are positive about clothing repair (plus alteration and rental) services being in shopping centers; 61% consider markets suitable locations; and 30% think such services could operate via online and postal service. Shopping centers and supermarkets got most support from those of 35-44. The youngest age groups (18-44) were more favorable towards the online option than older age groups.

Moreover, many stated they do not simply need repair services because they already buy long-lasting garments or that the items are often too damaged to be repaired at the end of their life. These types of responses were more typical of men than women.

Reasons	Examples
Repair skills 36 %, N=584	I'll repair it myself or take it to a friend to repair it. I fix what I can myself. I could have the zipper replaced by a professional, but there hasn't been a need for that.
Price 11 %, N=176	Too expensive I don't see it profitable to repair worn and cheap clothes. You can get clothes relatively cheaply. Repairs might cost more.
Availability and accessibility 9 %, N=148	The service offering is quite limited. There are no repair services nearby.
No need for repair service 8 %, N=135	I use them so that there is nothing left to be repaired. My clothes usually last a very long time and when they fall apart, I buy new ones. My clothes don't wear out much with use.
Lack of information 7 %, N=120	It is not advertised. I don't know where to take broken garments. I don't know where they are or what they cost or if they are easy to use.
Required efforts 2,5 %, N=41	It's complicated. Laziness to go and take the garment to the repair service separately. The hassle of waiting and picking up the repaired garment.

Table 1. Reasons for not using clothing repair services (% of respondents, n=1645).

Many also lack information about the existence of clothing repair services and how they operate. Surprisingly few mentioned that repair services require effort, although one might assume that this would be a reason for significantly more respondents. Other reasons for not using repair services were also mentioned, but they were marginal in this data (e.g. preference to buy new; lack of interest; lack of time; appearance of the repaired garment).

Discussion and conclusions

Finnish consumers are nowadays continuously informed about the unsustainability of the clothing industry through various media and encouraged to consider their clothing consumption more carefully. However, the use of clothing repair services in Finland seems still quite modest based on this research. Active engagement in self-repair practices might be a significant reason since it has been recognized that many Finnish consumers are capable to repair garments themselves, they are willing to learn these skills and garment repair workshops are very popular (e.g. Niinimäki et al., 2021). This might reduce interest in professional garment repair services and thereby hinder Finnish companies from developing such services even if the new EU regulations put pressure on them.

This research also supports what is already known regarding motivations for, and barriers to, using clothing repair services (e.g. Laitala et al. 2021; McQueen et al., 2023). Some consumers feel that repair services are too expensive, and cheap clothes are not worth repairing. In addition, finding repair services might require too much effort. Especially in Finland distances can be quite long to locations offering physical repair services. Therefore, it would make sense to place such services in locations where consumers visit regularly (supermarkets or shopping centers). Online services, which connect consumers to service providers (e.g. Vuota, n.d.) are also important and might encourage especially younger consumers and those living in rural areas to find professional repair help.

Surprisingly, there were no concerns among respondents about the repair results (e.g. aesthetics of repair, how the garment will look after repair, nor functional aspects of a repaired garment). This might show consumers' acceptance of wearing repaired garments, which previous research has identified being an issue (e.g. Qwilt, 2014). Alternatively, this may indicate trust in clothing repair services.

The unique feature of this research is the Finnish context of clothing repairs. Moreover, the paper sheds light to how much Finnish consumers might be willing to spend on clothing repair services. This is crucial information when

aiming to create viable repair business in Finland (or other similar markets) and thinking about the pricing of specific repairs. A business model, in which costs of garment repair services are already included totally or partly in the retail prices of garments, would be worth to address in the future research.

Acknowledgments

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References

Berninger, K., Heinonen, T., Korsunova-Tsaruk, A., Lundberg, P., Meriläinen, T., Myllärniemi, J., Mäkihelmi, M., Määttä, H., & Savolainen, H. (2024). Tavaroiden korjaus palveluiden laajentamisen potentiaali, hyödyt ja ohjauskeinot: REPAIRED-hankkeen loppuraportti. Valtioneuvoston kanslia. https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/165670/VNTEAS_2024_22.pdf

Cerulli-Harms, A., Porsch, L., Suter, J., Rodriguez Dias, A., Peroz., T., Vermeulen, J., Landzaat, W., Smit, T., Kettner, S., Lucica, E., Duke, C., Dekeulenaer, F., Svatikova, K., & Thorun, C. (2018). Behavioural Study on Consumers' Engagement in the Circular Economy - Final Report. European Commission. https://data.europa.eu/doi/10.2818/956512

Durrani, M. (2019). Through the threaded needle: A multi-sited ethnography on the sociomateriality of garment mending practices. Doctoral Thesis. Aalto University.https://urn.fi/URN:ISBN:978-952-60-8801-3

European Commission (n.d.). EU strategy for sustainable and circular textiles. https://environment.ec.europa.eu/strategy/textiles-strategy_en

Finnish Commerce Federation (2024). The popularity of supermarket fashion seems to be slowing down the emergence of Chinese ultra-fast fashion for now. https://kauppa.fi/en/uutishuone/2024/05/22/the-popularity-of-supermarket-fashion-seems-to-be-slowing-down-the-emergence-of-chinese-ultra-fast-fashion-for-now/

FINIX (n.d.). FINIX - Research areas.https://finix.aalto.fi/research-areas/

Frisk, M. (2023). Miksi vaatteiden korjaaminen ja muodistaminen väheni sotien jälkeisessä Suomessa? In Berg, A., Heiskanen, E., Matschoss, K., & Posti, M. (Eds.). *Kuluttajat kiertotaloudessa: Kohti kiertotaloutta ja korjaamista edistävää yhteiskuntaa*. Ympäristöministeriö, pp. 42–48. https://urn.fi/URN:ISBN:978-952-361-231-0

Laitala, K., & Klepp, I. G. (2018). Care and Production of Clothing in Norwegian Homes: Environmental Implications of Mending and Making Practices. Sustainability, 10(8), 2899. https://doi.org/10.3390/su10082899

Laitala, K., Klepp, I. G., Haugrønning, V., Throne-Holst, H., & Strandbakken, P. (2021). Increasing repair of household appliances, mobile phones and clothing: Experiences from consumers and the repair industry. Journal of Cleaner Production, 282. https://doi.org/10.1016/j.jclepro.2020.125349

Maguire, H., & Fahy, F. (2023). Sew what for sustainability? Exploring intergenerational attitudes and practices to clothing repair in Ireland. Irish Geography, 55(1). https://doi.org/10.55650/igj.v55i1.1469

McQueen, R.H., Jain, A., McNeill, L.S., & Kozlowski, A. (2023). The role of resources in repair practice: Engagement with self, paid and unpaid clothing repair by young consumers. *Textile Research Journal*, 93(3-4), pp. 576–591. https://doi.org/10.1177/00405175221123067

McQueen, R.H., McNeill, L.S., Huang, Q., & Potdar, B. (2022). Unpicking the Gender Gap: Examining Socio-Demographic Factors and Repair Resources in Clothing Repair Practice. Recycling, 7(53). https://doi.org/10.3390/ recycling7040053

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. Nature Reviews Earth & Environment 1, pp. 189–200. https://doi.org/10.1038/s43017-020-0039-9

Niinimäki, K., Durrani, M. & Kohtala, C. (2021). Emerging DIY Activities to Enable Well-being and Connected Societies, International Journal of Craft Research, 12(1), pp. 9–29. https://doi.org/10.1386/crre_00038_1

Jain, A. (2021). Influence of consumption behaviours, attitudes and barriers toward clothing repair. Master's Thesis. University of Alberta. https://doi.org/10.7939/r3-bekh-ry58

Potdar, B., McNeill, L. S., & McQueen, R. H. (2023). An investigation into the clothing repair behaviour of fashion-sensitive consumers. International Journal of Fashion Design, Technology and Education, 17(3), 321–335. https://doi.org/10.1080/17543266.2023.2285327

S Group (n.d.) About S Group. https://s-ryhma.fi/en/about-us/s-group-in-brief
Statistics Finland (n.d.). Work, wages and livelihood. https://stat.fi/tup/suoluk/suoluk_palkat_en.html
Vuota (n.d.) Vuota Repair Service Online. https://vuota.fi

Research paper
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Empowering Township Elderly Women: Upcycling Post-Consumer Waste Clothes into Sustainable Livelihoods

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Keywords: Upcycling; Post-Consumer Waste; Township; Sustainable Fashion; Community-Based Enterprise

Abstract: Post-consumer clothing waste poses significant environmental and economic challenges, with second-hand garments often discarded despite their potential for reuse. Addressing this issue requires solutions that reduce waste and empower communities, especially marginalised groups like elderly women in township settings. This study explores how upcycling post-consumer waste clothes, guided by cradle-to-cradle principles and co-design processes, can enhance sustainability and social empowerment among elderly women in a South African township. Adopting a qualitative, case-based approach, participants were engaged through Grandmothers Against Poverty and AIDS (GAPA). Second-hand clothes sourced from local stores served as raw materials. Data collection included semi-structured interviews, participant observations, and examination of final products. Initially, participants relied on intuitive sewing techniques. Later, an expert introduced a structured, step-by-step upcycling method, encouraging them to apply more deliberate design strategies. Participants exhibited resourcefulness and creativity before the expert's intervention without explicitly recognising their efforts as sustainable. After the expert-led workshops, their products showed improved quality, durability, and potential marketability. Participants recognised upcycling as personally enriching, potentially income-generating, and environmentally meaningful. They also expressed interest in sharing knowledge with other grandmothers, indicating a ripple effect of skill dissemination. This research demonstrates that blending community-based ingenuity with structured upcycling strategy guidance can transform second-hand clothing waste into a vehicle for environmental stewardship, social cohesion, and economic resilience. It illustrates how local craftsmanship, informed by sustainable design frameworks, can foster ecological sustainability and community empowerment

Introduction

The fashion industry is a significant contributor to global waste, with millions of tons of clothing discarded annually. Globally, the fashion industry produces around 92 million tonnes of textile waste each year, contributing significantly to environmental pollution and accounting for 10% of global carbon emissions (Bick et al., 2018). This waste is primarily driven by the fast fashion model, which encourages frequent purchases and disposals due to rapidly changing trends and low-cost production (Andreadakis & Owusu-Wiredu, 2023). The environmental impact is further exacerbated by the fact that less than 1% of the total fiber input used for clothing is recycled into new garments, resulting in substantial material value loss (Ellen MacArthur Foundation, 2017). In response to these challenges, sustainable practices such as upcycling have gained attention. Upcycling, the process of transforming waste materials into new, higher-value products, offers a sustainable solution to this problem. Unlike traditional recycling, which often downcycles materials into lower-quality products, upcycling adds value by creating items that are of equal or greater quality than the original materials (Sung et al., 2020). This process not only reduces waste but also conserves resources by minimizing the need for new raw materials. Upcycling supports a circular economy, where products are reused and repurposed, thereby extending their lifecycle and reducing environmental impact (Singh & Rani, 2021).

In South Africa, the fashion industry primarily engages with sustainability through second-hand clothing markets and informal recycling practices. However, research and implementation of advanced sustainable practices, such as upcycling, remain limited. Studies indicate that upcycling in the Global South focuses more on livelihoods and

employment, as opposed to environmental priorities emphasized in the Global North (Monyaki & Cilliers, 2023).

Cape Town-based businesses, for example, have highlighted the potential for remanufacturing and upcycling in advancing sustainable fashion; however, these efforts are constrained by limited skills and resources (Monyaki & Cilliers, 2023). Additionally, grassroots innovations play a significant role in addressing sustainability and socioeconomic challenges, particularly in marginalized communities (Calvo et al., 2020). Yet, these initiatives lack the formal structure and design strategies needed to scale their impact effectively.

This study explored how upcycling post-consumer waste clothes can empower elderly women in township communities, enhancing their skills and creating sustainable livelihoods. Elderly women in these communities often face economic and social challenges, including limited access to employment opportunities and social isolation. By engaging in upcycling activities, they can develop valuable skills, gain financial independence, and foster a sense of community (Tyler & Han, 2019). The workshop sessions designed for this study aimed to enhance their upcycling skills, enabling them to transform discarded clothing into trendy marketable products.

This research aimed to enhance both academic discourse and practical applications in sustainable fashion by integrating environmental sustainability and social empowerment. Addressing waste reduction and fostering skill development and economic opportunities are crucial for achieving sustainable development goals (Hajam et al., 2023). This study not only highlights the potential of upcycling as a sustainable practice but also demonstrates its capacity to create meaningful social change.

Literature Review

The linear production model of fast fashion and rapid consumption cycles present huge detriment to environmental. The way the industry does this is by focusing on frequency of turnover and cheap, poor quality garments that are meant to be used often, thereby depleting natural resources, producing huge amounts of waste and pollution. The following subsections examine the key environmental issues linked to fast fashion:

Resource Overexploitation

Many fast fashion models are based on intensive use of the raw materials and cheap labor and choose unsustainable practices. For example, the practice of cotton growing consumes gigantic amounts of water and pesticides and incurs enormous ecological damage. Aral Sea's good example of how large expanses of water can be destroyed by water intensive farming, ruching regional ecosystems and communities (Marrocco, 2024).

Waste generation

The reason why the textile waste is piling up is because of fast fashion's special focus on affordability and disposability. Currently, less than 1% of fast fashion garments are recycled, enabling a missed opportunity to recover valuable materials and reduce landfill use (Soudi & Mohssine, 2024). The problem is compounded by the fact that the industry is responsible for major contributions to micro plastic pollution. Approximately 35 per cent of all microplastics found in the ocean stem from synthetic apparel fibers that threaten marine life and food security over the long term (Marrocco, 2024).

The kind of severity implied by these challenges gives way to emerging innovations that can bring about a more responsible fashion industry (Sonnenberg et al., 2022). Closed loop recycling systems and bio based materials offer opportunities to conserve resources, minimise waste and alleviate reliance on dangerous chemicals (Hvass, 2014). Translating fast fashion from ecological crisis making, to a circular economy will facilitate the reorientation of fast fashion to be in line with sustainable development goals, minimizing its environmental footprint and securing long term ecological resilience (Lin & Chen, 2022).

Building on these environmental challenges and the potential solutions offered by circular economy principles, the following section further explores the role of upcycling as a strategic alternative to conventional recycling. This emphasis on value retention, creative reuse, and enhanced product durability not only aligns with the broader aims of circularity but also addresses many of the ecological and socioeconomic concerns identified above (Balu et al., 2022).

Circular Economy

In the context of the fast fashion industry, the circular economy (CE) has become an attractive alternative to the linear production models, which are predominant. According to CE, rather than the 'take-make-dispose' scenario, the Foundation advocates for resource efficiency, material waste minimization, and the ongoing circulations of materials at their highest available value (Ellen MacArthur Foundation, 2017). CE based strategies attempt to alleviate environmental pressures, minimize virgin material dependence and promote long term sustainability within the fashion sector through rethinking supply chains, product lifecycle and consumption behaviours (Bick et al., 2018).

Circular Economy: upcycling principle

Upcycling, under the CE paradigm, is increasingly garnered as a means extending a product's lifespan but also increasing product value. Compared to downcycling, upcycling converts post-consumer waste into equal or better value products, thereby saving resources, eliminating environmental footprints (Singh & Rani, 2021) This suggests that integrating upcycling into current fashion systems can alleviate clothing waste, reduce the overall emissions, and spur people to take on more ethical consumption habits (Soudi & Mohssine, 2024). This practice supports CE goals by that keeps materials in circulation for as long as possible, hence slowing resource depletion and reducing landfill use (Repp et al., 2021).

Cradle to Cradle (C2C) in Upcycling Clothing

Building on the cradle-to-cradle (C2C) framework proposed by McDonough and Braungart (2010) the principle that "waste equals food" underscores the potential for transforming post-consumer textile waste into valuable inputs for new garments. Two aspects of their design framework are particularly relevant to upcycling clothing: (1) viewing everything as a resource for something else, and (3) celebrating diversity in design.

Everything is a Resource for Something Else

Central to the first principle is the concept that materials should be perpetually cycled through biological or technical loops to eliminate waste (McDonough & Braungart, 2010). In the context of clothing, this means selecting textiles and components that can be continuously repurposed. Instead of discarding old garments, their fibers, buttons, and zippers become raw materials for new items. Previous studies on sustainable fashion have demonstrated how this aligns with the circular economy, reducing the need for virgin fibers while alleviating the burden on landfills (Ellen MacArthur Foundation, 2017). Upcycling, as a technique, operationalizes this principle by reintroducing value into discarded textiles and extending product lifespans.

Celebrate Diversity

The third principle emphasizes the importance of diversity in design, acknowledging that cultural, environmental, and material variation can drive innovation and resilience (McDonough & Braungart, 2010). For upcycled clothing, this principle encourages tailoring designs to local contexts, resources, and artisan skills, thereby producing garments that reflect unique community aesthetics and cultural narratives. Such an approach resonates with community-based initiatives, where incorporating local patterns, stitching techniques, and regional motifs can improve product desirability and marketability (Tyler & Han, 2020).

Cradle-to-Cradle Certified Product Standard

To operationalize these principles, the Cradle to Cradle Certified® Product Standard provides a structured assessment framework that encourages material health, product circularity, clean air and climate protection, water and soil stewardship, and social fairness (Cradle to Cradle Products Innovation Institute, 2013). By meeting these criteria, upcycled clothing ventures can ensure that their products not only utilize safe, renewable materials (material health) but are also intentionally designed for continuous cycling (product circularity). Applying such standards helps guarantee that upcycled garments contribute positively to local ecosystems (clean air & climate protection, water & soil stewardship) while respecting fair labor practices and community well-being (social fairness).

For example, selecting fabrics free of harmful chemicals (material health) and opting for fibers that can be mechanically or chemically recycled into high-quality yarns (product circularity)

supports continuous material flow. Simultaneously, integrating local craftsmanship respects cultural diversity, aligns with social fairness principles, and may enhance community livelihoods. Over time, meeting these certification criteria reinforces credibility and consumer trust, potentially enabling upcycled clothing brands to scale their operations sustainably.

By synthesizing C2C, upcycled clothing initiatives can move beyond ad hoc practices. This integrated approach ensures that repurposed garments meet rigorous sustainability benchmarks while remaining deeply attuned to local cultural contexts and environmental considerations.

Co-Design in Upcycling Clothing

Participatory methods that involve local stakeholders are necessary to implement upcycling and C2C strategies in a wide variety of social contexts. Understanding the relevance of co-design as an effective strategy for sustainability initiative adoption, scalability, and impact, it has been identified that co-design approach incorporating end users and the community members in processes of design, is a great strategy for that. Co-design is a process that engages participants to use their past knowledge (culturally and socially), existing skills, and creativity to 'upcycle' clothing into marketable, durable and contextually relevant garments (Calvo et al., 2020; Monyaki & Cilliers, 2023). The benefits of this collaborative framework are both in improving product outcomes — such as design quality and longevity — and enhancing social cohesion, confidence building, and the spread of sustainable practices at a grass roots level. In prior studies, engaging marginalized groups in co design can create more inclusive resilient circular fashion models that are more beneficial to all stakeholders (economically and socially) across communities (Sung et al., 2020; Tyler & Han, 2020).

Although the upcycling of clothing and textile waste is increasing globally, and cradle-to-cradle principles are gaining traction in sustainable design, research in South Africa has seldom examined how applying these concepts can empower less privileged groups, particularly elderly women in township communities.

Methodology

This study adopted a qualitative, case-based approach designed to capture the nuanced experiences, skill development, and product transformations within a community-based upcycling context. The primary setting was a township in Cape Town, South Africa, where elderly women were engaged through Grandmothers Against Poverty and AIDS (GAPA), a local non-profit organization well-established in supporting older women's health, social, and economic needs. GAPA facilitated initial contact, provided a safe and familiar space for participants, and ensured that all activities were culturally appropriate and sensitive to local dynamics.

The participant pool included elderly women aged 55 and above, who possessed basic sewing skills acquired through domestic crafts or informal garment alterations. Selection criteria emphasized willingness to participate, interest in improving sewing techniques, and openness to working with second-hand clothing. Purposive sampling ensured that those included would offer rich insights into the lived experiences, skill enhancement, and creative processes integral to upcycling. In total, 10 participants were recruited, allowing for manageable group interactions while maintaining sufficient diversity in age, experience, and personal circumstances.

Second-hand clothing items were sourced from two local thrift stores to ensure authenticity and relevance to the participants' context. These garments varied in fabric type, wear, and quality, reflecting the heterogeneous nature of post-consumer waste streams. By presenting participants with a range of materials, it was possible to observe how they navigated design challenges, identified opportunities for material reuse, and experimented with construction techniques.

Data collection employed multiple qualitative techniques to capture both process and outcome dimensions. Semi-structured interviews, conducted individually and in small groups, gathered personal reflections on participants' experiences, motivations, and perceptions of upcycling. Participant observations documented interactions during co-design workshops, noting how participants selected materials, applied sewing and design skills, and interacted with peers and the design expert. The final upcycled products were examined as tangible outputs that illustrated improvements in quality, durability, and aesthetic appeal. Photographs, field notes, and

reflective journals complemented direct observations, creating a rich data set for subsequent analysis.

Data analysis followed a thematic approach guided by Cradle-to-Cradle (C2C) design principles. Initial coding identified patterns related to skill development, product innovation, and environmental sustainability. Subsequent thematic refinement involved cross-referencing participant narratives with observed practices and product outcomes, clarifying how structured guidance influenced participants' understanding of sustainability and enhanced their craftsmanship. Ethical considerations were paramount throughout the study. Informed consent procedures ensured that participants understood the purpose, benefits, and potential risks of involvement. Confidentiality measures included secure data storage and anonymized reporting of findings, maintaining participants' privacy and autonomy.

By triangulating multiple data sources and drawing on a theoretical lens grounded in C2C principles, this methodology enabled an in-depth exploration of how co-design processes and structured upcycling guidance could transform discarded materials into meaningful, marketable products, ultimately fostering empowerment, social cohesion, and environmental stewardship.

Results and Discussion

The findings highlight that the participants not only improved their technical skills but also gained personal and social benefits that are often overlooked in similar initiatives. These include enhanced confidence, a sense of purpose, and emotional fulfillment, which were described as transformative. These non-tangible outcomes complement the tangible improvements, such as product quality and design structure, showcasing the broader impact of upcycling activities.

The findings indicate that participants, who initially relied on their household-level sewing skills and intuition, were already transforming post-consumer waste clothes into useful items before any formal intervention. Although these early efforts lacked a structured approach, the women demonstrated creativity, resourcefulness, and a willingness to engage with discarded materials. At this stage, participants did not recognize their actions as contributing to sustainability, yet their instinctive modifications aligned, in principle, with cradle-to-cradle ideals by giving old garments a second life.

The introduction of the design expert and a more systematic, step-by-step methodology brought a clear enhancement to both the process and the outcomes. Through co-design workshops, participants learned to dissect garments, sketch designs, and tailor their constructions more thoughtfully. This newfound structure did not replace their intuitive strengths; instead, it refined them. As a result, participants produced items that were more durable, aesthetically pleasing, and better suited for potential market ventures. The co-design environment encouraged collaboration, idea exchange, and the recognition that their work could serve broader environmental and economic purposes.

Interviews revealed that the women came to view upcycling as more than a set of techniques: it became personally fulfilling, therapeutic, and enriching. Many expressed plans to continue producing upcycled garments for extra income and saw value in sharing these skills with other grandmothers in their communities. In essence, blending local ingenuity with expert guidance not only improved product quality but also fostered environmental awareness, social cohesion, and economic resilience, thereby exemplifying the transformative potential of community-driven, sustainable fashion practices.

Conclusion and Recommendations

This study shows how integrating cradle-to-cradle principles with co design approaches allow township elderly women to make their post-consumer waste clothes sustainable livelihoods. Participants were able to learn to produce upcycled garments of improved quality, durability, and marketability by taking their existing local ingenuity and sewing skills and merging them with structured design guidance. What it accomplished went beyond technical outcomes: It developed essential non tangible skills such as confidence, creativity, and collaboration; it motivated individuals to take action; and it generated significant emotional fulfillment for participants.

Environmental waste management and socioeconomic marginalization are tackled by the study through the use of structured upcycling initiatives. In addition to environmental stewardship, participation

allowed participants to extend the lifecycle of discarded clothing, in the process improving economic resilience in their communities. With their new knowledge to share, and increased awareness of sustainable practices, they are now empowered as agents of change equipped to pass on the knowledge to their community in a compliant manner. This provides clear proof of the transformative upcycling can be a tangible, scalable solution for sustainability in resource scarce environments.

The research also provides a replicable model for enabling marginalized communities globally, particularly in parts of the Global South burdened with socioeconomic inequality and environmental pressure. Using local skills to bridge the gap between the informal craftsmanship and structured sustainable production systems provides a means by which transformation to the circular economy can be triggered and inclusive participation can be achieved. Upcycling is then seen more than as a sustainability tool, but as a driver for social cohesion, environmental awareness, and economic opportunities among under served populations.

It is recommended that future work concentrates on scaling these findings in collaboration with non profit organizations, policymakers and local businesses. Expanding such programs will depend crucially on providing access to funding, training, and market platforms. In addition, longitudinal studies could also test the long term beneficial effects of upcycling on participants' financial stability, skill retention or environmental contributions.

The research reinforces the value of upcycling to deal with textile waste and aggrandize marginalized communities. Upcycling represents an opportunity to combine local resourcefulness with the structure of sustainable design principles to create a powerful vehicle to achieve social justice and environmental sustainability within a circular economy.

References

Andreadakis, S., & Owusu-Wiredu, P. (2023). Fashion Footprint: How Clothes Are Destroying Our Planet and the Growing Impacts of Fast Fashion. In K. Vinay (Ed.), *Global Warming* (pp. Ch. 8). IntechOpen. https://doi.org/10.5772/intechopen.1002000

Balu, R., Dutta, N. K., & Choudhury, N. R. (2022). Plastic Waste Upcycling: A Sustainable Solution for Waste Management, Product Development, and Circular Economy. *Polymers*, *14*(22), 4788. https://doi.org/10.3390/polym14224788

Bick, R., Halsey, E., & Ekenga, C. C. (2018). The global environmental injustice of fast fashion. In *Environ Health* (Vol. 17, pp. 92). https://doi.org/10.1186/s12940-018-0433-7

Calvo, S., Morales, A., Núñez-Cacho Utrilla, P., & Guaita Martínez, J. M. (2020). Addressing sustainable social change for all: Upcycled-based social creative businesses for the transformation of socio-technical regimes [Article]. *International journal of environmental research and public health*, *17*(7), Article 2527. https://doi.org/10.3390/ijerph17072527

Cradle to Cradle Products Innovation Institute. (2013). Cradle to Cradle Certified Product Standard Version 3.1.

Ellen MacArthur Foundation. (2017). *A new textiles economy: Redesigning fashion's future*. https://www.ellenmacarthurfoundation.org/publications/a-new-textiles-economy-redesigning-fashions-future.

Hajam, Y. A., Kumar, R., & Kumar, A. (2023). Environmental waste management strategies and vermi transformation for sustainable development. *Environmental Challenges*, *13*, 100747. https://doi.org/https://doi.org/10.1016/j.envc.2023.100747

Hvass, K. K. (2014). Post-retail responsibility of garments – a fashion industry perspective. *Journal of Fashion Marketing and Management*, *18*, 413-430. DOI: 10.1108/JFMM-01-2013-0005

Lin, P.-H., & Chen, W.-H. (2022). Factors That Influence Consumers' Sustainable Apparel Purchase Intention: The Moderating Effect of Generational Cohorts. *Sustainability*, *14*(14), 8950. https://www.mdpi.com/2071-1050/14/14/8950

Marrocco, a. T. (2024). Environmental impact of the life cycle of textiles and mitigation options: online informative and educational resources / impatto ambientale dei prodotti tessili ed opzioni di mitigazione: risorse informative ed educative online. *European Journal of Social Sciences Studies*, *10*(3). https://doi.org/10.46827/ejsss.v10i3.1785

McDonough, W., & Braungart, M. (2010). *Cradle to cradle: Remaking the way we make things*. North point press.

Monyaki, N. C., & Cilliers, R. (2023). Defining Drivers and Barriers of Sustainable Fashion Manufacturing: Perceptions in the Global South [Article]. *Sustainability (Switzerland)*, *15*(13), Article 10715. https://doi.org/10.3390/su151310715

Repp, L., Hekkert, M., & Kirchherr, J. (2021). Circular economy-induced global employment shifts in apparel value chains: Job reduction in apparel production activities, job growth in reuse and recycling activities. *Resources,*

Conservation and Recycling, *171*, 105621. https://doi.org/https://doi.org/10.1016/j.resconrec.2021.105621

Singh, S., & Rani, J. (2021). Traditional Indian Textile Techniques Used to Upcycle and Recycle Textile Waste [Article]. *Textile and Leather Review*, *4*, 336-353. https://doi.org/10.31881/TLR.2021.29

Sonnenberg, N. C., Stols, M. J., Taljaard-Swart, H., & Marx-Pienaar, N. J. M. M. (2022). Apparel disposal in the South African emerging market context: Exploring female consumers' motivation and intent to donate post-consumer textile waste. *Resources, Conservation and Recycling*, *182*, 106311. https://doi.org/https://doi.org/10.1016/j.resconrec.2022.106311

Soudi, N., & Mohssine, T. (2024). The Role of Innovation in Making Fast Fashion Less Polluting. *International Journal of Advanced Multidisciplinary Research and Studies*, *4*, 129-138. https://doi.org/10.62225/2583049X.2024.4.6.3406

Sung, K., Cooper, T., Oehlmann, J., Singh, J., & Mont, O. (2020). Multi-Stakeholder Perspectives on Scaling up UK Fashion Upcycling Businesses. *Fashion practice*, *12*(3), 331-350. https://doi.org/10.1080/17569370.2019.1701398

Tyler, D. J., & Han, S. L. C. (2019). Designing Products for the Circular Economy. In *Technology-Driven Sustainability: Innovation in the Fashion Supply Chain* (pp. 93-116). https://doi.org/10.1007/978-3-030-15483-7_6

Tyler, D. J., & Han, S. L. C. (2020). Designing Products for the Circular Economy. In G. Vignali, L. F. Reid, D. Ryding, & C. E. Henninger (Eds.), *Technology-Driven Sustainability: Innovation in the Fashion Supply Chain* (pp. 93-116). Springer International Publishing. https://doi.org/10.1007/978-3-030-15483-7_6

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Idle and Active Dresses: Design Briefings from the Wardrobe

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Keywords: use phase; wearing; underutilisation; wardrobe study; dress archetype.

Abstract: This paper explores how a wardrobe study, the dress audit, was combined with literature on the dress archetype to create a brief for fashion design practice that aims to increase the active wearing of dresses. Overall, clothing utilisation has declined by over a third in the last 15 years, with dresses being the least worn of any significant item. Unworn dresses amount to hidden wardrobe waste, and increasing their utilisation could reduce fashion overconsumption.

A cultural examination of the dress through a lens of sustainability reveals an archetype of the Western fashion system, tied to production and consumption discourses with complex socio-political dimensions. In contrast, the wardrobe study provided vital insights into dress-wearing experiences.

Most dresses are now mass-produced, creating a disconnect between designers and wearers, and this paper highlights some of the implications of this divide. The wardrobe study identified three leading factors that impact wearing: fit, occasion, and style. If designers address these three factors alone, it could mitigate up to 80% of low usage issues. These findings helped develop five baseline parameters and create a new brief for fashion design practice that prioritises greater garment utilisation by incorporating the lived experience of wearing within the design process.

Introduction

Clothing utilisation has declined by over a third in the last 15 years (Sellers 2022). A recent Australian study (Payne et al. 2024) revealed that a third of participants did not wear half of their wardrobe in the past year. Dresses are believed to make up more than a quarter of Australian wardrobes–the most of any significant garment type–yet are also the least worn clothing item, with more than half rarely worn (Khan et al. 2022). Unworn or idle clothing amounts to hidden wardrobe waste, and it has been suggested that increasing the active use of clothing may reduce the overconsumption of fashion products (Coscieme et al. 2022).

This, however, assumes that dress owners can be compelled to wear their clothes more; Fletcher (2012) stated that within the existing fashion system, a designer's agency to impact the long-term utilisation of clothing is questionable, or, at the very least, there is little or no evidence to support it (Payne 2021). Fletcher (2012) also argues that designers rarely consider the wearing practices or 'lifeworld' that impacts garment longevity. Within the fashion system, knowledge of customer behaviour is limited to the point of purchase. Beyond acquisition, scant attention is given by fashion companies to the frequency with which people wear their clothes.

Increasingly sustainable fashion studies have highlighted clothing use practices and their implications for sustainability (Fletcher 2016; Klepp et al. 2020; Laitala and Klepp 2020; Niinimäki 2024). This project sought to bridge the production-consumption binary by exploring ways in which understanding dress utilisation could inform more responsible garment design. This paper identified five key dimensions that affect the utilisation of dresses: *sizing, style, occasion, textiles*, and *pockets*. It proposes a brief for fashion design practice that seeks to mitigate these issues.

Methodology and Methods

While wardrobe studies originated in the social sciences (Guy et al. 2001; Woodward 2007), these methods have been adopted within sustainable fashion studies because of their potential to understand the impact of the use phase from both social and material dimensions (Klepp and Bjerck 2014; Holgar 2022; Maguire

and Fahy 2022). This wardrobe study is positioned as research *for* design (Frayling 1994) within a practice-based research project exploring increased garment utilisation. It was speculated that the fashion designer's inclination toward an innate material and product emphasis could be complemented by greater adoption of such methods to help break down the divide between production and use.

A mixed-method approach was developed, combining a digital survey of dress ownership and usage patterns with reflection on literature spanning historical, social and industrial contexts inherent to the dress archetype to uncover insights that might inform design practice. In designing the study, several methods were adapted from Fletcher and Klepp's compilation Opening-Up the Wardrobe (2017); Twigger Holroyd's methods 14 and 15 informed a comparison of the most-worn and least-worn dresses across many wardrobes. While Halls's wardrobe method 26, participant-led photography, was employed to gather images of these dresses, which provided a richer understanding of the data when triangulated with the qualitative and quantitative responses.

The Dress Audit

The digital survey collected 134 unique responses from participants using the Qualtrics platform, primarily in Melbourne (Naarm), Australia. Participants were recruited from social media groups actively interested in sustainable fashion and answered a call for people who owned dresses. The survey was deliberately devised to be easy to complete to elicit as many responses as possible. Participants were asked to select and reflect on their *most-worn* and *least-worn* dress and upload a photograph of each (Figure 1). They were asked how they acquired these dresses, the textile type, the frequency of wear, why they liked or did not like wearing them, and how their *least-worn* dress could be improved.

Various methods were employed to interpret the data, beginning with cluster analysis of the quantitative data, exploratory for the qualitative responses and visual mapping for the photographic images to evaluate shape, colour, materiality, and form, techniques which are more akin to design practice. At stages, the data was triangulated to help unlock otherwise hidden patterns.

The analysis identified five key themes, which were expanded on by reviewing historical, cultural and industrial literature to make sense of the data. This was an iterative process, reflecting on a wide variety of sources. The following sections discuss the findings within these themes.



Figure 1. A selection of dress images provided by participants for the Dress Audit.

Sizing

The most frequent problem (32%) participants cited regarded their *least-worn* dress was the *fit*. This was determined through the quantitative survey question, "Why don't you wear it (your least worn dress) very often?"

The dress arose from a custom-made domestic and professional tradition, where dressmakers/ designers dealt directly with the wearer, often developing long-term working relationships. However, most dresses are now mass-produced to a standard size for generalised body proportions and imagined persons. Standardised sizing makes mass production more profitable by catering to as many people as possible while trying to avoid the steep costs of producing too many sizes (Volonté 2021). This standardisation inevitably makes assumptions about height, weight, shape, and proportion, ultimately problematising non-conforming bodies. Dresses are more vulnerable to standardisation than separates, like trousers, skirts and shirts, as they cover both the torso and lower body, which increases the variables and opportunity for poor fit.

Regrettably, many participants attributed this fit failure to their bodies and described wanting to change body size or shape rather than alter the fit of a dress. For example, "[I] am too fat for it

now, but maybe I'll fit into it again". Like all clothing, dresses are entangled with perceptions of the self (Woodward 2007; Mair 2018; Calefato 2021). Perhaps the standardisation of dress sizes contributes to an internalised expectation of *perfect* body proportions, that, combined with tight or poorly fitted dresses, reminds wearers that this body ideal is not represented in their flesh. So, while poor-fitting dresses can be considered a systemic industrial problem, the failure is transferred to the body, and the dress hangs hidden in the wardrobe unworn.

Style

17% of problems participants claimed about their *least-worn* dress were attributed to style; this involved either feeling a dress was outdated or no longer represented their identity. Possibly in response to this dissatisfaction, participants in the study owned an average of 23 dresses each–a previous Australian study showed that participants owned an average of 17 dresses (Khan et al. 2022)–This elevation of numbers could show a growing trend or perhaps an increase due to the exclusion of those without dresses. However, a quarter of participants owned 30 or more dresses; this group averaged 48 dresses each and owned over half of the total dresses[1]. 100% of the *least-worn* dresses were worn three times or less per year (Figure 2), with 63% never worn. Even 13% of the *most-worn* dresses were only worn one to three times a year (Figure 3).

A cultural examination of dresses reveals an iconic clothing archetype (Palmer 2021) or style trope (Payne 2021) of the Western fashion system (Kawamura 2004; Calefato 2021); tied to discourses of production and consumption with complex socio-political dimensions. Historically, the quality of one's dress and the sumptuousness of the textile were an indicator of class and social status (Ford 2021). It is now more of a marker of wealth and success displayed through the ability to wear the latest luxury designer 'look'. The mass market and fast fashion industry preys on this desire for apparent success by delivering new products more regularly than ever before, with some fast fashion brands releasing new garments every week of the year (Munasinghe et al. 2022). A marketing ploy used to sell more products has become a social pressure not to wear the same thing twice, which is rarely spoken about, yet performed on social media and instinctively understood by most (Maguire and Fahy 2023).

Coupled with a world of less social hierarchy and access to cheap clothing, wearers can create their ideal selves through what they wear more easily, expressing novelty, individualism or belonging to a social group (Mair 2018). However, this identity performance in the digital world of social media has inevitably accelerated matters into a never-ending recreation of self and dramatically reduced the active use of clothing. A study by Maguire and Fahy (2023) highlighted that outfit-of-the-day posts (#OOTD) have, for many, become a social pressure not to repeat wear *looks*. Mair (2018) explains that our brain is hardwired to seek out novelty or newness and receives dopamine hits in return. Rather than insist that wearers break an addiction, perhaps strategies that decouple continual change from material production may be more successful. This would be an enabling strategy rather than constraining (Niedderer et al. 2017).

Dresses also reinforce divisions along gender, class, status, and culture (Calefato 2021). They communicate an impression of femininity at odds with contemporary reality and, until recently, were (perhaps still are) a predominant female identifier (Palmer 2021). The deep-seated gendering of the dress persists; for example, gender-fluid and trans individuals use this archetype to either question, play with, or reposition and perform their identity (Catalpa and McGuire 2020). The dress 'becomes a site of political struggle' (Conway 2016) and symbolic activism. Behnke (2016) tells us that gender is not a fixed attribute but a constant, reiterative performance of gender roles as defined and expected by society. The gendered nature of dresses could be one reason it has declined in wear, with many individuals resisting what could be considered a patriarchal ideal of feminine dressing. When describing the style of their *least-worn* dress, one participant noted that it felt too 'girly' now that they were older; the gendered nature of dresses and historical dress codes may be weighing on the wearers' perception of suitability. So loaded with, or perhaps because of these conflicting meanings, the dress remains revered within museums, on the runway, and red carpet. Bari (2020) reminds us that searching for the perfect

[1] 134 participants collectively owned 3048 dresses.

dress to captivate all who look upon us is akin to magic, a deception that will either show or mask who we really are. Perhaps the reverential status afforded this garment category within popular culture also drives its underutilisation, a reality that cannot live up to the fantasy.

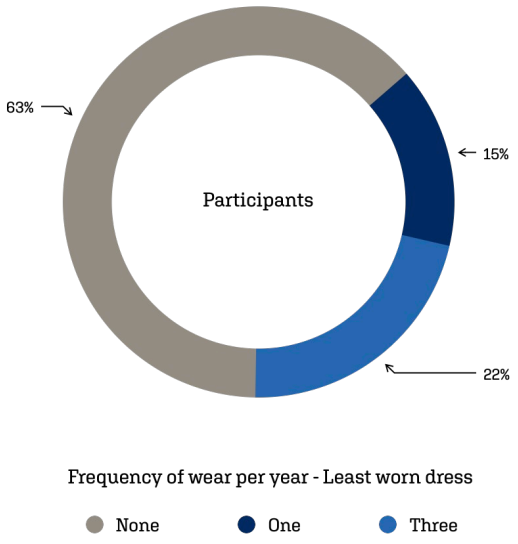


Figure 2. Least-Worn Dress Frequency of Wear

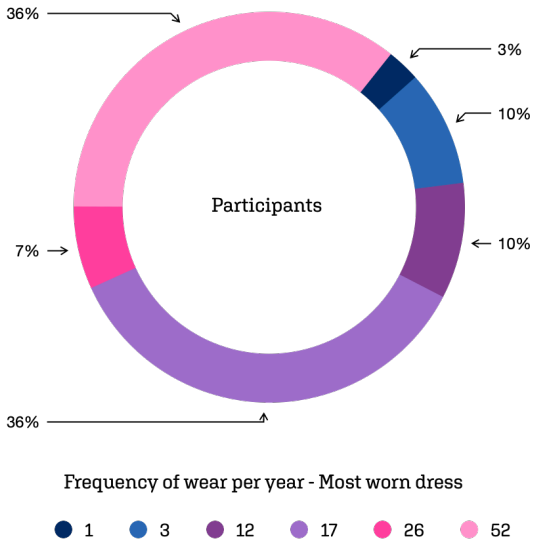


Figure 3. Most-Worn Dress Frequency of Wear

Occasion

Just over 30% of participants reported that their *least-worn* dress lacked versatility or suitability for their everyday life occasions (Figure 4). Historically, the dress has been defined by the occasion or place it is worn, for example, the evening dress. Contemporaneously, increased casualisation of clothing has made these demarcations subjective; however, the relaxing of rigid social stylistic rules has not increased dress-wearing. At the same time, the complexity of the contemporary supply chain has distanced the designer from the wearer, who creates for occasions determined by retail and marketing calendars without reference to the lived experience of wearing.

In the fashion industry, design inspiration is no longer a conversation with the intended wearer, instead it is a mix of generalised market, textile and visual research divorced from the embodied wearing experience (Robinson 2022). Design decisions are often made to meet price points and increase profits. New collections and dresses are based on previous bestsellers (Munasinghe et al. 2022), changing only the colour or minor details; these decisions favour the point of purchase and will likely result in higher sales volumes but not create more wearable dresses than the last.

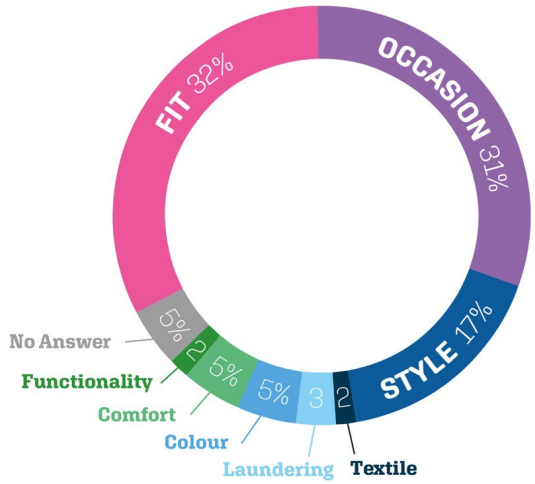


Figure 4. Least-Worn Dress Failures

Textiles

Nearly 80% of the *most-worn* dresses were made from bio-based fibre textiles (Figure 5), while synthetic polymer-derived textiles represented just over 20%. Of the *least-worn* dresses, synthetic polymer-derived textiles

almost doubled to just over 40%[2] (Figure 6). Although there was still a significant number of bio-based textiles in the *least-worn* category, cotton (the most significant proportion) had decreased by nearly half. When coupled with participant written feedback, it showed that many participants prefer and often seek out bio-based textiles to wear. "…also, it's a synthetic fabric, which is not always comfortable to wear." Previously, Neto and Ferreira (2023) had found little to no correlation between textile selection and longevity of use. However, contrasting the *most-worn* and *least-worn* dresses allowed previously elusive underlying patterns to emerge, revealing that participants seem to prefer wearing bio-based fibre dresses over synthetic polymer-derived textiles.

Silk-derived dresses, however, reversed this trend and increased by more than half from the *most-worn* to *least-worn* category to 14%. Considering that silk production is only around 0.07% of the worldwide textile production (Textile Exchange, 2024), it seems an overly large representation in both dress categories, particularly in the *least-worn*. Silk's higher material cost meant wearers are less likely to discard a garment they have spent more money on and believe is higher quality (Paço et al. 2021). Also, the luxurious nature of silk means it is often used in more special occasion dresses and numerous participants described not having many occasions appropriate to wear their silk dress, stating, "I don't wear it very often because I don't go to many formal events". Most silk dresses presenting in the *least-worn* category were acquired for special occasions and often deemed too formal to wear. Although these dresses are likely to have memorable life moments attached (Goldsworthy 2017), which would suggest higher emotional durability (Chapman 2005), which explains why they are kept, the data reinforces that emotional durability does not always equate to current and ongoing utilisation (Paço et al. 2021). This also vividly illustrates how societal casualisation has impacted the utilisation of more formal types of dresses, making them difficult to wear.

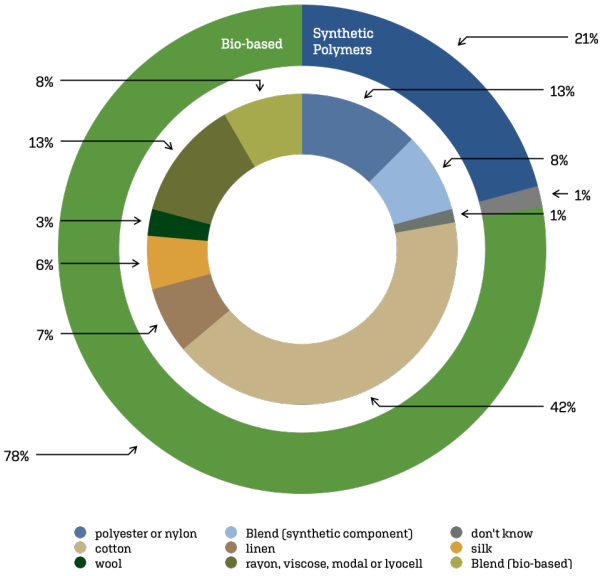


Figure 5. Most-Worn Dress Textile Type

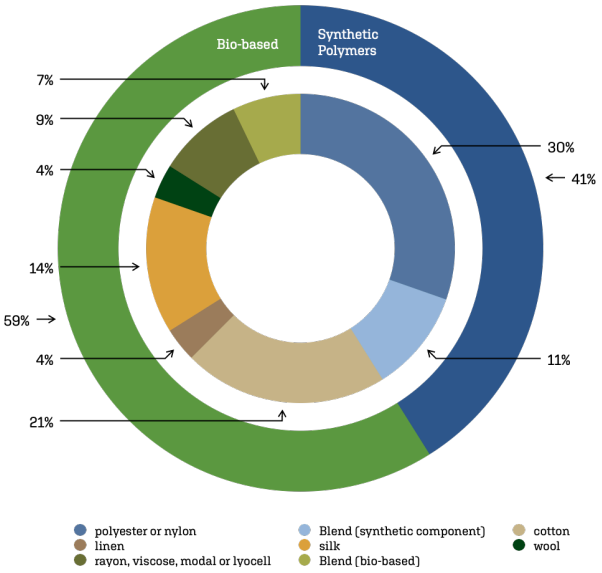


Figure 6. Least-Worn Dress Textile Type

Pockets

Twenty per cent of the participants in this study commented on pockets in their dress, either exuberantly when their *most-worn* dress had pockets, "It has POCKETS!", or remarking that

[2] Any dress that contained a blend of fibres consisting of any percentage of synthetic fibres was categorised as synthetic polymer derived.

adding pockets would improve their *least-worn* dress.

Historically, dresses (and female-gendered clothing) have lacked usable pockets. For around 200 years in the 17th-18th century, women tied large pockets around their waists hidden under skirts (Buran and Fennetaux 2020) to subvert this exclusion. Emancipation has not overly improved the addition of pockets to female-gendered clothing, and patriarchal-driven beliefs persisted as late as the 1940s, with style commentators and production houses often believing only men needed utility in garments (Carlson 2023). Although these views have mostly shifted, pockets remain lacking in many contemporary styles (Gaillard and Visser 2022). This contemporary lack of usable pockets is now more of a cost-cutting measure, accelerated by fast fashion and ever-cheaper production; their historical scantness, justifies the loss (Carlson 2023).

A New Brief: designing for wearing

In the context of professional and industrially situated design, a 'brief' is described by Buchanan (1992) as "a problem and a set of issues to be considered in resolving that problem", often for a specific client. However, unlike most other design disciplines, fashion designers devise a brief for an imaginary customer and occasion (Payne 2021). Chapman (2021) proposed that designers need to understand why people discard working products, or in this case, why dresses are underutilised if they hope to prevent this outcome. This study's insights on dress-wearing were transformed into a new brief for dress design focussed on maximum wear encompassing five key parameters (Figure 7): 1. Make changeable for diverse body shapes and sizes, 2. Design for versatility across different life and wearing occasions, 3. Allow for style renewal, 4. Use only bio-based textiles, 5. Include useable pockets**.**

Buchanan (1992) regards the brief as an "indeterminate subject waiting to be made specific and concrete". As such, it was distilled into a graphic to inform a dress design process that might activate increased utilisation. The graphic presentation of the brief illustrates the design researcher's interest in modularity as a concept underpinning their practice. It suggests modules that may be selectively utilised, amplified, or explored to address one or more wearing issues that can be further tested.

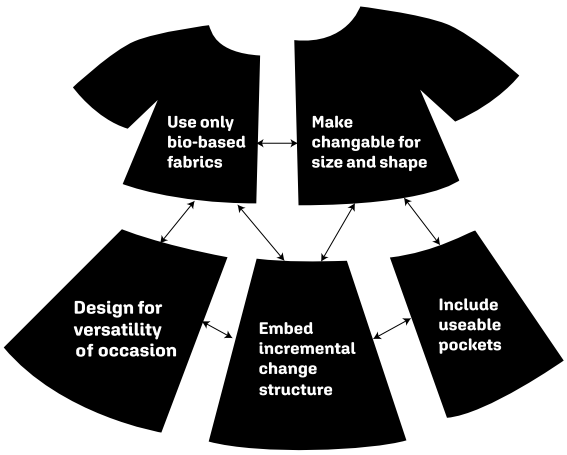


Figure 7. The New Brief Diagram

Conclusion

The dress audit wardrobe study has shown the magnitude of dresses languishing unworn in wardrobes. It reflects how the cultural, historical and industrial contexts influence use. Many problems, especially poor fit, have evolved out of mass production standardisation of sizing and production rationalisation, alongside the dislocation of the designer from those they design for, through a production/consumption binary. Three main factors; fit, occasion, and style, impact up to 80% of utilisation problems. As such, designing for a changing body, versatility for life occasions, and the ability to update the style over time could help to negate dress failures that wearers experience.

Moreover, the findings give insight into one way that designers could focus on increasing dress and clothing utilisation within their practice. The dress audit comprises a form of research for design that considers garment use and wearing experiences as fundamental to fashion design practice, an approach lacking within a mostly disconnected and industrialised contemporary fashion system. Five baseline parameters were identified that form a new brief for designing dresses for greater utilisation.

Limitations

The data's scalability may be limited by the sample size (n134) and the specificity of the place, predominantly Melbourne (Naarm), Australia. The recruited participants were actively interested in sustainable fashion while those who did not own a dress were excluded. The study only examined the *most-worn* and *least-worn* dresses, so utilisation between

those extremes is unknown and may explain more about how dresses are worn.

Future Research

The proposed *new brief* is intended for the design application to speculative dress prototypes and testing with participants. This will lead to further refinement of the brief and the process of collecting and utilising wearing experiences to inform fashion design practice for increased wear.

Acknowledgments

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References

Bari S (2020) Dressed: A Philosophy of Clothes. Basic Books, New York

Behnke A (2016) The International Politics of Fashion: Being Fab in a Dangerous World. Taylor & Francis Group, London

Buchanan R (1992) Wicked Problems in Design Thinking. Des Issues 8:5. https://doi.org/10.2307/1511637

Buran B, Fennetaux A (2020) The Pocket: A Hidden History of Women's Lives. Yale University Press, New Haven & London

Calefato P (2021) Clothed Bodies. In: Fashion As Cultural Translation: Signs, Images, Narratives. Anthem Press, London

Carlson H (2023) Pockets: An Intimate History of How We Keep Things Close. Algonquin Books of Chapel Hill, Chapel Hill and New York

Catalpa JM, McGuire JK (2020) Mirror Epiphany: Transpersons' Use of Dress to Create and Sustain Their Affirmed Gender Identities. In: Reilly A, Barry B (eds) Intellect Books. Intellect Books, Bristol

Chapman J (2005) Emotionally Durable Design: Objects, Experiences and Empathy, 2nd edn. Routledge, London

Chapman J (2021) Meaningful Stuff: Design That Lasts. The MIT Press, Cambridge, Massachusetts; London, England

Conway D (2016) Margaret Thatcher, dress and the politics of fashion. In: Behnke A (ed) The International Politics of Fashion: Being Fab in a Dangerous World. Taylor & Francis Group, London and New York

Coscieme L, Akenji L, Latva-Hakuni E, et al (2022) Unfit, Unfair, Unfashionable: Resizing Fashion for a Fair Consumption Space. Hot or Cool Institute, Berlin

Fletcher K (2012) Durability, Fashion, Sustainability: The Processes and Practices of Use. Fash Pract J Des Creative Process Fash 4:221–238. https://doi.org/10.2752/175693812x13403765252389

Fletcher K (2016) Craft of Use: Post-Growth Fashion. Taylor & Francis Group, Oxon & New York

Ford RT (2021) Dress Codes: How the Laws of Fashion Made History. Simon & Schuster, New York

Frayling C (1994) Research in Art and Design. Royal College of Art Research Papers 1:

Gaillard SDM, Visser J (2022) Pockets, dresses and suppression – A philosophical reflection on clothing, agency, and identity. Technol Soc 69:101972. https://doi.org/10.1016/j.techsoc.2022.101972

Goldsworthy K (2017) The Speedcycle: a design-led framework for fast and slow circular fashion lifecycles. Design Journal. https://doi.org/10.1080/14606925.2017.1352714

Guy A, Green E, Banim M (2001) Through the Wardrobe: Women's Relationships with Their Clothes. Berg, Oxford

Holgar M (2022) Systemic Fashion Change and Wardrobe Research–Related Tools for Supporting Consumers. Int J Crime Justice Soc Democr 11:129–142. https://doi.org/10.5204/ijcjsd.2373

Kawamura Y (2004) Fashion-ology : An Introduction to Fashion Studies. Bloomsbury Publishing, Oxford

Khan SI, Shaw M, Bandara P (2022) Socially Responsible Consumption and Marketing in Practice, Collection of Case Studies. 291–307. https://doi.org/10.1007/978-981-16-6433-5_18

Klepp IG, Bjerck M (2014) A methodological approach to the materiality of clothing: Wardrobe studies. Int J Soc Res Methodol 17:373–386. https://doi.org/10.1080/13645579.2012.737148

Klepp IG, Laitala K, Wiedemann S (2020) Clothing Lifespans: What Should Be Measured and How. Sustainability 12:6219. https://doi.org/10.3390/su12156219

Laitala K, Klepp IG (2020) What Affects Garment Lifespans? International Clothing Practices Based on a Wardrobe Survey in China, Germany, Japan, the UK, and the USA. Sustainability-basel 12:9151. https://doi.org/10.3390/su12219151

Maguire H, Fahy F (2022) Practising fashion and wardrobe studies: A geographical reframing? Area 54:69–77. https://doi.org/10.1111/area.12761

Maguire H, Fahy F (2023) Unlocking insights in the everyday: Exploring practices to foster sustainable maximum use of clothing. Clean Responsible Consum 8:100095. https://doi.org/10.1016/j.clrc.2022.100095

Mair C (2018) The Psychology of Fashion (The Psychology of Everything), 1st edn. Routledge, New York

Munasinghe PD, Dissanayake DGK, Druckman A (2022) An investigation of the mass-market fashion design process. Res J Text Appar 26:323–342. https://doi.org/10.1108/rjta-08-2020-0089

Neto A, Ferreira J (2023) Lasting Bonds: Understanding Wearer-Clothing Relationships through Interpersonal Love-Theory. Fash Theory ahead-of-print:1–31. https://doi.org/10.1080/1362704x.2023.2170706

Niedderer K, Clune S, Ludden G (2017) Design for Behaviour Change. 250–260. https://doi.org/10.4324/9781315576602-20

Niinimäki K (2024) Recycling and Lifetime Management in the Textile and Fashion Sector. Taylor & Francis Group

Paço A, Filho WL, Ávila LV, Dennis K (2021) Fostering sustainable consumer behavior regarding clothing: Assessing trends on purchases, recycling and disposal. Text Res J 91:373–384. https://doi.org/10.1177/0040517520944524

Palmer A (2021) A cultural history of dress and fashion in the modern age. Zed Books, London, England

Payne A (2021) Designing Fashion's Future: Present Practice and Tactics for Sustainable Change. pp 103–122

Payne A, Jiang X, Street P, et al (2024) Keeping Clothes Out of Landfill: A landscape survey of Australian consumer practices

Robinson T (2022) Body Styles: Redirecting Ethics and the Question of Embodied Empathy in Fashion Design. Fash Pract 1–23. https://doi.org/10.1080/17569370.2022.2026048

Sellers K (2022) Australian Fashion Council - National Clothing Product Stewardship

Volonté P (2021) Fashion Technology: The Sizing System. In: Fat Fashion: The thin Ideal and the Segregation of Plus-Size Bodies. pp 121–141

Woodward S (2007) Why Women Wear What They Wear. Berg, Oxford, New York

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I feel more like myself when I wear my velskoene: Exploring South African male millennial consumers' attachment to their velskoene

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Keywords: Product attachment; Velskoen; Footwear; South Africa; Longevity.

Abstract: Due to fast fashion, the lifespan of products like footwear has shortened, with consumers discarding shoes prematurely due to poor quality or for newer options. Extending the product lifespan through product attachment offers a potential solution. While product attachment studies have explored multiple product categories, few have focused on one product within a particular context. This study focuses specifically on the velskoen, a leather footwear style known for being durable and long-lasting. The velskoen has not been formally researched in South Africa, nor has its product attachment been explored. Therefore, the study aims to explore product attachment among millennial males in South Africa, specifically velskoen attachment. Qualitative, semi-structured interviews were conducted with ten participants and focused on four determinants of attachment: memories, pleasure, self-expression, and group affiliation. Object elicitation enabled participants to showcase their velskoene and comfortably chat about them to extract valuable insights. Participants described their memories, how their velskoene allowed self-expression, to which groups they affiliated themselves and their velskoene, the different types of pleasure their velskoene afforded, and product care practices. While memories featured strongly, physical pleasure emerged the most. More often than not, these two determinants complemented each other. Additionally, results showed that the velskoen allowed participants to express themselves and feel connected to specific groups on a cultural and national level. This suggests a notable attachment to velskoene among the male millennials in South Africa, which is linked primarily to pleasure and memories, which causes extended ownership, increased care, and improved sustainability.

Introduction

Since the 1950s, footwear consumption has increased while overall quality has decreased, resulting in higher disposal rates and more waste (Mittal et al., 2024; Mwinyihija, 2018; Sahimaa et al., 2023; Van Rensburg et al., 2020). A significant contributor to this is fast and ultra-fast fashion, which aims to produce products as quickly and cost-effectively as possible to meet demand and trend changes and accelerate lead times, leading to increased waste production (Sahimaa et al., 2023; Sumo et al., 2023). This is unsustainable, as environmental and social damages are strongly associated with the actions of the fast fashion industry, contributing to higher CO^2 emissions, wastewater pollution and working condition violations (Dzhengiz et al., 2023; Sahimaa et al., 2023).

Furthermore, consumers are disposing of products at a shocking rate due to the accessibility of new products, reduced product quality, and merely trying to keep up with changing trends (Cooper, 2016; Mittal et al., 2024). The footwear industry and consumers need to change their practices to ensure longevity and prosperity for all; this necessitates the footwear industry to think beyond profits and implement more circular business operations, while consumers need to reject the throw-away culture by resisting, reducing, reusing, repairing and recycling products (Mittal et al., 2024; Sahimaa et al., 2023; Sonnenberg et al., 2022).

Recycling footwear offers an environmentally friendly way of combatting overconsumption culture; however, within the African context, the lack of infrastructure, initiatives, technology and capital hinders this method as a primary approach (Arkorful et al., 2023; De Ferran et al., 2020; Sonnenberg et al., 2022). Government interventions may provide some relief to fast fashion consumption practices, as the increase in local tariffs for imported textile products has proven helpful for South Africa in recent months as more jobs have been created

and consumption of locally produced products has increased (Nedbank, 2024; Sonnenberg et al., 2022). While technological, capital, and infrastructure-based circular economy practices like recycling are developing, addressing South Africa's overconsumption dilemma may also lie with consumers through product life extension, which could be achieved by altering their perceptions and behaviours regarding disposal and product longevity (Ackermann et al., 2018; Cooper, 2016; Sahimaa et al., 2023; Van den Berge et al., 2021).

Product attachment

Product attachment offers a solution as it extends the product's lifespan by increasing the positive relationship between the consumer and their products (Kowalski & Yoon, 2022; Van den Berge et al., 2021). This product-person-oriented model focuses on the intensity of the emotional bond between a consumer and a product, causing the consumer to retain the product, take better care of it, and refrain from its disposal to avoid the emotional loss they will endure if they were to part with it (Schifferstein & Zwartkruis-Pelgrim, 2008; Van den Berge et al., 2021). Consequently, this could lead to less waste and fewer resources being used during the production of replacement products (Van den Berge et al., 2021).

Product attachment studies are prevalent, with some exploring various products in unknown contexts (Kowalski & Yoon, 2022; Page, 2014) or touching on the concept when assessing culturally and symbolically relevant shoes in European contexts (Hockey et al., 2013; Sampson, 2020; Sherlock, 2014). While each country is unique, South Africa's distinct cultural, economic, and social makeup may show different patterns or consumer perspectives concerning product attachment (Lappeman et al., 2020).

Mugge et al. (2008) proposed four determinants of product attachment, namely memories, pleasure, self-expression, and group affiliation, which designers may utilise to increase the consumer-product relationship. Additionally, a consumer may experience attachment to a specific product or a *product variant*, indicating attachment to the particular product or product type (Mugge et al., 2008; Schifferstein & Pelgrim, 2004).

Other studies explored product attachment and introduced new categories such as narrative, appearance, reliability, emotion and irreplaceability (Chapman, 2009; Kowalski & Yoon, 2022; Page, 2014). While similar concepts such as emotional durable design (Chapman, 2009) and material possession attachment (Kleine et al., 1995) are relevant, the determinants identified by Mugge et al. (2008) remain prominent and are still utilised in product attachment literature (Van den Berge et al., 2021).

The velskoen

The velskoen (skin + shoe), or the 'vellie', is an ankle-length, raw-hide type of chukka boot made using a stitch-down construction method and was first seen on the feet of Khoisan tribe members before 1652 (Du Plessis, 2004; Kwela, 2020; Strutt, 1975). The shoe was adopted, developed and refined over the past four centuries to become what it is today, a footwear style praised for its longevity and quality (Rangongo, 2020). The velskoen is available in various leather textures, colours, styles and spin-offs (Du Plessis, 2004; Rangongo, 2020; Strutt, 1975). **Figure 1** depicts the typical construction and style of a classic velskoen.



Figure 1. Classic velskoen design.

One of the first velskoen companies notes that the only downside to a velskoen is that it lasts too long, pointing out that South African consumers wear their velskoene for five to 15 years or until they physically cannot be repaired anymore (Du Plessis, 2004). While the velskoen has been present in South African dress culture since before 1652, it has steadily increased in popularity since its feature at the 2016 Summer Olympic Games (Rangongo, 2020). The subsequent escalating exports and improvement of the South African leather and footwear industry via established local brands prove its growing popularity (Dickson, 2023; Rangongo, 2020). *Clarks Originals*, a popular footwear brand culturally significant in the UK, was inspired by the velskoen when Nathan Clark first viewed it on South African soldiers'

feet (Nasson, 2012; Sherlock, 2014). Sherlock (2014) explored memories associated with *Clarks Originals* and found that the shoes' location, the environmental traces on the shoes, and the versatility and comfort participants obtained from their shoes were notable (Sherlock, 2014). When considering the velskoen's long-standing history and cultural connotations, similar results related to memory and symbolic associations were expected from this study.

Despite their growing popularity, cultural relevance, and marketing claims, velskoene remain unexplored for their sustainable value, durability, and longevity. While product attachment research identifies factors influencing attachment, it lacks context and product specificity to account for economic, cultural, and social differences. Examining culturally relevant products like velskoene may reveal unique attachment patterns, enriching product attachment theory. This study could also inform strategies to enhance footwear longevity, reduce overconsumption, and improve circular economy practices locally and globally.

This study, therefore, takes a preliminary approach to uncovering male millennials in South Africa's attachment to their velskoene by utilising the determinants of attachment theory as detailed by Mugge et al. (2008) as a base for thematic analysis.

Methodology

A phenomenological design with a qualitative approach was used to explore consumers' thoughts, feelings, and perceptions of their velskoene (Babbie, 2016; Creswell & Poth, 2025). This method provided rich insights into participants' memories, associations, emotions, and beliefs (Wiid & Diggines, 2013). With nearly half of South Africa's population aged 20–44 (StatsSA, 2023), participants born between 1980 and 2004 (predominantly millennials) were recruited to align with various cohort definitions (Grace et al., 2023). Millennials value unique experiences, authenticity, and environmental consciousness (Grace et al., 2023; Louw & Steyn, 2021). While female velskoen styles and unisex options are available today, the footwear style is historically associated with male dress practices and traditions (Strutt, 1975). Furthermore, the velskoen is stereotypically associated with male consumers in specific contexts such as farming communities (Moller, 2013). Due to these findings, the focus of this study was placed on male consumers as the velskoen is, to date, more prominent among male consumers and has not yet been as extensively adopted by female consumers.

Ten male millennial velskoen owners were invited for semi-structured interviews using purposive sampling, and object elicitation was used to facilitate discussion and gain deeper insights (O'Brien & Charura, 2024; Willig, 2017). As such, participants were asked to bring their favourite velskoene pair(s) to their interview.

The four determinants of attachment and literature on product care were used to formulate the relevant questions (Mugge et al., 2008; Schifferstein & Zwartkruis-Pelgrim, 2008). The questions explored their velskoene acquisition, memories and associations, personal style, most liked characteristics, and care practices. The researcher used probing questions to encourage deeper discussions. Participants were asked to handle their velskoene, highlighting markings or unique features. Their shoes were photographed and depicted in Figure 2, where scuff marks, stains, tears, general style, and worn laces are visible. Some participants brought three pairs, while others brought only one.

Otter.ai was used to record and transcribe the interviews, after which the transcriptions were manually checked, cleaned and numbered. Any identity markers were removed to ensure anonymity. Thematic analysis was conducted in Atlas.ti using *ad priori* codes developed using Mugge et al.'s (2008) determinants of product attachment. The codes were then merged into four themes to enable interpretation and discussion.

Results and discussion

Participants' velskoene varied in style, ankle length, leather texture, stitching, eyelets, and colour as visible in Figure 2. Ownership ranged from 10 months to over a decade, with the oldest pair originally purchased in 2014. Responses revealed connections to memories, pleasure, self-expression, group affiliation, and care practices. All but one participant actively wore their velskoene. The following sections present key themes and verbatim discussions.



Figure 2. Participants' velskoene

Memories

Memories form a crucial part of product attachment development, as when a memory is associated with a product, the consumer is less likely to dispose of it (Schifferstein & Zwartkruis-Pelgrim, 2008). All participants recalled memories during the interviews and associated their velskoene with people, places, or events.

P7 relayed how his velskoene symbolised parts of his life by being *"a reminder of where I've been, what I've seen, what I've done, what I've survived, and they've been there".* P3 shared the same sentiment, saying that his velskoene are *"like a reminder of my first job, what I did back then"*, while P5 noted that his velskoene *"remind me of me".* P6 connected his first-ever velskoene to other people, saying he had *"a distinct association of my vellies [velskoene] with my grandfather",* and P9 similarly noted that his dad *"used to wear these all the time".*

Participants linked specific markings and splotches on their velskoene to particular memories. However, these markings were not viewed as a reduction in the product's aesthetic appeal; instead, they added to the shoe's look and gave it more character, making it more unique. P9 put it nicely, saying that the *"creases"* across the shoe's bridge were what he liked most about his velskoene because he *"can't get rid of them*". This finding supports the observations made by Schifferstein and Zwartkruis-Pelgrim (2008) and Page (2014), indicating that products that age gracefully and acquire marks often have positive connotations and foster greater emotional attachment. Chapman (2009) and Mugge et al. (2008) also highlight this unique trait of leather to age well and promote attachment.

Memories and pleasure emerged simultaneously in the interviews, where participants recalled certain situations and then proceeded to detail their pleasurable experiences through their memories.

Pleasure

Pleasure derived from the velskoen product properties was at the forefront of participants' reasons for choosing the specific velskoen as their favourite and a motivating factor for their length of ownership. Comfort was repeated throughout the interviews, where P7 noted, *"It's the most comfortable shoe I've got".* P9 further expressed that his velskoene provided comfort

beyond the general physical sense, stating they were *"also psychologically, mentally comfortable".* Participants also liked the aesthetic appeal of the shoe, saying things like *"I love how they look"* [P4] and *"When I saw them on the shelf, I thought 'this is beautiful'"* [P9].

Pleasure was more strongly featured among participants with active attachment, with comfort, functionality, aesthetic appeal, efficiency, longevity, and style versatility coming up repeatedly. This finding differs from literature that suggests that pleasure decreases as the length of ownership increases (Mugge et al., 2008; Schifferstein & Zwartkruis-Pelgrim, 2008). In the case of the velskoen, the longer the shoe is worn, the more comfortable it becomes as it moulds to one's foot, enhancing its physical appeal and uniqueness. Scuff marks or spills on the shoes, whether linked to a memory or not, did not emerge as negative feelings but contributed to the shoe's aesthetic pleasure, reinforcing the positive appeal of ageing leather (Chapman, 2009; Mugge et al., 2008; Page, 2014; Schifferstein & Zwartkruis-Pelgrim, 2008).

Self-expression

Self-expression encapsulates all the aspects of a product a consumer uses to express themselves (Mugge et al., 2008). In this case, the velskoen's unique characteristics were strongly featured, making the participants feel special and allowing them to express themselves, as most participants viewed their velskoene as special or rare in some way. P2 detailed that despite them being unattractive, he "*love(s) how they look".* P8 expressed that he *"feels serious"* when wearing them, and P7 noted that he felt *"more like myself"* and that they *"represent"* him. P9 detailed that the wear and tear obtained on the shoe becomes *"like a fingerprint […] this fingerprint is mine"*, emphasising the shoes uniqueness. P5 sums this expression up nicely, stating that his velskoene *"makes me feel quite unique"*, a sentiment shared by multiple participants. These quotes highlight how the velskoen allowed the consumers to feel and portray themselves as confident, unique and express themselves through the shoe's properties.

Hockey et al. (2013) showed similar results when a participant showcased how her heels made her feel sexy and serious, while Sherlock (2014) found that the *Clarks Originals* helped the participants feel authentic when considering the shoe's physical and symbolic qualities.

Group affiliation

Participants felt that their velskoene related to groups beyond their identities, linking them to a cultural group, ethnic group or country, which helped them form and feel part of something bigger than themselves. P8 described that he went through an initiation process as part of Xhosa traditions and received his velskoene as a gift, symbolising his transition from boy to man in the rural Eastern Cape province of South Africa, detailing *"it feels like I'm part of them [ethnic group and family]".* P2 reiterated this by stating, *"It's part of my heritage"*, and multiple participants expressed the shoe forming part of the Afrikaans culture. The velskoen has an Afrikaans farming stereotype attached to it (Moller, 2013), and while some referred to it specifically as a stereotype, others were fond of the connotation. P5 particularly noted, *"It's a very Afrikaans thing"*.

The velskoen held a South African essence and appeal among all the participants. They relate the velskoen to something that belongs to South Africa, and it makes them feel proud to wear it and have something unique as part of their country and nationality. Participants further felt they represented South Africa by wearing their velskoene; P4 said it has a *"South African feel",* and P7 expressed that his velskoene *"represents something uniquely South African"* to him.

Product care

Participants indicated that they have engaged in shoe care practices, such as P1's ritual procession of cleaning his velskoene. However, most did not take consistent or deliberate care of their velskoene. P7 summarised this notion by saying his velskoene must be able to *"fight for themselves"*, indicating that they should not need care and survive whatever they go through.

A typical wear cycle emerged: buy, wear, repair, wear, possibly repair again, then donate or dispose of the shoe based on its condition. Some participants had repairs done at general stores but were disappointed, preferring the original retailer for sole repairs as they place more trust in the retailer. P3

owned the oldest pair (bought in 2014), which he had repaired himself, and planned to do so again if needed. Others, less confident in their skills, preferred professional repair services or the original retailer.

All participants indicated that once their velskoene lost functionality, they would keep them as mementoes, donate them, or dispose of them if they were beyond repair. Guilt was a common subject, as many felt uneasy donating shoes in poor condition and preferred to dispose of or recycle them. This guilt around donating worn-out, attached items warrants further research.

These findings reinforce literature on how emotional connection to a product fosters greater care and improves attachment but warrants further exploration and more data as not all individuals care for their velskoene in the same way (Mugge et al., 2008; Page, 2014; Van den Berge et al., 2021; Van Nes & Cramer, 2006). Additionally, future research could explore product-service systems, as some velskoen brands offer in-house repairs (Sapmok, 2024; Wildebees, 2024). The demand for product-service systems in South Africa remains uncertain, yet this seems like a plausible business option to enhance a circular business model, potentially boosting brand loyalty, extending velskoen lifespan, and reducing waste (Ackermann et al., 2018; Terzioğlu, 2021).

Conclusions

All participants displayed the four determinants of attachment and provided great detail about each. The determinants emerged concurrently and linked, showing that each contributed to the consumer's product attachment, albeit in varying degrees. Memories were strongly associated with their velskoene, yet pleasure emerged more strongly as the determinant that made them keep it.

Participants showed a strong affinity for velskoene, with some, like P1 and P4, owning three and eight pairs, respectively, all actively worn. This attachment to a product category aligns with the *product variant* concept (Mugge et al., 2008; Schifferstein & Zwartkruis-Pelgrim, 2008). The prevalence of multiple actively worn velskoene suggests a research opportunity to explore why some consumers own and retain several pairs for years.

With its enduring reputation, the velskoen is a unique South African product that forms part of the consumer and cultural landscape. The male consumers in this study associate parts of their lives with their velskoene. Additionally, their shoes hold memories and allow them to express themselves through their inherent aesthetic and style, making them feel unique and confident. It allows them to connect on cultural and nationalistic planes with others, all while feeling mentally and physically comfortable. While attachment was present, more research is required to determine the degrees of attachment and explore the care practices these consumers engage in in more depth.

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References

Ackermann, L., Mugge, R., & Schoormans, J. (2018). Consumers' perspective on product care: An exploratory study of motivators, ability factors, and triggers. *Journal of Cleaner Production*, *183*, 380-391. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.02.099

Arkorful, V. E., Lugu, B. K., & Shuliang, Z. (2023). Unearthing mask waste separation behavior in COVID-19 pandemic period: An empirical evidence from Ghana using an integrated theory of planned behavior and norm activation model. *Current Psychology*, *42*(10), 8515-8530. https://doi.org/10.1007/s12144-021-02313-2

Babbie, E. (2016). *The practice of social research* (14th ed.). Cengage learning.

Chapman, J. (2009). Design for (emotional) durability. *Design Issues*, *25*(4), 29-35. https://doi.org/https://doi-org.uplib.idm.oclc.org/10.1162/desi.2009.25.4.29

Cooper, T. (2016). The Significance of Product Longevity. In T. Cooper (Ed.), *Longer Lasting Products : Alternatives to the Throwaway Society* (1 ed., pp. 3-36). Routledge. https://www.bloomsburyvisualarts.com/encyclopedia-chapter?docid=b-9781315592930&tocid=b-9781315592930-chapter1

Creswell, J. W., & Poth, C. N. (2025). *Qualitative inquiry & research design: choosing among*

five approaches (5th ed.). SAGE Publications, Inc.

De Ferran, F., Robinot, E., & Ertz, M. (2020). What makes people more willing to dispose of their goods rather than throwing them away? *Resources, Conservation and Recycling*, *156*, 104682. https://doi.org/https://doi.org/10.1016/j.resconrec.2020.104682

Dickson, T. (2023). *The rise and rise of Velskoen as it seeks to double turnover.* (S & V Footwear and Leather Goods, Issue 11). https://www.svmag.co.za/issuepage/315/SV_Footwear_Leather_Goods_Magazine_Vol89_No11_November_2023

Du Plessis, E. (2004). *Strassberger Skoene* [Familial Historical Account]. Strassberger Skoene.

Dzhengiz, T., Haukkala, T., & Sahimaa, O. (2023). (Un) Sustainable transitions towards fast and ultra-fast fashion. *Fashion and Textiles*, *10*(1), 19. https://doi.org/https://doi.org/10.1186/s40691-023-00337-9

Grace, R., Springer, D., & Mukarati, T. (2023). *Millennials fact or fiction: how South African millennials differ from the global generalisation*. M. C. S. G. S. Africa. https://mcsaatchigroup.co.za/wp-content/uploads/2023/06/MCSaatchi%20Group%20SA_Report_Millennials_Fact%20or%20Fiction_updated.pdf

Hockey, J., Dilley, R., Robinson, V., & Sherlock, A. (2013). Worn shoes: identity, memory and footwear. *Sociological Research Online*, *18*(1), 128-142. https://doi.org/http://doi.org/10.5153/sro.2897

Kleine, S. S., Kleine, R. E., III, & Allen, C. T. (1995). How is a possession "Me" or "Not me"? Characterizing types and an antecedent of material possession attachment. *Journal of Consumer Research*, *22*(3), 327-343. https://doi.org/10.1086/209454

Kowalski, M. C., & Yoon, J. (2022). I love it, I'll never use it: exploring factors of product attachment and their effects on sustainable product usage behaviors. *International journal of design*, *16*(3), 37-57. https://doi.org/https://doi.org/10.57698/v16i3.03

Kwela. (2020). *Strassbergers skoenfabriek* [Television broadcast]. KykNET. https://www.youtube.com/watch?v=pjlwE3H90w0

Lappeman, J., Egan, P., & Coppin, V. (2020). Time for an update: proposing a new age segmentation for South Africa. *Management Dynamics: Journal of the Southern African Institute for Management Scientists*, *29*(1), 2-16. https://doi.org/doi:10.10520/EJC-1be5816423

Louw, T., & Steyn, R. (2021). Workplace engagement of South African Millennials: a non-issue? *The Journal for Transdisciplinary Research in Southern Africa*, *17*(1), 1-9. https://doi.org/http://doi.org/10.4102/td.v17i1.938

Mittal, S., Khan, M. A., Yadav, V., & Sharma, M. K. (2024). Footwear as product-service systems: toward sustainable alternative consumption scenarios. *Business Strategy and the Environment*. https://doi.org/https://doi.org/10.1002/bse.3519

Moller, P. (2013, 2024-03-22). Die keuses van die lewe. *Veeplaas*, *4*(7), 5. https://journals.co.za/doi/abs/10.10520/EJC139523

Mugge, R., Schoormans, J. P., & Schifferstein, H. N. (2008). Product attachment: Design strategies to stimulate the emotional bonding to products. In *Product experience* (pp. 425-440). Elsevier. https://doi.org/https://doi.org/10.1016/B978-008045089-6.50020-4

Mwinyihija, M. (2018). *Value creation and opportunity management in Africa's leather sector*. Rowman & Littlefield.

Nasson, B. (2012). *South Africa at war, 1939-1945*. Jacana Media.

Nedbank. (2024). *Shein and Temu taxes: What you need to know*. Retrieved 2025-02-01 from https://personal.nedbank.co.za/learn/blog/shein-temu-taxes-south-africa.html

O'Brien, C., & Charura, D. (2024). Object elicitation: A compassionate and culturally informed method for psychotherapy research. *Counselling and Psychotherapy Research*, *24*(1), 39-50. https://doi.org/http://doi.org/10.1002/capr.12703

Page, T. (2014). Product attachment and replacement: implications for sustainable design. *International Journal of Sustainable Design*, *2*(3), 265-282. https://doi.org/http://doi.org/10.1504/IJSDES.2014.065057

Rangongo, T. (2020). Making an iconic South African shoe globally recognisable. *finweek*, *2020*(14), 42-43. https://hdl.handle.net/10520/EJC-1f82d8b392

Sahimaa, O., Miller, E. M., Halme, M., Niinimäki, K., Tanner, H., Mäkelä, M., Rissanen, M., Härri, A., & Hummel, M. (2023). The only way to fix fast fashion is to end it. *Nature Reviews Earth & Environment*, *4*(3), 137-138. https://doi.org/https://doi.org/10.1038/s43017-023-00398-w

Sampson, E. (2020). *Worn: Footwear, attachment and the affects of wear*. Bloomsbury visual

arts. https://doi.org/10.5040/9781350087217

Sapmok. (2024). *Revive to survive: Be kind to the planet, revive your vellies*. Retrieved 2024-04-11 from https://sapmok.com/revive-survive/

Schifferstein, H. N., & Pelgrim, E. (2004). Consumer-product attachment: The construct and its measurement. *Unpublished manuscript. Delft University of Technology, the Netherlands*.

Schifferstein, H. N., & Zwartkruis-Pelgrim, E. P. (2008). Consumer-product attachment: Measurement and design implications. *International journal of design*, *2*(3), 1-13. https://www.researchgate.net/publication/254759164_Consumer-Product_Attachment_Measurement_and_Design_Implications

Sherlock, A. (2014). 'It's kind of where the shoe gets you to I suppose': Materializing identity with footwear. *Critical Studies in Fashion & Beauty*, *5*(1), 25-51. https://doi.org/https://doi.org/10.1386/csfb.5.1.25_1

Sonnenberg, N. C., Stols, M. J., Taljaard-Swart, H., & Marx-Pienaar, N. J. M. M. (2022). Apparel disposal in the South African emerging market context: Exploring female consumers' motivation and intent to donate post-consumer textile waste. *Resources, Conservation and Recycling*, *182*, 106311. https://doi.org/https://doi.org/10.1016/j.resconrec.2022.106311

StatsSA. (2023). *Statistical release: Census 2022*. StatsSA. https://census.statssa.gov.za/assets/documents/2022/P03014_Census_2022_Statistical_Release.pdf

Strutt, D. H. (1975). *Fashion in South Africa 1652-1900: An illustrated history of styles and materials for men, women and children, with notes on footwear, hairdressing, accessories and jewellery*. Cape Town: Balkema (AA).

Sumo, P., Arhin, I., Danquah, R., Nelson, S. K., Achaa, L., Nweze, C., Liling, C., & Ji, X. (2023). An assessment of Africa's second-hand clothing value chain: A systematic review and research opportunities. *Textile Research Journal*, *93*, 1-20. https://doi.org/10.1177/00405175231175057

Terzioğlu, N. (2021). Repair motivation and barriers model: Investigating user perspectives related to product repair towards a circular economy. *Journal of Cleaner Production*, *289*, 125644. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.125644

Van den Berge, R., Magnier, L., & Mugge, R. (2021). Too good to go? Consumers' replacement behaviour and potential strategies for stimulating product retention. *Current opinion in psychology*, *39*, 66-71. https://doi.org/https://doi.org/10.1016/j.copsyc.2020.07.014

Van Nes, N., & Cramer, J. (2006). Product lifetime optimization: a challenging strategy towards more sustainable consumption patterns. *Journal of Cleaner Production*, *14*(15-16), 1307-1318. https://doi.org/https://doi.org/10.1016/j.jclepro.2005.04.006

Van Rensburg, M. L., Nkomo, S. p. L., & Mkhize, N. M. (2020). Life cycle and end-of-Life management options in the footwear industry: A review. *Waste Management & Research*, *38*(6), 599-613. https://doi.org/https://doi.org/10.1177/0734242X20908938

Wiid, J., & Diggines, C. (2013). *Marketing research* (2nd ed.). Jute.

Wildebees. (2024). *Need your Wildebees shoes resoled or repaired?* Retrieved 2024-04-11 from https://wildebees.com/resole-your-shoes/

Willig, C. (2017). Reflections on the use of object elicitation. . *4*(3), 211-222. https://doi.org/http://doi.org/10.1037/qup0000054

Research paper
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Wearing and sharing #wardrobechallenges: Finding inspiration when you have nothing to wear

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Keywords: #wardrobechallenge; wardrobe work; sustainable behaviour change; user-generated content; fashion communication.

Abstract: Since the emergence of the fashion blogosphere, sharing personal fashion choices and inspirations using hashtags such as #OOTD (outfit of the day) have become commonplace. The speed and volume of this content has grown exponentially, providing a mediated view of self-fashioning as well as a common trope of marketing communications adopted by influencers. Recently, there has been a noted change in wardrobe activities being shared on social media, that focus on the challenges fashion users have as they navigate their existing wardrobe. User-generated content (UGC) tagged with #wardrobechallenge draws together diverse posts ranging from how to re-wear wardrobe items through techniques such as the 30 wears challenge, struggles with closet decluttering and laundry tips. This type of wardrobe work is predominantly an activity undertaken in private; however, when shared and mediated through digital channels it offers greater visibility on the use phase of garments.
Recognising that the use-stage holds much potential to extend the lifecycle of garments (Gwilt & Rissanen, 2012), this paper explores UGC to understand whether the sharing of wardrobe challenges holds potential to drive sustainable behaviour change. With many fashion users mistrustful or confused by what fashion brands say regarding sustainability and little evidence of industry engagement with the post-purchase phases of fashion – the study asks if #wardrobechallenge content offers an effective way of communicating sustainable fashion practices. This is a socio-material investigation, that draws on data from Instagram and TikTok tagged with #wardrobechallenge. A typology of wardrobe challenge practices has been developed; its classifications offer inspiration for 'doing' fashion beyond consumption and designations of the fashion industry. The study concludes by discussing how this form of UGC could build new ways of socialising and supporting sustainable behaviour change.

Introduction

Design academic Jonathan Chapman stated, "Material consumption is out of control…. resulting in a harried and exhausted consumer" (Chapman, 2021, p5), and the rise in personal wardrobe management strategies suggest that some fashion users are taking steps to address the negative impacts of their material consumption habits. Social media platforms have been spaces used for sharing individual fashion choices and preferences for almost two decades. These practices – typified by outfit of the day (#OOTD), have become commodified and co-opted as marketing communications through the growth of fashion influencers. The format and aesthetics of sharing fashion choices on social media are as a finished and perfect outcome, the messy indecisive processes of selecting 'the outfit' are seldom revealed in this genre.

Recently, there has been a change in the visibility of wardrobe work on social media; activities are being shared that focus on the challenges fashion users have as they navigate their existing wardrobe in search of 'something to wear'. The content captures approaches adopted to change material consumption habits that have come to feel compulsive, overwhelming or unfulfilling. Previously experiments in reducing fashion consumption have been undertaken as a 'fashion detox challenge' in academic settings in both USA (Ruppert-Stroescu et al., 2015) and in UK (Ritch et al., 2020). Similarly, current online wardrobe work takes the form of a fashion 'challenge.' The concept of an online 'challenge' is an invitation or call to action, to participate in a competitive situation, and tagging social media content with #wardrobechallenge is the way for individuals to share their "experiments in voluntary reduction of apparel consumption" (Vladimirova

2021, p112). #wardrobechallenge data reveals various terms for these challenges, such as the *Rule of 5* (5 high quality new garments per year + 4 second-hand), *10 X 10* (pick 10 garments from your wardrobe and wear only these for 10 days), *30 wears* (only buy something new only if you can wear it 30 times), *Project 333* (33 garments only for 3 months, excluding jewellery, underwear, sleepwear, gym gear) and *75 day hard style challenge* (track what you wear for 75 days and buy nothing new). All focus on intentional wardrobe tracking to reset existing wardrobe habits and all require a familiarity with existing wardrobe contents.

There is a growing body of research into wardrobe practices, supported and advanced through the establishment of wardrobe methods (Fletcher & Klepp, 2017), a field of research designed specifically to understand the use phase of garment life, something that is usually undertaken in private. Because of changing social norms, there is a willingness to 'work things out online', resulting in a digital corpus of wardrobe work. Much research on sustainable behaviour change in fashion has focused on purchase behaviours (Sumner, 2018 for example); however, the rise in user-generated content documenting wardrobe management practices offers an alternative avenue for the study of user behaviours beyond just acquisition. The remediation of user experiences and perspectives on social media has limitations (Rocamora, 2023; Hipfl, 2018) impacted by algorithms, filters, self-censorship. Nevertheless, this is an era where the mediatisation of production and consumption of fashion is normalised and embedded in daily life and can influence and socialise change.

The study seeks to contribute to wardrobe studies, whilst situating this investigation within fashion communications; this is an influential field still struggling to counter messages that perpetuate overconsumption or empower fashion users to make sustainable behaviour change. Below, the research design sets out the theoretical framing, data collection and analysis used. The findings detail patterns and themes revealed through analysis, subsequently developed in a typology of #wardrobechallenge practices and a map of contextual factors of the study. These generate a view of users re-negotiating notions of novelty in fashion, devising creative constraints and connecting through shared experiences. The article then discusses how #wardrobechallenge practices reveal nascent fashion and clothing systems, designed to both promote and support sustainable behaviour change. It concludes by discussing how, through the promotion of new experiences to be had with fashion, we may be able to create a pathway to Chapman's (2021) vision of a future that is rich in experience, whilst being light on materials.

Research methods

The study is a qualitative, interpretative project, with the data collected from Instagram and TikTok, tagged with #wardrobechallenge. It adopts a socio-material perspective to examine the mediation of wardrobe work in this data. This approach has its roots in Science and Technology Studies (STS) and Actor-Network Theory (ANT) (Latour, 2005) and views materials as dynamic and entangled with human activity. It considers socio-material objects as heterogeneous assemblages, where all things (human, non-human, technology, systems) become linked in webs of activity that decentre the predominance of the human agency (Fenwick et al., 2015) and generate knowledge. Socio-materiality considers whole systems, not separating out human relations from material objects, rather recognising how understanding is enhanced and deepened by our relations with stuff. This viewpoint accepts the fundamental uncertainty, fluidity, and messiness of everyday life (Orlikowski, 2007). Socio-materiality enables analysis of the disparate elements as they interconnect; the approach underpins the analysis of the UGC on social media tracing practices that create meaning and engagement with objects (Hipfl, 2018).

Data collection has focused on social media platforms Instagram and TikTok. These two popular, interactive communication channels have been instrumental in creating the #wardrobechallenge phenomenon (Kwon 2018). Posts on Instagram and videos on TikTok were collected manually during October 2024. Only content in English language was selected. #wardrobechallenge was the central anchor for identifying relevant data; however, this hashtag is used on a variety of content, so further exclusions were applied to ensure the data captured concerned personal wardrobe organisation and self-fashioning practices (not advertising). 120 Instagram posts were captured on October 16 and 17 2024 and 120

TikTok videos were captured October 25 and 26 2024 all tagged with #wardrobechallenge amongst hashtags (see Table 1). Each was considered as a digital artefact - a unit of analysis comprising of image / video, written post, hashtags. The process of analysis employed mixed methods, adopting a layered semiotic approach to analyse images, context, and text (Barthes, 1991). Having refined the data sets to ensure the content was concerned with personal wardrobe practices, image and text were considered together, paying particular attention to the coherence of the message delivered through visual and textual means.

Platform	Gender presentation (from observation)	Approx. age (from observation)	Location (where included)
Instagram (120 posts)	M: 1 F:119	Millennials and Gen X	US, UK, Malaysia, Germany
TikTok (120 videos)	M: 3 F: 117	Gen Z and younger Millennials	US, UK, Singapore

Table 1. Details of user-generated content (UGC) collected from social media platforms.

Content analysis was combined with visual mapping techniques to analyse the elements converging in the content. Experimental assemblages were created, which grouped types of images used and to document reoccurring features of the data. The techniques for tracking and visualising findings as a means of analysis are taken critical cartography (Cosgrove, 1999; Butler-Kisber & Poldman, 2010), where mapping techniques enable multiple elements to be viewed in relationship to each other. Here mapping deconstructs a linear readings of social media feeds, disrupting algorithms and automated formatting that remain invisible yet shape what/how we see the data. Content analysis and visual mapping became integrated through iterative and relational analysis techniques (Orlikowski & Scott, 2016). Subsequently thematic analysis (Braun & Clarke, 2006) of the data was undertaken and iteratively refined, this revealed common motivations in the types of #wardrobechallenge content being shared. The themes are detailed in the typology (see Table 2 in the appendix).

In addition, situational analysis was undertaken to consider the broader relational context for the research. It is important to acknowledge the complexity of researching social and socio-material phenomena, and resist limiting the study to a single specific focus to see the assemblage of actants at work. Self-fashioning and fashion consumption practices are shaped and influenced by a range of entangled factors and actants. Situational analysis provides a methodological approach that retains and manages the complexity the situation being researched, a view of the arena in which meaning is being negotiated (Clarke, 2014). This analysis was undertaken using academic sources, industry data and grey literature to build a picture of political, economic, social, technological, environmental and legal context of the study with a view to surfacing various actants. Findings from the situational analysis enable a meso-level view - a 'social world' (Clarke, 2014) against which to view of the UGC. Figure 1a. sets out significant factors relevant to the study.

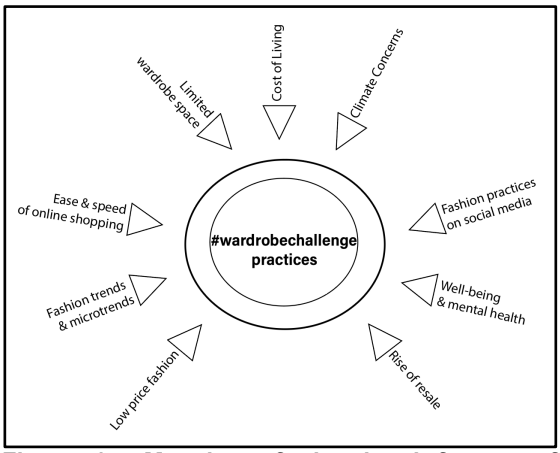


Figure 1a. Mapping of situational factors of #wardrobechallenge (© Matthews, R. 2024).

Findings

The motivations to participate in wardrobe challenge activities ranged from struggles with storing wardrobe contents, desire to develop more confidence in personal style, guilt about volumes of unworn clothing (or fabrics purchased to make clothing), a need to curb shopping habits for financial, body image and fit issues. Some content was explicitly linked of sustainability as #slowfashion or #sustainablefashion as well as strategies for managing too much choice and availability; but the overarching objective appeared to be motivated by a desire to change their relationship with fashion. Through more systematic analysis of #wardrobechallenge data, characteristics in the types of wardrobe challenges emerged. These have been developed as a typology of

#wardrobechallenge practices (see Table 2 in the appendix). The classifications group socially negotiated use phase strategies being employed in everyday self-fashioning, by types of online communities. The typology contributes a perspective on use practices, often designed to manifest a less chaotic and more joyful relationship with fashion and clothing over time, deepen connection with wardrobe contents and extending garment lifecycles.

Makers & Menders

The wardrobe challenge for this group is that they make or modify garments, but don't wear them as often as they would like, so they post about finding ways to increase the number and the ways they wear the things they have made themselves. The group connects through a love of making, knitting, mending, re-modelling or adjusting garments at home for themselves. They post prompts and motivations for themselves (and others) to wear more of what they have made and adapted rather than buying new clothing as well as describing processes and sharing recent making projects.

De-clutterers

The wardrobe challenge for this group is managing quantities of wardrobe contents in ways that make storing and finding items easy. The group share solutions for more ordered, less chaotic relationship with garments and their wardrobe space through a 'less is more' mantra. They post practical interior design tips on decluttering wardrobe spaces, efficient storage, quality of hangers and fixtures and appear to be particularly concerned by what constitutes a 'capsule' wardrobe.

Style experimenters

The wardrobe challenge for this group is concerned with notions of personal style and identity expression through self-fashioning. The group is motivated by a desire to feel more confident and less reliant on fashion industry trends. Many post their style experiments to test, receive feedback and seek approval from others, as if getting dressed with a close friend. Others in this group promote 'dress to please yourself' message encouraging others to look beyond social norms and expectations and liberate themselves from fashion trends.

Fancy dressers

The wardrobe challenge for this group is akin to fancy-dress competition. The group use their wardrobe content like a dressing-up box to compose outfits to resemble the style of their current favourite inspiration, paying homage to certain celebrities or characters. The characters / personalities that inspired the fancy-dressers in the data captured for this study ranged from Iris Apfel, Michelle Obama and Emily in Paris through to Disney and Anime characters.

Fashion refrainers

The wardrobe challenge for this group is their overconsumption, always shopping for new items rather than wearing what they already own. The group are on a shopping diet, and post to keep themselves accountable. They share prompts and motivations to refrain from buying new clothes, such as promoting the idea of shopping in your closet. Many follow the wardrobe challenge strategies such as the Rule of FIVE or Project 333.

There are underlying tactics in #wardrobechallenges typology: the renegotiation of novelty in fashion, the creative use of constraints and sharing and connecting through socio-material experiences (see Figure 1b.). The insights build a view of alternative problem-solving strategies users are employing to 'do' fashion beyond consumption and the designations of the fashion industry; approaches that counter the usual dichotomous (sometimes judgmental) statements about deficit or limitations in some sustainable behaviour discourse (Tham, 2010).

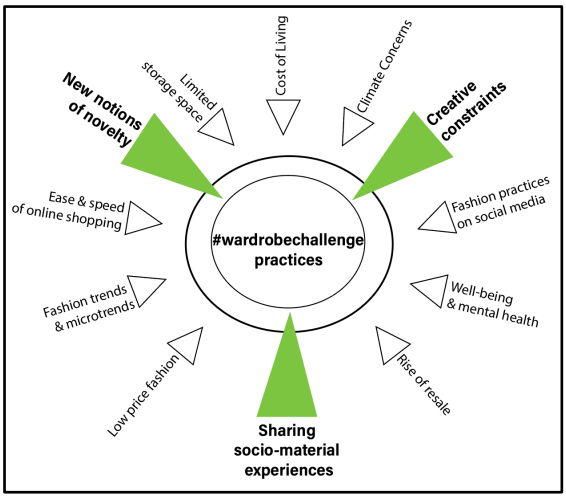


Figure 1b. Mapping of situational factors and key characteristics of #wardrobechallenge (© Matthews, R. 2024).

New notions of novelty

This captures the way groups are renegotiating ideas of newness in their existing wardrobe contents. The examples reveal a variety of (non) consumption fashion practices, where shopping and trend-driven newness is replaced with socially negotiated experiences with fashion and clothing. Ideas of newness are re-shaped from a user perspective and contain a spirit of resourcefulness / inventiveness that is not motivated by commercial imperatives. Further, this sense of liberation from fashion is reflected in activities such as 'fashion week bingo' or 'fashion roulette' where users parody industry tropes. Examples from the data:

"*Its Monochrome Monday*"(IG007)

"*Today I styled looks from the floor up! Yep, started on the shoes and built a look from there!"* (TT054)

"*Fun fact: I'm actually wearing it backward! The front is a higher scoop neck, but the v on the back and the cut of the shirt makes it versatile enough to wear both ways. Have you ever turned a piece of clothing around?"* (IG073)

Creative constraints

The use constraints here are not as a negative or a deficit. They are creatively employed to prohibit acquisition. According to Bogost (2016) in his analysis of play, rules and reduced options do not limit the joy of experience but rather provide structure for interesting and creative choices and experiences. It is in this spirit that constraints are employed in the #wardrobechallenge data. Numerical or temporal constraints are utilised, as over time the new ways of thinking, feeling and acting in relation to fashion becomes habitual (Saunders et al., 2024). The findings illustrate creative remaking rules and systems around fashion and clothing from user perspective. Examples from the data:

"*No buy July*" (IG012)

"*100 days and no repeats…and you must donate what didn't get worn in 100 days"* (TT034)

"If you didn't touch it last season, it's time to sell it or donate it" (TT023)

Sharing of socio-material experience

Another feature of the data is how wardrobe choices are entangled with life events and social interactions, illustrating the tacit emotional connections we have with our wardrobe. The sentiment is shared as a justification of choice, while connecting the emotional and tactile / haptic experiences involved in self-fashioning. This content builds visibility of the multiple actants converging in self-fashioning. Examples from the data:

"I know its boring talking about the weather but a wool jumper in July?? Getting dressed is definitely challenging right now. I'm currently aiming to build my outfits around one summery item along with the warmer ones I need to stay warm. That way at least some of my summer wardrobe is getting worn" (IG067)

"Fuss free look for an unmotivated day. I am so tired today, I genuinely can't wait to go to bed" (IG061)

"I haven't felt much like posting yet this month wading through sadness at the loss of a beautiful friend. But she always admired my me-mades, and her last ever message to me was to say how happy she was for me starting my new job (emoji heart / cotton reel) wearing the snuggliest hug of #cardiganno4" (IG090)

#wardrobechallenge participation has allowed fashion users to make space - physical, temporal or mental space (Martin-Woodhead, 2022) to test different relationships with fashion. By 'working it out' on social media, users have encouraged others to participate, tell their stories, generating alternative ways of thinking, feeling and practicing self-fashioning. Although, the study analyses only a small sample, the variety of voices and sense of enjoyment with fashion is evident, often articulated by those who may have felt alienated by the fashion system. The implications of these findings and the potential to socialise and support other types of fashion and clothing systems is discussed below.

Discussion

Communicating about sustainable fashion and clothing is complex and difficult to pin down (Saunders et al., 2024). Sustainable fashion is not a singular or stable concept (Fletcher, 2013). It is a "tricky" expression (Payne &

Ferrero-Regis, 2019, p180) because the very meaning of fashion – continuous change predicated on newness – negates the possibility of sustaining sustainability. Users' experiences with fashion are also difficult to pin down, being neither homogenous nor static. To evolve a discourse in this space requires the negotiation and co-creation of language and forms of representation. With little evidence of the industry's willingness to engage with the use phases of fashion and clothing, we must look elsewhere for trusted and engaging communications that supports users to rethink material consumption.

The study provides insights that suggest ways for fashion communication practices to build counter-narratives to the 'new is always better' message that remains a feature of fashion media. Further, the online discourse around 'doing' fashion sustainably often invokes feelings of guilt rather than enjoyment or side-steps genuine use practices. To gain traction, mediations of sustainable behaviour change need to be appealing and feel achievable; the content captures mood-boosting DIY approaches to fashion, used to disrupt norms and reshape former behaviours towards material consumption. Shared on online, this becomes a form of fashion media that opens ways to speak about individual experience and socialise alternative interactions with material worlds. It elevates use practices and experiences with fashion, making visible a nascent pluriverse of fashion and clothing systems, where shopping and trend-driven newness is replaced with socially negotiated experiences. The content begins to evolve a more democratic discourse where sustainable use practices come with guidance and a support network. This suggests how networked communities can grow decentralised, autonomous 'Commons' (Bollier, 2014), where individuals share assorted fashion-abilities (Von Busch, 2022) as the open-source resources. These networked groups stimulate ways to decentralise, undermine and dismantle constructs of fashion built on commercial drivers. Viewed collectively, a genre emerges, co-created communications capable of mediating different sustainable behaviours and practices.

It is important to acknowledge that social media content is influenced by multiple interacting factors (from platform and algorithmic limitations through to micro-trends), recognising the "moulding power of media" (Rocamora, 2023) despite individuals' intention. There are restrictions when trying to gain ground or bandwidth within digital platforms such as Instagram, designed to prioritise paid for content and advertising. However, it remains possible for online collectives or media-related pioneer communities (as described by Hepp, (2016)) to drive change in culture, by amplifying different voices and perspectives in an evolving communications landscape. The enactment and sharing of novel experiential approaches to sustainable fashion use online, can generate communication networks that both promote and support behaviour change. In doing so, effective ways of speaking about and representing Chapman's (2021) vision for a future enriched by experience while drawing lightly on material resources emerges.

Conclusions

This paper has investigated UGC tagged #wardrobechallenge to better understand whether the sharing of wardrobe challenges holds potential to drive sustainable behaviour change. Analysis revealed groups of individuals seeking less chaotic and more harmonious relationships with fashion through wardrobe management; these groups encouraged others to participate and in doing so co-created spaces for discussion of fashion and clothing systems operating beyond consumption and designations of the fashion industry. Recognising that fashion communications is powerful yet currently ineffectual in driving sustainable change, the paper envisions the findings as a communication strategy designed to support a fashionable future shaped through novel experiences not material consumption.

References

Bollier, D. (2014). The commons as a template for transformation. *Great Transition Initiative*, p.1-14.

Butler-Kisber, L. and Poldman, T. (2010). 'View of the power of visual approaches in qualitative inquiry: The use of collage making and concept mapping in experiential research', Journal of Research Practice, vol 6, no.2.

Chapman, J. (2021). *Meaningful stuff: design that lasts*. Mass, The Mit Press.

Chapman, J. (2012). *Emotionally durable design: objects, experiences and empathy*. Oxon: Routledge.

Clarke, A. E. (2014). Grounded theory: Critiques, debates, and situational analysis. In A. E. Clarke & K. Charmaz (Eds.), *Grounded theory and situational analysis*. Volume I. History, essentials and debates in grounded theory, p. 225-251. Thousand Oaks: Sage.

Cosgrove, D. (1999). 'Introduction: Mapping meaning', in D. Cosgrove (ed.), *Mappings,* London: Reaktion, p. 1–3.

Fletcher, K. (2013). *Craft of Use: Post-growth Fashion*, Oxon: Routledge.

Fletcher, K., & Klepp, I. G. (Eds.). (2017). *Opening up the wardrobe: A methods book*. Novus press.

Gwilt, A., & Rissanen, T. (2012). *Shaping Sustainable Fashion*. Oxon: Routledge.

Hepp, A. (2016). Pioneer communities: collective actors in deep mediatisation. *Media, Culture & Society*, 38(6). https://doi.org/10.1177/0163443716664484

Hipfl, B. (2018). Affect in Media and Communication Studies: Potentials and Assemblages. *Media and Communication*, *6*(3). https://doi.org/10.17645/mac.v6i3.1470

Kwon, K. (2018). Public Referral, Viral Campaign, and Celebrity Participation: A Social Network Analysis of the Ice Bucket Challenge on YouTube. *Journal of Interactive Advertising*, *19*(2). https://doi.org/10.1080/15252019.2018.1561342

Latour, B. (2005). *Reassembling the social: an introduction to actor-network-theory*. Oxford: Oxford University Press.

Martin-Woodhead, A. (2022). Making wardrobe space: The sustainable potential of minimalist-inspired fashion challenges. *Area*, *55*(2). https://doi.org/10.1111/area.12848

Payne, A., & Ferrero-Regis, T., (2019) Sustainable fashion in Australia: Raw fibre, fast fashion, and new localism. In Gwilt, A, Payne, A, & Ruthschilling, E A (Eds.) *Global Perspectives on Sustainable Fashion*. Bloomsbury Visual Arts, UK, p. 180-190.

Oh, T. T., & Pham, M. T. (2021). A Liberating-Engagement Theory of Consumer Fun. *Journal of Consumer Research*, *49*(1). https://doi.org/10.1093/jcr/ucab051

Orlikowski, W. (2007). 'Sociomaterial Practices: Exploring Technology at Work', Organization Studies, vol. 28, no. 9, p. 1435–1448.

Orlikowski, W., & Scott, S.V. (2016). Digital work: A research agenda. *A research agenda for management and organization studies*, p.88-95.

Ritch, E., Carey, L.D. and Kidd, E. (2020). The fashion detox challenge: An experiment in reduced clothing consumption. In *Global Fashion Conference: The Legacy of Fashion: Past, Present and Future.*

Rocamora, A. (2023). Deep Mediatisation and the Datafication of Fashion. In *Contemporary Challenges in Mediatisation Research* p. 63-79. Oxon: Routledge.

Ruppert-Stroescu, M., LeHew, M. L. A., Connell, K. Y. H., & Armstrong, C. M. (2015). Creativity and Sustainable Fashion Apparel Consumption: The Fashion Detox. *Clothing and Textiles Research Journal*, *33*(3). https://doi.org/10.1177/0887302X15579990

Saunders, C., Griffin, I., Hackney, F., Barbieri, A., Hill, K. J., West, J., & Willett, J. (2024). A Social Practices Approach to Encourage Sustainable Clothing Choices. *Sustainability*, 16(3). https://doi.org/10.3390/su16031282

Sumner, M. (2018). Mind the gap: Fashion consumers' intentions and behaviours. In *Eco-Friendly and Fair* p. 27-35. Oxon: Routledge.

Tham, M. (2010). Languaging fashion and sustainability: Towards synergistic modes of thinking, wording, visualising and doing fashion and sustainability. *Nordic Textile Journal, 3(1),* p.*14-23.*

Vladimirova, K. (2021). Consumption corridors in fashion: deliberations on upper consumption limits in minimalist fashion challenges. *Sustainability: Science, Practice and Policy*, *17*(1), p. 102–116. https://doi.org/10.1080/15487733.2021.1891673

Von Busch, O. (2022). '"What is to be sustained?": Perpetuating systemic injustices through sustainable fashion', *Sustainability: Science, Practice and Policy*, vol. 18, no. 1, p. 400–409.

Woodward, S. (2014). Accidentally Sustainable? Ethnographic approaches to clothing practices. In *Routledge handbook of sustainability and fashion* p. 131-138. Oxon: Routledge.

Appendix

Type / typology #wardrobechallenge	Wardrobe challenge	Characteristics	Novelties & constraints
1.Makers & Menders #DIYwardrobe #memade #sewersofinstagram	A desire to wear more things that they have made themselves	• Feel guilty about fabric hoarding • Pride & satisfaction in their making • Themes: fabrics, patterns, sizing, fitting & construction tips • Clothing maintenance, repairs, recutting, upcycling • Telling garment stories • Overall, discourse invites feedback & comments of self-made pieces & edutainment on pattern, fit & make	Months of year / days of the week to wear only self-made items Colour or pattern related themes Some reference to fashion trends (barbie core, cottage core)
2.Declutterers #getorganised #capsulewardrobe #cluttertocapsule	A desire for a neater and more organised wardrobe	• Practical and organisational focus • Connection with health & well-being through order and control (escaping chaos and overwhelm) • Themes: interior design including fixtures & fittings, efficiency & functionality of wardrobe spaces, packing & storage tips, what to do with excess clothing • Lots of before and after content or timelapse, overall discourse about advice & tips	Numbers and formulas for "capsule wardrobe" Strategies & definitions of wardrobe "staples" Specific times of the year for seasonal declutters and wardrobe re-organisation Marie Kondo type guide decluttering
3.Style Experimenters #stylechallenge #fashionover40 #shopyourcloset	A desire to find personal style & be more creative in self-fashioning	• Personal style as a means of freeing themselves from 'fashion' trends or social norms • Make connection with building self-confidence through style • Despite wanting to be free of fashion trends, inspiration sometimes refers to trends • Not really about restraint, more about having fun, liberation and finding inspiration themselves • Overall discourse is about style & enjoyment, seeking feedback and approval, occasionally competitive tone	Mostly about styling, inspiration and style challenges (styling version of Project 333) Themes: outfit planning, styling details tips, sharing insecurities (age, body shape), French girl, nautical, events such as WFH Games like fashion roulette, fashion week bingo
4.Fancy-dressers #disneybounding #irisyourcloset #eglwardrobechallenge	A desire to use their wardrobe to pay homage to celebrities / characters	• Wardrobe as dressing-up box • Special interest groups, such as cosplayers, fans of celebrities and fantasy characters • Inspiration through dressing up as other people - fantasy and escapism • Overall discourse social connection through fandom	Themes: Iris Apfel, Disney characters, Elegant & Gothic Lolita's, Emily in Paris, Barbie, Michelle Obama
5. Refrainers #nobuyjuly #fashiondetox #75hardstylechallenge	A desire to wear what they own more, rather than buying any new clothes	• Putting themselves on a fashion diet – comments like 'a fast from fashion' and 'fashion detox' • Confessions of struggles with fashion & shopping (like addiction) • Disenchantment with clothes shopping, guilt / shame about volume of clothing they own and about clothing they own and don't wear • Discussion of events or activities that proved easier / harder because they weren't allowing themselves to shop for new products • Overall discourse, seeking encouragement and accountability as they refrain from shopping	Lots of use of the wardrobe management formulas – quantitative or temporal - #ruleof5, #30wearschallenge, #75daystylechallenge, 10X10challenge Wearing items that haven't been worn for a year

Table 2. Typology of #wardrobechallenge practices (© Matthews, R. 2024).

Research paper
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CircularMAT: Materials Advisor Tool to promote circular material selection in fashion design

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Keywords: Circular Fashion; Durable fashion design; Design Tool; Material Selection.

Abstract: Discussing fashion entails revisiting history through both individual and collective expressions. However, the narrower meaning traditionally associated with the term has, for centuries, referred to the replacement of the old with the new—something that better reflects the Zeitgeist. By embracing the spirit of the time, fashion has evolved in response to today's uncertain future and precarious environmental conditions, moving beyond impulsive opulence toward sustainability. The sector may now be prepared to adopt a new definition of fashion as something not transient, but rather enduring. Durability is a cornerstone of the circular economy model, which seeks to keep materials and products in regenerative production cycles for as long as possible. In this context, the present paper introduces CircularMAT, a practical material advisory tool developed to support fashion designers in selecting materials that promote durability and enable circular design strategies. CircularMAT offers a structured system for material exploration, providing comprehensive information on traditional, preferred, and emerging materials. It links material characteristics to core principles of circular fashion and maps them against design strategies intended to extend product lifecycles and reduce environmental impact. The tool is designed to integrate seamlessly into the designer's workflow, fostering conscious and informed material selection decisions during the early stages of the creative process. By emphasizing the relationship between material properties, durability, and circularity, CircularMAT supports the adoption of more sustainable design practices—without compromising creativity.

Introduction

In recent decades, the fashion industry has witnessed a sharp increase in clothing production, accompanied by shrinking profit margins and escalating environmental and social impacts (McKinsey & Company, 2020a). Between 2000 and 2014, global production doubled while garment longevity declined by 36%, fostering a pervasive "throwaway culture" (Ellen MacArthur Foundation, 2017; Joy et al., 2015).

The rise of fast fashion has significantly exacerbated these issues. In 2018, the industry generated 2.1 billion tonnes of greenhouse gas emissions—approximately 4% of global emissions—alongside high levels of energy, water, and chemical consumption (McKinsey & Company, 2020b; Shirvanimoghaddam et al., 2020). Globalized production systems have further intensified poor labour conditions in manufacturing countries (Heinze, 2020; Ozdamar Ertekin et al., 2020), while contributing to a culture of disposability and growing volumes of textile waste (Freudenreich & Schaltegger, 2020; Niinimäki et al., 2020; Thorisdottir & Johannsdottir, 2020).

One of the most effective strategies to address these challenges is the promotion of durability in fashion products. Garments designed to last longer reduce demand for virgin materials and help minimize textile waste. However, durability encompasses more than physical resistance—it also includes emotional, symbolic, and cultural dimensions that influence how long a garment is retained and used (Fletcher & Tham, 2019; Chapman, 2015).

Inadequate material selection, often driven by purely aesthetic criteria, can significantly undermine a product's capacity to remain in circulation, even when other design strategies aim to enhance emotional or symbolic attachment. As several studies have

emphasized, systemic durability—emotional, symbolic, and cultural—must be supported by a strong material foundation (Chapman, 2015; Fletcher & Tham, 2019). A garment that deteriorates rapidly due to underperforming materials loses both its functional and aesthetic value, ultimately severing the connection with the user.

Material selection is therefore critical for achieving both physical and systemic durability. Natural fibres such as wool, cotton, and silk typically offer higher durability when properly treated, whereas synthetic fibres commonly used in fast fashion—such as polyester and nylon—tend to degrade more rapidly, exhibiting issues like pilling and diminished appearance after repeated washing (Niinimäki & Hassi, 2011). Material selection also influence recyclability, repairability, and reusability of the final product, all of which are fundamental to circular design strategies.

The central role of material selection in sustainable fashion design is well recognized. It is estimated that up to 80% of a product's total environmental impact is determined during the design phase, primarily through material-related decisions (Dzhengiz, Haukkala, & Sahimaa, 2023). The extraction and processing of raw materials—particularly across tiers 2, 3, and 4 of the supply chain—are major contributors to greenhouse gas emissions and resource depletion. Tier 2 activities alone, such as textile preparation and dyeing, account for more than half of the industry's total GHG emissions (Apparel Impact Institute, 2023).

Despite growing awareness, recycling technologies for fibres and textiles remain limited, fragmented, and often technologically immature (Eppinger, 2022). Furthermore, the long-term implications of designers' material choices—especially their influence on circular design strategies—are still underexplored.

Although several material libraries and selection tools are available (Papile & Del Curto, 2021), these often prioritize technical specifications or aesthetic qualities, without fully integrating circular economy principles. For instance, resources like the Textile Exchange Preferred Fiber and Materials Market Report offer valuable sustainability data, but are primarily geared toward corporate environmental reporting rather than creative design processes.

This gap becomes particularly evident when attempting to align fashion design practices with eco-design and circular strategies. In a circular economy, materials and products are kept in use for as long as possible through reuse, repair, remanufacturing, and recycling (Ellen MacArthur Foundation, 2020). Effective material information management is thus essential to support circular and eco-design approaches (Italia, Papile, Santi, & Del Curto, 2023), especially in the early phases of the design process, when the most influential decisions are made.

In response to these challenges, the present study introduces CircularMAT, a materials advisory tool designed to assist fashion designers in selecting materials that promote durability and facilitate circular design strategies. CircularMAT offers a structured and accessible system for material exploration, integrating sustainability criteria directly into the early stages of the creative process.

This paper outlines the theoretical background and methodological development of CircularMAT, describes its structure and components, and presents findings from its preliminary validation with fashion design students and industry professionals. The discussion highlights the tool's potential contributions to advancing sustainable practices in fashion design.

Methodology

Research Approach and Framework Development

Although the standardized language of product design effectively supports material characterization, it is not always directly applicable to the fashion context, due to the complexity and variability of textile-based products. Nevertheless, structured design methodologies developed in product design can be successfully adapted to fashion-specific applications (Italia et al., 2023).

To address this disciplinary gap, a hybrid methodological framework was developed by combining Life Cycle Assessment (LCA) with qualitative strategies focused on durability and circularity. LCA was selected for its capacity to assess environmental impacts across the full

product life cycle (Joint Research Centre, 2010). However, its limitations—particularly in accounting for emotional durability, social factors, and variability in the use phase—necessitated the integration of additional qualitative indicators. These included material longevity, recyclability, and alignment with circular design principles.

The framework followed the five standard life cycle stages outlined by Vezzoli et al. (2022): pre-production, production, distribution, use, and end-of-life. Previous research (Mazzitelli et al., 2024) identified the pre-production/production and use phases as the most environmentally impactful. Relevant impact categories included climate change, eutrophication, toxicity, and the consumption of water and energy resources (Moazzem et al., 2018; Gray, 2017). These environmental aspects were then cross-referenced with circular design strategies proposed by the European Union (Beton et al., 2014), establishing the conceptual foundation for the development of CircularMAT.

Exploratory Analysis and Tool Benchmarking

An exploratory analysis was conducted to map existing circular design strategies, material innovation trends, and life cycle assessment frameworks. Key references included Beton et al. (2014), Ellen MacArthur Foundation (2020), Papile et al. (2021), and Vezzoli et al. (2022).

This phase also included a benchmarking study of existing material selection tools, such as CES EduPack, Circular Material Library, Innovatheque, and fashion-specific platforms like the Higg Materials Sustainability Index (MSI) and the Preferred Fiber & Materials Market Report (PFMM). The analysis revealed that most tools prioritize technical performance indicators or corporate sustainability metrics, often lacking accessibility and creative relevance for fashion designers. These insights informed the design of a more intuitive and designer-oriented resource to support circularity during the early stages of the creative process.

Taxonomy and Content Structure

Drawing from the exploratory findings, a taxonomy was developed to define the structure and categorization of the CircularMAT toolkit. The content was organized into four main card types, each serving a distinct purpose within the design process:

- **Material Cards**, presenting detailed profiles on individual materials;
- **Neo-Material Family Cards**, introducing emerging material groups based on innovation trends;
- **Material Comparison Cards**, enabling side-by-side evaluation of key parameters;
- **Circularity Strategy Cards**, outlining relevant design and business strategies aligned with circular principles.

Each card type was conceived to support specific phases of fashion design—from material exploration to strategic planning—facilitating the early integration of sustainability criteria within the creative workflow.

Validation with Users

To evaluate the usability and effectiveness of CircularMAT, an experimental study was conducted involving participants from both academic and professional backgrounds in fashion design. Each participant received a curated selection of cards, along with a contextual presentation and a narrative framework designed to simulate realistic design scenarios.

Following independent interaction with the toolkit, participants completed a structured questionnaire aimed at assessing clarity, usability, and potential integration into the design workflow. The study combined quantitative data (collected through Likert-scale items) with qualitative insights (via open-ended responses), enabling a comprehensive evaluation. The feedback informed targeted refinements to the toolkit's content, structure, and visual communication system.

Strategies	Description	Best practices
Ecodesign	Ecodesign takes environmental aspects into account at all stages of the product development process and strives for products that have the lowest possible environmental impact throughout the product's life cycle, where economic aspects are also considered	*Ensure maximum product lifetime
		*Use recycled materials
		*Ensure production sustainability
Material innovation	Innovation material, replacing fossil supplies with biobased and recycled content	*Substitution of fossil materials with biobased and recycled materials
Refurbishing	The process of repairing or restoring a garment through which the garment is given a new life	*Repair of clothing
		*Garment alterations
Recycling	Clothing recycling where clothes are processed and new fibres are obtained	*Use of technologies for easy recycling of clothing materials
		*Use of digital passports
		Improving waste sorting
Change in the distribution model	To look at textiles in a new way not only in terms of sales	*Offer textile lease/rental business models

Table 1 Summary of circular strategies in the textile sector

Results

Toolkit Overview

Based on the methodological framework described, CircularMAT was implemented as a modular, card-based toolkit designed to assist fashion designers in selecting materials that align with principles of durability and circularity. Its structure facilitates the integration of sustainability criteria into the early stages of the design process, offering a clear, visual, and user-oriented system.

The final toolkit comprises **49 cards**, organized into four distinct categories:

- **Material Cards** (27): Provide information on material origin, composition, cradle-to-gate LCA-based impact, durability, care requirements, end-of-life options, and available certifications.
- **Neo-Material Family Cards** (10): Group emerging material types (e.g., bio-based, biomimetic) and include SWOT analyses to outline their design potential and limitations.
- **Circularity Strategies Cards** (5): Present actionable strategies related to design, materials, components, and business models, with corresponding benefits.
- **Material Comparison Cards** (4): Enable side-by-side evaluation of selected materials based on indicators such as the fiber cradle-to-gate CO_2 emissions.

The toolkit also includes a tab index, a user guide, and a bibliographic section to support navigation and usability within both professional and educational design workflows. All cards are printed in A5 unbound format, encouraging hands-on exploration and flexible use.

Each **Material Card** synthesizes critical information derived from LCA studies and durability research. A visual icon system indicates the availability and relevance of data:

- Solid icon = compatible;
- Transparent icon = incompatible;
- "n.d." = not determined.

Sections of the sheet cover general properties, environmental impact categories, durability and care, end-of-life paths, typical applications and certifications that a given fibre can obtain(Figs. 1–2).

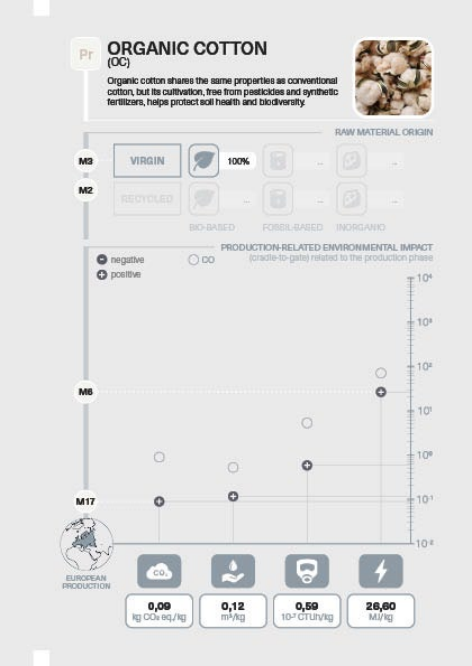


Fig. 1: Example Material Card [Front]. Author's Elaboration.

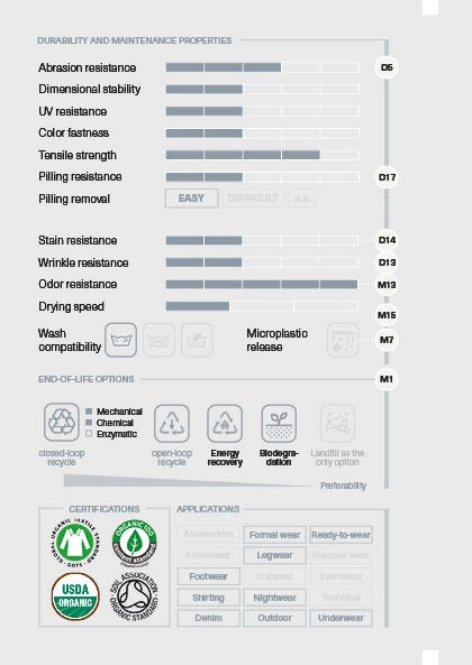


Fig. 2: Example Material Card [Back]. Author's Elaboration.

The **Neo-Material Family Cards** present future-oriented material groupings, including bio-based, bio-fabricated, living, recycled, and food-derived families. Each card (Figs. 3–4) includes a definition, SWOT analysis, and a curated list of representative materials.



Fig. 3: Example Neo-Material Family Card [Front]. Author's Elaboration.

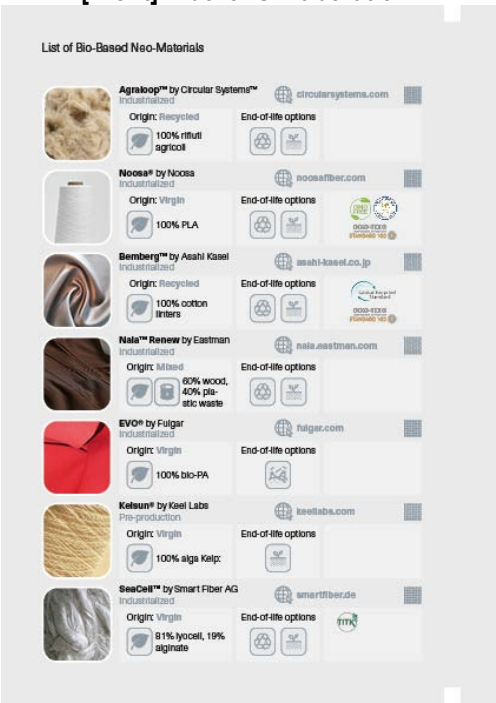


Fig. 4: Example Neo-Material Family Card [Back]. Author's Elaboration.

The **Material Comparison Cards** (Figs. 5–6) consolidate data from individual materials to facilitate comparative evaluation. Each card is structured into three sections: the selected parameter and unit, comparative table, and an explanatory section answering: *What does the*

parameter represent? Why is it relevant? How can it inform design decisions?.

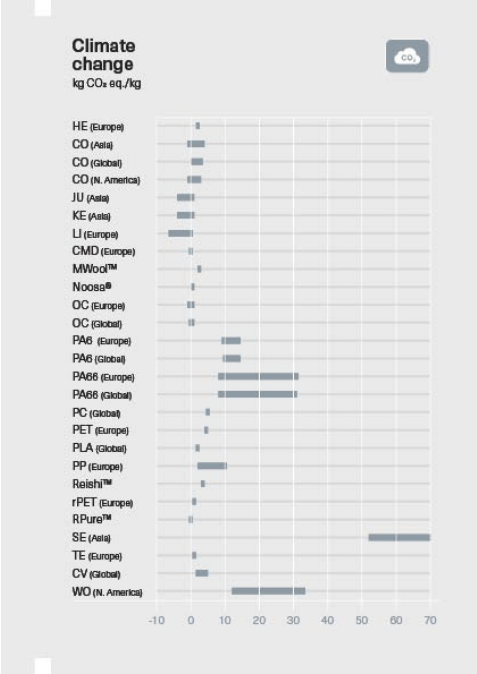


Fig. 5: Example Material Comparison Card [Front]. Author's Elaboration.

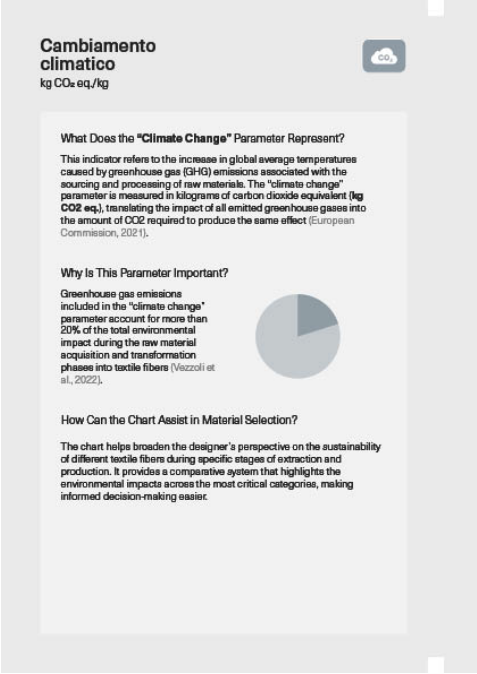


Fig. 6: Example Material Comparison Card [Back]. Author's Elaboration.

The **Circularity Strategies Card** organizes circular approaches applicable to fashion, supporting both technical and emotional durability.
Each card (Fig. 7) includes:

- strategy category, identified by a code (design, components, materials, business models),
- corresponding strategy codes,
- a list of specific actions,
- explanatory notes with examples,
- icons linking strategies to three core principles: **resource optimization**, **product longevity**, and **waste valorization**.

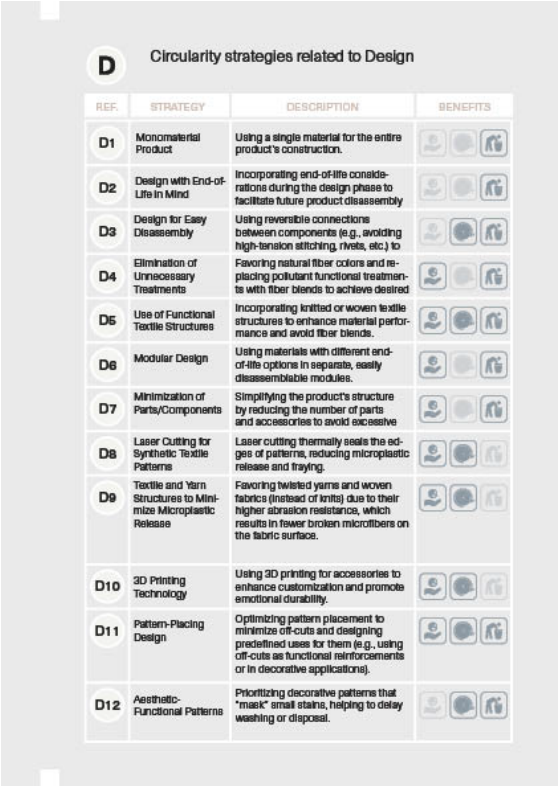


Fig. 7: Example Circularity Strategies Card [Front]. Author's Elaboration.

User Feedback and Refinement
User evaluation confirmed the toolkit's alignment with typical design practices, especially its **physical format** and **modular structure**, which were regarded as effective in supporting early-stage material research and hands-on exploration. Participants noted that the visual language and iconography facilitated intuitive understanding and comparison of materials.
However, feedback also highlighted areas for improvement. Suggestions included:

- Enhancing **icon clarity and legibility**;
- Improving **visual hierarchy** in comparison cards;

- Expanding **information depth** regarding end-of-life scenarios and certifications.

These insights informed a targeted refinement process aimed at improving both **visual communication** and **content accessibility**. The updated version includes revised graphic elements, additional practical examples, and enhanced explanatory sections to better support decision-making during the material selection phase.

Discussion

CircularMAT was developed to integrate seamlessly into the workflows of fashion designers, serving as a practical support tool for incorporating circular economy principles into the creative process. While many sustainability tools are digital and data-driven, CircularMAT offers a physical, tactile, and immediately accessible alternative. Its format aligns with the intuitive and material-oriented practices common in fashion design—such as the use of fabric moodboards, physical samples, and iterative prototyping.

The toolkit's **modular and pocket-sized format** facilitates portability and adaptability, enabling designers to manipulate and compare material information in a flexible and user-driven manner. This tangible interaction not only enhances usability but also promotes creative autonomy, encouraging critical material evaluation without imposing rigid constraints.

In contrast to digital platforms such as the **Higg Materials Sustainability Index (MSI)** or the **Textile Exchange Preferred Fiber & Materials Market Report (PFMM)**—which primarily address corporate-level sustainability metrics—CircularMAT is explicitly designed for the designer's perspective. Rather than providing prescriptive assessments or environmental scoring, it offers a structured yet flexible framework for material selection that accommodates diverse design approaches and project typologies.

By emphasizing adaptability, the toolkit encourages the integration of sustainability considerations from the earliest stages of ideation. Its structure promotes the inclusion of **durability**, **end-of-life scenarios**, and **circular design strategies** as inherent components of design thinking, rather than as external impositions.

The experimental validation conducted with fashion design students and industry professionals provided preliminary evidence of the toolkit's usability and relevance in real-world design contexts. Participants highlighted the utility of the card-based format, the clarity of its visual language, and its alignment with established creative practices.

More broadly, these findings underscore the importance of design tools that respond to the **cognitive and material practices** of designers, particularly in facilitating the early-stage integration of sustainability principles. Within this context, CircularMAT may be seen as a contribution to the ongoing development of resources aimed at embedding circularity within design processes—not only in outcomes, but also in methods and decision-making frameworks.

Conclusions

This study investigated the integration of sustainability and circular economy principles within the fashion industry, focusing specifically on material selection and its role in enabling circular design strategies. The findings reinforced the central role of designers in driving the transition from linear to circular models, where creativity is interwoven with environmental responsibility.

CircularMAT, introduced as part of this research, offers a tangible and accessible tool to support informed material selection aligned with circularity and durability goals. By organizing complex environmental and technical data into a visual and designer-friendly format, the tool supports the incorporation of sustainability considerations from the earliest phases of the design process.

The tool's experimental application provided initial insights into its practical value, with participants confirming its usability, relevance, and potential to foster critical reflection on material choices. Feedback collected during the validation phase also informed targeted refinements aimed at improving content clarity and overall effectiveness.

Looking ahead, further development of CircularMAT will focus on enhancing its

adaptability across varied design contexts, exploring digital applications, and integrating user-centered strategies that address emotional and symbolic durability. These future directions may contribute to narrowing the gap between material performance and user experience, further supporting the implementation of circular principles within fashion design practice.

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References

Apparel Impact Institute. (2023). Taking Stock of Progress Against the Roadmap to Net Zero. Retrieved from https://apparelimpact.org/wp-content/uploads/2023/06/Aii_RoadmapReport-615-1.pdf

Beton, A., Dias, D., Farrant, L., Gibon, T., Le Guern, Y., Desaxce, M., Perwueltz, A., Boufateh, I., Wolf, O., Kougoulis, J., Cordella, M., & Dodd, N. (2014). *Environmental Improvement Potential of Textiles (IMPRO Textiles)*. Lussemburgo: Publications Office of the European Union.

Chapman, J. (2015). *Emotionally durable design: Objects, experiences and empathy*. Routledge, Taylor & Francis Group.

Dzhengiz, T., Haukkala, T., & Sahimaa, O. (2023). (Un)Sustainable transitions towards fast and ultra-fast fashion. *Fashion and Textiles, 10*(1), 19. https://doi.org/10.1186/s40691-023-00337-9

Ellen MacArthur Foundation. (2017). *A New Textiles Economy: Redesigning fashion's future*. Retrieved from https://ellenmacarthurfoundation.org/publications/a-new-textiles-economy

Ellen MacArthur Foundation. (2020). *Vision of a Circular Economy for Fashion*. Retrieved from https://ellenmacarthurfoundation.org/our-vision-of-a-circular-economy-for-fashion

Eppinger, E. (2022). Recycling technologies for enabling sustainability transitions of the fashion industry: Status quo and avenues for increasing post-consumer waste recycling. *Sustainability: Science, Practice and Policy, 18*(1), 114-128. https://doi.org/10.1080/15487733.2022.2027122

Fletcher, K., & Tham, M. (2016). *Routledge Handbook of Sustainability and Fashion*. Routledge.

Freudenreich, B., Lüdeke-Freund, F., & Schaltegger, S. (2020). A stakeholder theory perspective on business models: Value creation for sustainability. *Journal of business ethics, 166(1), 3-18. https://doi.org/10.1007/s10551-019-04112-z*

Gray, S. (2017). *Mapping clothing impacts in Europe: The environmental cost*. WRAP. Retrieved from https://www.ecap.eu.com/wp-content/uploads/2018/07/Mapping-clothing-impacts-in-Europe.pdf

Heinze, L. (2020). Fashion with heart: Sustainable fashion entrepreneurs, emotional labour and implications for a sustainable fashion system. *Sustainable Development, 28(6), 1554-1563.* https://doi.org/10.1002/sd.2104

Italia, M., Papile, F., Santi, R., & Del Curto, B. (2023). Sustainable material selection framework: Taxonomy and systematisation of design approaches to sustainable material selection. *Sustainability, 15*(24), 16689. https://doi.org/10.3390/su152416689

Joint Research Centre. (2010). *ILCD Handbook: Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment*. Brussels, Belgium: European Commission.

Joy, A., Sherry Jr, J. F., Venkatesh, A., Wang, J., & Chan, R. (2012). Fast fashion, sustainability, and the ethical appeal of luxury brands. Fashion theory*, 16(3), 273-295.* https://doi.org/10.2752/175174112X13340749707123

Kashkoush, M., & El Maraghy, H. (2016). Optimum Overall Product Modularity. *6th CIRP Conference on Assembly Technologies and Systems (CATS) Procedia CIRP, 44*, 55–60. https://doi.org/10.1016/j.procir.2016.01.023

Mazzitelli, M., Papile, F., & Del Curto, B. (2024). Materials selection and fashion design: Strengthening reflections on fibre's nature in fibres and textiles selection. *Discover Sustainability, 5*(180). https://doi.org/10.1007/s43621-024-00294-3

McKinsey & Company. (2020a). *Sustainable Style: How Fashion Can Afford and Accelerate Decarbonization*. Retrieved from https://www.mckinsey.com/industries/retail/our-insights/sustainable-style-how-fashion-can-afford-and-accelerate-decarbonization

McKinsey & Company. (2020). *Fashion on Climate*. Retrieved from https://www.mckinsey.com/industries/retail/our-insights/fashion-on-climate

Moazzem, S., Daver, F., Crossin, E., & Wang, L. (2018). Assessing environmental impact of textile supply chain using Life Cycle Assessment Methodology. *The Journal of The Textile Institute, 109*(12), 1574–1585. https://doi.org/10.1080/00405000.2018.1434113

Niinimäki, K., & Hassi, L. (2011). Emerging design strategies in sustainable production and consumption of textiles and clothing. *Journal of Cleaner Production, 19*(16), 1876-1883. https://doi.org/10.1016/j.jclepro.2011.04.020

Ozdamar Ertekin, Z., Atik, D., & Murray, J. B. (2020). The logic of sustainability: Institutional transformation towards a new culture of fashion. *Journal of Marketing Management, 36(15-16), 1447-1480.* https://doi.org/10.1080/0267257X.2020.1795429

Papile, F., & Del Curto, B. (2021). *Improving the material selection process in product design activity: An overview of material repositories*. In *EDULEARN21 Proceedings* (pp. 7574-7580). IATED. https://doi.org/10.21125/edulearn.2021.1539

Shirvanimoghaddam, K., Motamed, B., Ramakrishna, S., & Naebe, M. (2020). Death by waste: Fashion and textile circular economy case. *Science of the total environment, 718, 137317.* https://doi.org/10.1016/j.scitotenv.2020.137317

Thorisdottir, T. S., & Johannsdottir, L. (2020). Corporate social responsibility influencing sustainability within the fashion industry. A systematic review. *Sustainability, 12(21), 9167.* https://doi.org/10.3390/su12219167

Vezzoli, C., Conti, G. M., Macrì, L., & Motta, M. (2022). *Designing sustainable clothing systems: The design for environmentally sustainable textile clothes and its product-service systems*. FrancoAngeli.

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Measuring physical garment durability: An assessment of 47 T-shirts

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Keywords: Circularity; Durability; Garment Testing; Ranking; Longevity.

Abstract: Designing for durability, both physical and emotional, has been identified as non-negotiable in the battle against overconsumption, underutilization and the devasting effects of climate change. There is currently no consistent method of measuring physical garment durability or the ability to compare garments on the market. This study presents a reproducible and novel method for measuring and ranking the physical durability of 47 t-shirts. Multiple durability factors were used to modulate the ranking whereas previous studies have only reported on single factors to evaluate durability. The benchmarking results reveal that price cannot be used as an indicator of durability and that fabric composition does influence the physical durability of a t-shirt. The garments in this study were donated by the signatories of the Waste Resource Action Programme's (WRAP) Textile 2030 initiative as part of their strategy to reduce the environmental impact of UK fashion.

Introduction

In the UK alone, the physical waste created by the fashion industry is excessive. 779,000 tonnes of textile waste were reportedly sent to landfill or for incineration in 2021, with 72% of this coming through the kerbside residual waste stream (WRAP, 2024). Furthermore, by 2030, global apparel consumption is projected to rise by 63% to 102 million tonnes (Casado et al., 2024), and in turn inflating the future textile waste stream. Increased garment durability has been cited as a lifespan extension strategy to increase utilisation, producing garments which are designed to last longer, and reduce the number of garments produced and ultimately generate less waste. A physically durable garment can be defined as one that will remain functional without exhibiting any degradation or damage in comparison to a similar garment (Annis, 2012). An emotionally durable garment is one that the user has a connection to, it remains relevant and desirable to the wearer (Chapman, 2005). For the purpose of this study, physical durability will be the main focus with the aim of developing a consistent and adoptable method to measure physical durability which currently does not exist.

Eco-design for Sustainable Products Regulation (ESPR) and Extended Producer Responsibility (EPR) schemes have been suggested and will be implemented across Europe and the UK which will legally require brands to declare a garment's durability credentials. There is currently no uniform method to measure the physical durability of a garment. To increase the durability on the market as well as meet the criterion being laid out in legislation, a method of measuring physical durability must first be devised. Through assessing the physical factors which affect the lifespan of a specific garment type, a t-shirt in this case, a testing protocol and benchmarking framework can be developed. These tools can be used to moderate the garments being placed on the market to ensure durability as a design core has been considered and that each product can withstand multiple lifetimes within a circular economy (Sun et al., 2021).

Methodology

This study aimed to create a tool to measure and compare the durability of T-shirts to further understand how design for durability can be

Test	Test Standard
Bursting Strength	ASTM D3787
Pilling	BS EN ISO 12945-2:2020
Spirality	BS ISO 16322-3:2021
Dimensional Stability	BS EN ISO 5077:2008
Visual Assessment	Modified ISO 15487

Table 1. Summary of test methods used to measure garment durability.

used as a lifespan extension strategy. 47 t-shirts in total, 24 Men's, 23 women's, from UK clothing brands were procured in the spring/summer of 2024. A testing protocol to measure physical durability was devised based on the main modes of failure for a t-shirt (Cooper & Claxton, 2022) . Table 1 displays the test methods and standards used to test the performance of the garments.

All the t-shirts were washed in a domestic washing machine and tumble dried 50 times. The washing and drying process can significantly damage a piece of clothing (Card et al., 2006; McQueen et al., 2017) and therefore, must be accounted for when assessing physical durability. The t-shirts were removed and assessed at wash intervals 5, 15, 30 and 50. Garments were reviewed under D65 illuminant while six factors were assessed including, pilling, surface disruption, colour fading, colour change, component damage, and visual stability. A graded system was used to assess these factors, Grade 5 equaling no change, while Grade 1 equates to severe change. This system is based on ISO 15487 – Method for assessing appearance of apparel and other textile end products after domestic washing and drying (British Standards Institution, 2018). This standard outlines a method of assessing garments after washing, however it is not specifically investigating the durability of the garment. Therefore, this method has been used as a building block to create a 6-aspect assessment process focusing on physical durability only. The grades of the six aspects at the 50th wash interval have been added together to create a visual assessment score. 30 is the highest score and indicates excellent visual garment durability, 0 is the lowest and indicates extremely poor visual garment durability.

Dimensional Stability has been condensed into an overall score out of 8 based on the measurements taken across 2 measurement points at each of the 4 intervals. 8 is the highest score and indicates excellent garment dimensional stability, 0 is the lowest and indicates extremely poor dimensional stability.

All results were fed into the durability benchmark system where garments can be directly compared and ranked based on overall physical durability. The benchmarking system is a method of ranking the garments based on the level of importance for each test, thresholds, and the actual results of all the tests conducted as listed in Table 1. Other studies have attempted to create a method of measuring and ranking the durability of a garment (Benkirane et al., 2022; Ghaani Farashahi et al., 2018) however little information is shared about the method used to judge how physically durable a garment is and there is currently no agreed method. This iterative method uses a comprehensive approach that uses a combination of results to dictate how durable a t-shirt is as opposed to other studies which only compare single tests (Badgett, 2019; Wakes et al., 2020).

Thresholds have been developed for each test which modulate how the garments move through the benchmark. Each test has been allocated a level of importance, with the most important test having the most weight on where the garment is placed in the benchmark and the least important having less of an impact.

The ranking process was automated using the process explained above using the Excel 'Custom Sort' function by adding levels of rules. Figure 1 provides the framework for the ranking process which can be used for all garment categories regardless of the durability factors that need to be considered in the ranking process. Table 2 displays the results once the benchmarking framework has been applied.
The tests are ordered by level of importance, pilling being the most important and bursting strength being the least, the threshold for each test can be found at the top of Table 1. Thresholds have been developed using existing industry standards (pilling and spirality) and the mean average (visual assessment, dimensional stability, and bursting strength). The results which did not meet the basic threshold have been highlighted in red. All samples have been coded to keep all brands anonymous, codes use the letters TSW (T-shirt women's) and TSM (T-shirt men's) followed by a randomised number.

Pilling has been found to be the main reason why consumers dispose of a t-shirt, while the typical pass rate for the dry pill test in industry is a Grade 3-4, it is not uncommon for a Grade 2-3 to be commercially accepted (Cooper & Claxton, 2022) hence why the threshold for pilling is a Grade 2-3 (2.5). Anything below a Grade 2-3 could be seen by a consumer as a reason to stop wearing the t-shirt. Visual assessment is weighted the 2nd most important

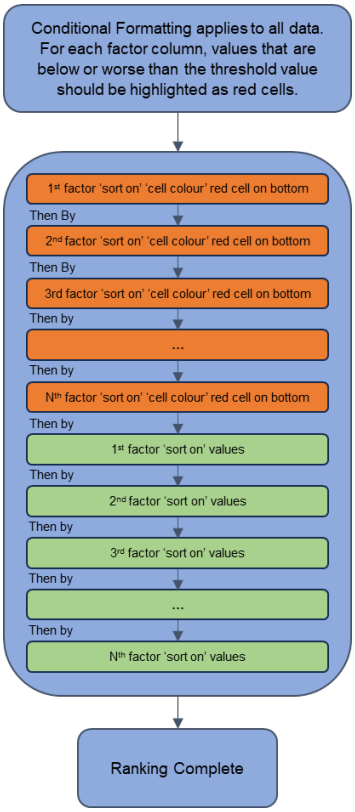


Figure 1. Automated step by step benchmarking process

test, this assessment is a grade representation of how the t-shirt changes over time considering colour fading, texture change and visual stability, all aspects cited as reasons for disposal (Cooper & Claxton, 2022). If by 50 washes a low score is observed, it is likely that a consumer would not continue to wear the garment due to its appearance regardless of whether it is still technically functional. It is this aspect where emotional durability must be considered. Dimensional Stability has been placed as the 3rd most important followed by Spirality. Changes to shape and fit have been cited as reasons to no longer wear a t-shirt (WRAP, 2022). Bursting strength has been placed as the least important, although there are tight fitting styles available, many t-shirt styles have a looser fit. On the styles which are tighter fitting if the consumer is wearing the appropriate size it is unlikely that enough force will be placed on the fabric for the fabric breaking to be a common issue.

Results and Discussion

There is a wide variation in the results across the 47 t-shirt samples. Pilling results range from a Grade 5, indicating no change down to a Grade 1 which implies severe pilling present. Most of the samples achieved an above threshold result, with only 10 samples falling below the Grade 2-3 threshold. Interestingly, 80% of the samples which did not reach the threshold result for pilling also did not reach the threshold for visual assessment. The final scores for visual assessment ranged from 27.5 down to 9 out of 30. The average final score is 19 out of 30. Scores for dimensional stability spanned the full range from a score of 0 to 8. Some garments which exhibited excellent dimensional stability (samples 25 – 30) ranked lower down on the benchmark due to the below average visual assessment score. Spirality results also varied from 1.2%, hardly any change, to 18.2%. 8 samples exhibited double or more than the industry standard of 5% spirality after 5 wash cycles. Finally, results range from 156N up to 598N for bursting strength. Only 18 out of the 47 samples achieved an above threshold result.

A Pearson correlation coefficient was used to assess the linear relationship and significance between the different variables assessed, several significant correlations were found both at the 0.5 and 0.01 confidence level. $p<0.05$ is significant, and correlation was identified by calculating Pearson's r, where $r(45)<0.5$ represents a strong correlation and $r(45)<0.7$ a very strong correlation. A strong positive correlation between the pilling and visual assessment was found $r(45)=0.608$, $p=<0.001$. This infers that a garment which scores well on the dry pilling test will also score well for visual assessment. A small positive correlation was observed between visual assessment and bursting strength at the 0.5 significance level $r(45)=0.289$, $p=0.048$. Furthermore, dimensional stability and spirality exhibit a negative correlation $r(45)=-0.320$, $p=0.028$. This correlation is not surprising considering both are wash related aspects and for spirality the higher the number the worse the result as opposed to dimensional stability where the higher the number the better the result. Two other correlations were observed including a positive correlation between bursting strength and dimensional stability $r(45)=0.304$, $p=0.038$ and a negative correlation at the 0.01 significant level between spirality and bursting strength, $r(45)=-0.406$, $p=0.005$.

				Test Result Thresholds				
				Grade 2-3	19	5	5%	287N
Rank	Retail Price	Fabric Composition	External Code	Pilling (7000revs)	Visual Assessment (Final Grade)	Dimensional Stability Score	Spirality (%)	Bursting Strength (N)
1	£28	87% Polyamide, 13% Elastane	TSW7	5	25.5	7	4.1	425.5
2	£35	94% Polyester, 6% Elastane	TSM36	5	24.5	8	1.2	421.7
3	£12	100% Polyester	TSM15	5	24.5	5	1.3	598.3
4	£10	100% Cotton	TSW8	4	21.5	8	2.5	287.4
5	£32	100% Cotton	TSM6	3	19.5	8	3.5	420.6
6	£10	96% Cotton, 4% Elastane	TSM25	4	22.5	5	3.8	204.6
7	£12	70% Cotton, 30% Polyester	TSM38	4	22	4	2.5	232.4
8	£24.99	100% Cotton	TSM8	4	20	4	3.5	260.3
9	£5	60% Cotton, 40% Polyester	TSW20	4	19.5	4	1.9	233.6
10	£8	100% Cotton	TSW43	4	19	4	4.6	241.8
11	£35	75% Cotton, 25% Polyester	TSW28	4.5	21	6	6.3	336.9
12	£24	75% Polyamide, 25% Elastane	TSW39	5	27.5	8	7.9	156
13	£8	100% Cotton	TSM23	3.5	19.5	6	5.6	244.3
14	£18	100% Polyester	TSM12	5	26.5	3	2.4	485.3
15	£4	95% Cotton, 5% Elastane	TSW4	4	20	1	1.4	244.7
16	£20	100% Cotton	TSM11	3.5	21	2	4	268.2
17	£7.50	100% Cotton	TSM28	3	19	1	6.3	296.4
18	£15	100% Cotton	TSM14	4	21.5	1	9.1	264.4
19	£12	100% Cotton	TSW47	3.5	24	0	12.8	264.8
20	£9	48% Cotton, 47% Modal, 5% Elastane	TSW34	3.5	23	3	7.6	271.4
21	£7	100% Cotton	TSM33	3.5	19.5	3	5.8	254.4
22	£14.99	100% Cotton	TSM9	3.5	19	3	11.9	242.4
23	£5	100% Cotton	TSM35	3	20.5	1	12.7	270.9
24	£12	100% Cotton	TSW45	3	19	3	5.3	274.7
25	£31.99	95% Polyester, 5% Elastane	TSM34	4	18	8	3.5	347.7
26	£55	100% Cotton	TSM1	3.5	15.5	8	4.1	303.0
27	£16	50% Polyester, 50% Viscose	TSW30	3	17.5	8	4	347.6
28	£395	100% Cotton	TSM40	5	18	6	4.3	205.1
29	£18	100% Cotton	TSM17	3	16.5	8	5.8	451.6
30	£28	92% Modal, 8% Elastane	TSW26	3	17	8	18.2	206.8
31	£28	100% Cotton	TSW23	4	17.5	1	3.7	404.4
32	£5	100% Cotton	TSM29	3	18.5	2	4.1	303.5
33	£6	100% Cotton	TSW36	3	18.5	0	4.6	252.6
34	£8	100% Cotton	TSW40	4.5	16.5	1	10.6	190.6
35	£12.50	95% Cotton, 5% Elastane	TSW10	4	17.5	1	7.8	240.1
36	£8	100% Cotton	TSM19	3.5	17.5	2	11.7	270.1
37	£45	100% Linen	TSW14	3	15.5	0	17	180.7
38	£5	100% Cotton	TSM3	2	19.5	2	1.5	312.9
39	£40	100% Cotton	TSM22	2	20	1	7.7	296.6
40	£10.50	95% Lyocell, 5% Elastane	TSW22	1.5	16.5	8	2.9	206.4
41	£29	68% Bamboo Viscose, 28% Cotton, 4% Elastane	TSM5	1	17.5	4	4.8	180.9
42	£35	100% Cotton	TSM31	2.5	11.5	7	5.3	393.5
43	£16	100% Cotton	TSW38	1	18	4	8.6	308.4
44	£12	100% Cotton	TSW31	2.5	17.5	4	9.1	257.7
45	£42	100% Cotton	TSW3	2	9	0	4.1	189
46	£29	100% Cotton	TSW17	2.5	16.5	1	10.8	186.8
47	£7.99	100% Cotton	TSW18	1.5	15	1	15.1	245

Table 2. Final Benchmarking Results of 47 commercially available T-shirts

The results indicate that the more durable t-shirts have a percentage of synthetic fibers in the composition, including polyester, polyamide, and elastane. 64% of the garments which contain synthetic fibers rank in the top 50% of all the garments tested, while 60% of the top 10 garments contain synthetic fibers.

Cotton or other natural fibers are known to have higher shrinkage issues due to swelling shrinkage (Saville, 1999) which can be exacerbated through tumble drying (Higgins et al., 2003). Therefore, it is not surprising that only 3 out of the 23 garments which did not meet the dimensional stability score threshold, had synthetic fibers in the composition. Aligning with previous research to show that t-shirts with natural fibers are likely to have more shrinkage issues, which has been identified as a reason for disposal (Cooper & Claxton, 2022). There are 29 100% Cotton t-shirts that have been tested. The ranking for these garments ranges from 4th most durable down to the least durable. This suggests that all 100% Cotton single jersey t-shirts cannot be presumed to have a similar performance. Other factors such as fiber quality and processing must be considered. Spearman's rank correlation was used to investigate whether fabric weight and the rank of all 100% cotton t-shirts were correlated. The results indicated that garments which used heavier 100% cotton fabrics ranked higher $r(45)=0.442$, $p=0.016$. This suggests that when assessing 100% cotton t-shirts a heavier fabric is likely to be more physically durable. Further investigation into the processing of the cotton should be conducted to explore whether other factors may be contributing to the variation in results such as Open ended versus Ring spun.

Price is commonly used by consumers as an indicator of a durable product (Degenstein et al., 2020). However, the benchmark clearly demonstrates that price cannot be used as an indicator of durability. The most expensive t-shirt priced at £395 was ranked 28th out of 47, while the cheapest at £4 placed 15th. Furthermore, the t-shirt which was ranked the most durable is priced at £28 while the t-shirt which was ranked as the second least durable is priced similarly at £29. Equally, the garment, which is placed last in the benchmarking, after failing to reach the thresholds on every test, cost £7.99. This indicates that there is no correlation between price and garment durability $r(45) = -0.95$, $p=0.527$. An expensive t-shirt is not necessary physically durable and likewise with a cheaper counterpart. Therefore, price cannot be used by consumers as a predictor of overall garment durability for a t-shirt.

Conclusions

This study tested 47 t-shirts from various UK brands to a durability testing protocol considering end use. Results were fed into a benchmarking framework to directly compare the physical durability of each t-shirt. This comparison has allowed for observations to be made regarding the properties of the most durable and least durable garments. These observations can be used in research going forward to investigate how to improve the durability of t-shirts on the market. The findings showed that:

- Composition can be used as an indicator of durability. T-shirts which had synthetic fibers in the composition were on average ranked higher.
- Heavier 100% Cotton t-shirts ranked higher on average than lighter 100% Cotton t-shirts.
- Price is not an indicator of durability. Although some more expensive garments ranked highly, some also ranked low down on the benchmark. Furthermore, several of the cheaper t-shirts performed just as well or better than the expensive ones.

Although this paper presents a comprehensive approach to measuring physical durability, it does not address the vital role emotional durability, the concept of a garment being kept and worn due to emotional attachment, must play in utilisation. Further work must be conducted to explore the dynamics of physical and emotional durability.

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References

Annis, P. A. (2012). Testing textile durability. In *Understanding and Improving the Durability of Textiles* (pp. 126–142). Woodhead Publishing. https://app.knovel.com/hotlink/pdf/id:kt00B

S0001/understanding-improving/durability-in-textiles

Badgett, J. (2019). An Evaluation of the Quality of Men's 100% Cotton Jersey Knit T-Shirts. *Journal of Textile Science & Fashion Technology*, *3*(2), 1–10. https://doi.org/10.33552/jtsft.2019.03.000557

Benkirane, R., Thomassey, S., Koehl, L., & Perwuelz, A. (2022). A New Longevity Design Methodology Based on Consumer-Oriented Quality for Fashion Products. *Sustainability (Switzerland)*, *14*(13). https://doi.org/10.3390/su14137696

British Standards Institution. (2018). *Textiles. Method for assessing appearance of apparel and other textile end products after domestic washing and drying. ISO 15487:2018.* British Standards Publications.

Card, A., Moore, M. A., & Ankeny, M. (2006). Garment washed jeans: impact of launderings on physical properties. *International Journal of Clothing Science and Technology*, *18*(1), 43–52. 10.1108/09556220610637503

Casado, C., Kliger, M., Louvet, P., Poveda, S., Preston, J., Sinha, N., Thukral, N., Symonenko, I., Wadle, L., Wong, J., Fowakes, J., Galley, F., Jia, H., Kent, S., Maki, R., Miller, D.-Y., Morris, M., Negrescu, A., Rawling, A., … Zhang, R. (2024). *State of Fashion 2025*.

Chapman, J. (2005). *Emotionally Durable Design: objects, experiences and empathy*. Earthscan.

Cooper, T., & Claxton, S. (2022). Garment failure causes and solutions: Slowing the cycles for circular fashion. *Journal of Cleaner Production*, *351*. https://doi.org/10.1016/j.jclepro.2022.131394

Degenstein, L. M., McQueen, R. H., McNeill, L. S., Hamlin, R. P., Wakes, S. J., & Dunn, L. A. (2020). Impact of physical condition on disposal and end-of-life extension of clothing. *International Journal of Consumer Studies*, *44*(6), 586–596. https://doi.org/10.1111/ijcs.12590

Ghaani Farashahi, B., Easter, E., & Annett-Hitchcock, K. (2018). Price and perceived product quality: a comparison of denim jeans in three price categories. *Journal of Fashion Marketing and Management*, *22*(3), 369–386. https://doi.org/10.1108/JFMM-10-2017-0104

Higgins, L., Anand, S. C., Hall, M. E., & Holmes, D. A. (2003). Factors during tumble drying that influence dimensional stability and distortion of cotton knitted fabrics. *International Journal of Clothing Science and Technology*, *15*(2), 126. https://doi.org/10.1108/09556220310470132

McQueen, R., Batcheller, J., Moran, L., Zhang, H., & Hooper, P. (2017). Reducing laundering frequency to prolong the life of denim jeans. *International Journal of Consumer Studies*, *41*(1), 36–45. https://doi.org/10.1111/ijcs.12311

Saville, B. P. (1999). Dimensional Stability. In B. P. Saville (Ed.), *Physical Testing of Textiles*. Woodhead Publishing. https://doi.org/10.1533/9781845690151.168

Sun, J. J., Bellezza, S., & Paharia, N. (2021). Buy Less, Buy Luxury: Understanding and Overcoming Product Durability Neglect for Sustainable Consumption. *Journal of Marketing*, *85*(3), 28–43. https://doi.org/10.1177/0022242921993172

Wakes, S., Dunn, L., Penty, D., Kitson, K., & Jowett, T. (2020). Is price an indicator of garment durability and longevity? *Sustainability (Switzerland)*, *12*(21), 1–13. https://doi.org/10.3390/su12218906

WRAP. (2022). *Citizen Insights Clothing Longevity and circular business models receptivity in the UK*. https://wrap.org.uk/resources/report/citizen-insights-clothing-longevity-and-circular-business-models-receptivity-uk

WRAP. (2024). *Textile Market Situation Report*.

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Extending the Lifespan of Garments Globally through Local Upcycling: A Multimethod Approach

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Keywords: garment durability; circularity; product lifespan; upcycling; sustainable fashion.

Abstract: Extending the lifespan of garments is considered a solution to counteract a culture that views them as disposable objects. However, how this is to be done in practice remains unclear. Using a multimethod approach, this study aims to investigate how garments can adapt to their local environment(s) and user(s) so that they can go through different life cycles. To this end, the authors combined data from semi-structured interviews conducted in five different countries and enriched them through triangulation with available literature. We discovered that the durability of garments is dynamic in nature, and that upcycling is a method to extend their lifespans. Furthermore, how the materials of the garment are perceived locally, influences if it is considered eligible for upcycling. As local conditions have not been considered in the definition of the concept so far, we have defined local upcycling as: a process in which materials and garments that are considered worth discarding in their current state are transformed into a product of higher value that is suitable for the local environment, eliminating the need for a new product. Although the lack of field research at the organizational level is a limitation of this study, the authors view this as a potential avenue for future research.

Introduction

Upcycling is an integral part of modern fashion (Popa and Curteza 2024). The latter industry operates within a mass production system, where consumption depends on widespread acceptance and even enjoyment of exchangeability—replacing the old, the broken, and the out-of-fashion with the new. This serial replacement capacity leads also to the capacity to discard without concern (Hawkins 2001). The habit of discarding products after use (Paras and Antonela 2018) has increasingly extended to garments, with the textile industry generating 92 million tons of waste yearly (Abbate et al. 2024). While a common definition for textile waste remains ambiguous, the European commission has developed a set of end-of-waste criteria, forming the basis for its policy documents (European Commission 2023).

Textile reuse refers to various means of prolonging the practical service life of textile products by transferring them to new owners (Fortuna and Diyamandoglu 2017). Textile recycling primarily refers to the reprocessing of pre- or postconsumer textile waste for use in new textile or non-textile products (Sandin and Peters 2018). If a product from a recycled material has a higher value (or quality) than the original product, it is termed upcycling (Sandin and Peters 2018). Upcycling involves reusing clothing products that are no longer useful or have reached the end of their life cycle and converting them into new, value-added products (Popa and Curteza 2024). Over the last decade, the term “upcycling” has been introduced and integrated into the discourse on sustainability efforts, first appearing in William McDonough’s book “Cradle to Cradle” (McDonough and Braungart 2002). Sung (2015) observed that the concept has received increasing attention in recent years from numerous business practitioners, researchers, craft professionals, and hobbyists, a trend similarly noted by other authors (Agrawal and Bhatt 2020; Aus et al. 2021; Emgin 2012; Paras and Antonela 2018; Popa and Curteza 2024; Sung 2023).
Research findings show that the main goal of upcycling is to increase the lifespan of a product

and/or its materials (Paras and Antonela 2018), thereby enhancing its durability. The authors previously defined garment durability as the ongoing interaction between a garment and its changing environment(s) and user(s), enabling it to move through different life cycles via the practices of care, mending and repair. This definition was formed via a literature review (Vanacker et al. 2023) and later confirmed in the field through semi-structured interviews. These interviews were organically initiated during a field visit to the Kantamanto market in Ghana, where Authors 1 and 2 engaged in a range of exchanges with actors who were part of the local value chain.

As one of the largest second-hand clothing markets worldwide, the Kantamanto community succeeds in recirculating approximately 25 million garments monthly (The OR Foundation 2021). Learning from these initial conversations led to their continuation with other communities worldwide, particularly in France, Indonesia, Norway, and South Africa. Consciously, these countries were positioned in both the Global North and Global South. Although the aim was to understand garment durability better, many participants naturally referred to upcycling. This led the authors to shift from a more global vision of garment durability to a focus on how upcycling has the potential to making garments last locally. Based on this, the following research questions are posited: (1) How are upcycling and garment durability interconnected? (2) Which materials are considered suitable for “upcycling”? (3) How do local conditions influence upcycling practices? To answer these questions, the data gathered from semi-structured interviews were combined with findings from a literature review, using a multimethod study design.

The remainder of this paper is organized as follows: First, the method is explained, and its relevance in answering the research questions is demonstrated. This section is followed by the findings and an interpretation of the findings in the discussion. Finally, the conclusions, including the study limitations and future research perspectives, are explained.

Methodology

Study design—Multimethod approach

Multimethod research involves combining any different methods (Hunter and Brewer 2015) and is an appropriate research response to understanding, explaining, and intervening for transformation (Cram and Mertens 2015).

Data gathering through semi-structured interviews

Semi-structured interviews enable researchers to understand the actors’ behaviors and interactions and capture their voices (Daniels and Cannice 2004; Denzin and Lincoln 2011). The study was conducted in five countries: France and Norway in the Global North and Ghana, Indonesia, and South Africa in the Global South. This selection enabled the analysis of different sociocultural, economic, and political landscapes. Furthermore, each country was accessible to at least one of the interviewers. Many global challenges, such as climate change and economic inequality, affect northern and southern regions differently. Including both perspectives is crucial when studying these challenges. This allowed for comparisons across diverse communities and helped identify universal patterns and context-specific nuances.

In total, 73 participants were selected through purposive sampling based on their technical and strategic knowledge of the design, production, use, reuse, sorting, repurposing, and recycling of garments and textiles which they have obtained through their work as a designer, activist, brand owner, second-hand vendor, student, tailor, upcycler or sorting center. The interviews were conducted between January and May 2024 and lasted for an average of 45 min. Approximately half of these occurred in person, whereas the other half were conducted online. The transcripts were made available to each participant, who had the opportunity to provide feedback. This step was crucial to ensure that the principles of participatory research, which are rooted in collaboration (Kindon, Pain, and Kesby 2007), are adhered to and that the results are used and interpreted in a way that is representative of the interviews.

Data analysis

The available literature on upcycling was reviewed prior to the interviews, building upon two extensive literature reviews conducted by the authors on garment durability (Vanacker et al. 2023; Vanacker, Lemieux, and Bonnier 2022). The data analysis from the interviews was conducted using inductive coding, which is exploratory in nature and enables themes to

emerge organically. During the data analysis stage and given the iterative nature of a qualitative approach of interviews in multimethod research, we revisited the literature at different points to help contextualize the research findings within a broader framework. Furthermore, the literature referred to evolved throughout this process, as the focus of the research did as well (Hesse-Biber 2010).

Value-informed evaluation framework

This study employed a qualitative research methodology rooted in a value-based evaluation framework that describes and understands rather than predicts or controls (Streubert and Carpenter 1999). Participatory Action Research (PAR) is characterized by its participatory and action-oriented nature (Kindon et al. 2007). PAR assumes that "those who have been most systematically excluded, suppressed, or denied possess particularly insightful knowledge" (Cammarota and Fine 2008). Multimethod research helps to counteract this oppression as it enables the inclusion of indigenous research to reinforce the importance of respectful research relationships that strengthen connectedness and knowledge (Cram and Mertens 2015). Therefore, the authors deliberately chose to conduct the interviews in 5 different countries with a cultural insider for each region. Furthermore, the literature analyzed includes sources from both Native and Western science.

Results

The findings of the data analysis were organized according to the three research questions. First, the relationship between garment durability and upcycling was investigated. Second, we assessed the types of materials suitable for upcycling, and finally, we examined how upcycling was defined.

The link between garment durability and upcycling

As mentioned in the Introduction, the primary goal of upcycling is to increase the lifespan of a product and/or its materials (Paras and Antonela 2018), thereby enhancing its durability. Both concepts were confirmed to be closely linked during the interviews. A key trend emerging from the data was that durability is "dynamic," as opposed to "static," which resists any changes. The authors believe that this concept can be defined by the relationship created by the wearer and that it continuously evolves through cycles of wear, care, repair, and remanufacturing. A French upcycling brand explains that the different cycles a garment undergoes to make it last do not necessarily result in it remaining in the same condition. Participants mention the aspect of change, but also the aspect of use. A product can remain the same, but it can also be used differently. An upcycling designer in Ghana perceives this as changing the destiny of garments. Since "change" is perceived as a key characteristic of durability, it suggests that transforming a garment's appearance through remanufacturing or upcycling can contribute to enhancing its durability. This contradicts the conventional definition of durability, which typically implies that a product can withstand any type of change (Vanacker et al. 2022).

Materials appropriate for upcycling

While a conventional design process begins with a design from a fabric, in upcycling, the creative process most often begins with an already-made garment. Its elements, such as pockets, trims, belts, and other details, inspire designers and are often preserved to make the garments even more attractive. This creates an increased need for creativity, which most designers identified as stimulating during the interviews.

Creativity in this context involves taking existing materials and adding value to them. As one designer explained: This suggests that what may be seen as restrictions by certain designers can become a source of inspiration for others in the upcycling design process. For example, adaptations such as smaller pattern pieces or the use of standardized designs offer greater flexibility in fabric and color combinations and substitutions (J. Han, Seo, and Ko 2017). However, this flexibility has its limitations, as respondents from all regions reported that upcycling with low-quality (multi) synthetic materials, primarily from fast fashion garments, is not feasible. In Ghana, for example, communities struggle to integrate polyester garments into their local value chains as it is not comfortable to wear in the local climate and the value of the material is perceived to be extremely low. The latter perception was confirmed by a large-scale upcycler in France, which also does not include low-quality materials in its remanufacturing process.

One upcycling brand shared that after initially accepting garments with all types of fibers, they now only work with denim, preferably 100% cotton, to extend the life of a material that has an environmentally damaging production process. It is understandable that certain materials are either too damaged or of insufficient quality to be upcycled successfully. However, several designers have questioned whether it is appropriate to dismantle an entire garment for upcycling when it is still in perfect or near-perfect condition. Other participants countered that if a particular garment can no longer be used in its current form, or its look is not desirable, design in the sense of upcycling acts as a tool of transformation, reintroducing what was once considered waste back into society. This opposes the theory that an object is considered "dead" once it is disposed of (Han, Seo, and Ko 2017; Zhuo 2014) and supports the idea that upcycling can give it a second life.

The materials considered suitable for upcycling, as noted by both the participants and the literature, vary greatly and include "used materials," "waste materials," "obsolete materials," "discarded materials," "available materials," "useless materials," "textile waste," "leftovers," or simply "waste" (Agrawal and Bhatt 2020; Cumming 2017; J. Han et al. 2017; Sung 2015). This suggests that upcycling can only be performed with materials that have already been used and are of no or low value; hence, this is why a person discards them or is on the verge of doing so (Harris, Roby, and Dibb 2015; Heiskanen and Jalas 2003).

In contrast, certain studies claim the greatest success in translating upcycling to mainstream retail is by using post-industrial (or pre-consumer) waste, as these textiles provide more consistent quality and reliable supply as source materials (J. Han et al. 2017). They support this vision by claiming that working with postconsumer clothing on a larger scale is more challenging and comes with more restrictions, especially regarding the availability and reliability of materials with controlled quality in terms of composition and impurities (J. Han et al. 2017; Zhuo 2014).

The influence of local conditions on upcycling

Local conditions, such as the climate, customs or culture, influence garment durability (Vanacker et al. 2023); thus, communities also adopt this approach regarding upcycling. Upcycling involves a combination of individuals, knowledge, ideas, needs, and creativity. Therefore, there is no identical upcycling process or result for each product produced (Parung and Viviany 2022). These practices in product (re)creation with used materials at the individual level are claimed to be deep-rooted collective human behaviors. However, how they have evolved over time and how they can be harnessed at the household level to make bigger impacts have not been investigated (Sung 2015).

Bramston and Maycroft (2013) suggested that upcycling practitioners gain an opportunity to develop an inherent understanding of objects, merge disciplines, cultures, and experiences, and create subjective and individual beauty while maintaining the sentimental value of a used product. The interviewed designers share the latter perspective, as they believe that upcycling offers the opportunity to add value to the already existing value of a garment. One sorting center in South Africa believes that products are ideally upcycled in the communities or areas where they are worn. This upcycling also supports economic localization by utilizing locally sourced materials, workforce, and skills, in addition to the development of local communities by engaging with the public through activities connected to sustainable consumption, skills sharing, and education (Sara. Han et al. 2017).

In South Africa, a few brands utilize local scraps and leftovers to create upcycled products, which they redistribute within the same community. This approach reduces the need for transport, minimizing the carbon emissions and enhancing the positive impact of upcycling. However, one small upcycling brand mentioned the difficulty of keeping the local aspect in mind when sourcing similar-looking materials, mostly garments, to achieve certain production volumes, knowing that these garments often travel long distances before reaching the production facility. Across the five regions studied, upcycling involves some kind of transformation, but the desired outcome

depends on local skills, style, infrastructure, culture and demand.

Discussion

In this section, we interpret the above findings to identify the contributions of this study. Garment durability and upcycling are intrinsically related. Through the interviews, garment durability was determined to be "dynamic," as opposed to "static," and upcycling is a method of increasing the durability of garments, which can be in various forms. However, a clear definition of upcycling is lacking. An upcycler from France summarized very concisely the concept's ambiguity: "The meaning of upcycling is not very precise and is interpreted in different ways by many people." However, certain elements continue to serve as building blocks for defining the concept, which is considered the second contribution of this study.

Upcycling involves transforming materials to have a higher value at the end of the process than at the beginning, differentiating it from downcycling and recycling. The goal of upcycling is to avoid wasting valuable materials by providing them with a new purpose or second life. The authors identified a clear gap, notably after connecting upcycling with garment durability, in consideration of how local conditions affect its meaning. Where a garment is worn influences how the wearer(s) will make it last, as upcycling is influenced by individuals, knowledge, ideas, needs, and creativity.

Based on this, the authors describe local upcycling as follows: a process in which materials and garments that are considered worth discarding in their current state are transformed into a product of higher value that is suitable for the local environment, eliminating the need for a new product. This suggests that discarded or soon-to-be-discarded materials are no longer labeled as waste, as they still have value. In addition, local conditions were considered to ensure that the craftsmanship and cultural appropriateness developed by the local community were honored. Third, the authors identified that materials fit for upcycling have ambiguous labels, and the criteria for distinguishing them are lacking. This issue also extends to sorting centers, which lack transparency regarding how garments are separated and where they ultimately end up.

Conclusions

This study used a multimethod approach to investigate the value of local upcycling to increase garment durability. Based on the findings, there are several contributions to the field. First, we identified garment durability as a dynamic concept involving upcycling, which adapts and transforms garments based on the user and environment. This contradicts the conventional understanding of the concept of durability as resistance. Second, because upcycling primarily does not begin from the fabric, the imposed restrictions are deemed a source of inspiration. While this stimulates greater creativity, the respondents found it unfeasible to upcycle low-quality (multi) synthetic materials, mainly from fast fashion garments. Hence, we identify the restrictions on this concept. Third, the study identified the need to stop referring to upcyclable materials as waste, as they still have enough value for certain people to be reused, even if others consider them worth discarding. This also includes the need to consider the recipient communities when sorting materials. Finally, keeping local conditions in mind, the authors defined upcycling as a process in which materials and garments that are considered worth discarding in their current state are transformed into a product of higher value that is suitable for the local environment, eliminating the need for a new product.

This study has two main limitations. First, only English-language literature was included in the analysis; therefore, valuable sources published in other languages were not considered. Second, although the authors conducted field research in the form of interviews, they did so only at the actor level and not at the organization level.

The authors have identified a gap in the available studies that address how upcycling practices can be effectively implemented. This gap could be explored by establishing a local upcycling hub. This could help to clarify the criteria for the effectiveness of this hub and investigate how its impact can be measured. This could ultimately lead to the development of a set of indicators that will help create a replicable model for local upcycling hubs that enable communities around the world to make garments last a lifetime

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References

Abbate, Stefano, Piera Centobelli, Roberto Cerchione, Simon Peter Nadeem, and Emanuela Riccio. 2024. "Sustainability Trends and Gaps in the Textile, Apparel and Fashion Industries." *Environment, Development and Sustainability* 26(2):2837–64. doi: 10.1007/s10668-022-02887-2.

Agrawal, Muskan, and Latika Bhatt. 2020. "Upcycling: An Emerging Textile Waste Management Strategy for the Fashion Industry." *International Journal for Modern Trends in Science and Technology* 06(9S):161–65. doi: 10.46501/IJMTST0609S26

Aus, Reet, Harri Moora, Markus Vihma, Reimo Unt, Marko Kiisa, and Sneha Kapur. 2021. "Designing for Circular Fashion: Integrating Upcycling into Conventional Garment Manufacturing Processes." *Fashion and Textiles* 8(1):34. doi: 10.1186/s40691-021-00262-9.

Bramston, David, and Neil Maycroft. 2013. "Designing with Waste in Materials Experience: Fundamentals of Materials and Design, E. Karana, O. Pedgley, and V. Rognoli, Eds., Oxford, Butterworth-Heinemann, 2013, Pp. 123–133." *Materials Experience: Fundamentals of Materials and Design* 112–23. https://doi.org/10.1016/B978-0-08-099359-1.00009-6

Cammarota, Julio, and Michelle Fine, eds. 2008. *Revolutionizing Education: Youth Participatory Action Research in Motion*. 1st ed.

COM. 2019. *Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions on the European Green Deal*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN (accessed on the 10th of October 2024)

Cumming, Deb. 2017. "A Case Study Engaging Design for Textile Upcycling." *Journal of Textile Design Research and Practice* 4:1–15. doi: 10.1080/20511787.2016.1272797.

Cram, Fiona, and Donna M. Mertens. 2015. "Transformative and Indigenous Frameworks for Multimethod and Mixed Methods Research." *The Oxford Handbook of Multimethod and Mixed Methods Research Inquiry*, edited by S. N. Hesse-Biber and R. B. Johnson. Oxford University Press.

Daniels, J. D., and Mark. V. Cannice. 2004. "Interview Studies in International Business Research." in *Handbook of Qualitative Research Methods for International Business*, edited by R. Piekkari.

Denzin, Norman K., and Yvonna S. Lincoln. 2011. *The SAGE Handbook of Qualitative Research*. SAGE.

Emgin, Bahar. 2012. "Trashion: The Return of the Disposed." *Design Issues* 28(1):63–71. doi: 10.1162/DESI_a_00124.

Fortuna, Lorena M., and Vasil Diyamandoglu. 2017. "Optimization of Greenhouse Gas Emissions in Second-Hand Consumer Product Recovery through Reuse Platforms." *Waste Management* 66:178–89. doi: 10.1016/j.wasman.2017.04.032.

Han, Jinghe, Yuri Seo, and Eunju Ko. 2017. "Staging Luxury Experiences for Understanding Sustainable Fashion Consumption: A Balance Theory Application." *Journal of Business Research* 74:162–67. doi: 10.1016/j.jbusres.2016.10.029.

Han, Sara L. C., Priscilla Y. L. Chan, Praburaj Venkatraman, Phoebe Apeagyei, Tracy Cassidy, and David J. Tyler. 2017. "Standard vs. Upcycled Fashion Design and Production." *Fashion Practice* 9(1):69–94. doi: 10.1080/17569370.2016.1227146.

Harris, Fiona, Helen Roby, and Sally Dibb. 2015. "Sustainable Clothing: Challenges, Barriers and Interventions for Encouraging More Sustainable Consumer Behaviour." *International Journal of Consumer Studies* 40(3):309–318. doi: 10.1111/ijcs.12257.

Hawkins, Gay. 2001. "Plastic Bags: Living with Rubbish." *International Journal of Cultural Studies* 4(1):5–23. doi: 10.1177/136787790100400101.

Heiskanen, Eva, and Mikko Jalas. 2003. "Can Services Lead to Radical Eco-Efficiency Improvements? - A Review of the Debate and Evidence." *Corporate Social Responsibility and Environmental Management* 10(4):186–98. doi: 10.1002/csr.46.

Hesse-Biber, Sharlene Nagy. 2010. *Mixed-Methods Research: Merging Theory with Practice*.

Hesse-Biber, Sharlene Nagy, and Patricia Leavy. 2006. *Emergent Methods in Social Research*. SAGE Publications, Inc.

Hesse-Biber, Sharlene Nagy, and Patricia Leavy. 2008. "User-Centered Perspectives on Qualitative Data Analysis Software: Emergent Technologies and Future Trends."

Hunter, Albert, and John D. Brewer. 2015. "Designing Multimethod Research." *The Oxford Handbook of Multimethod and Mixed Methods Research Inquiry*, edited by

S. N. Hesse-Biber and R. B. Johnson. Oxford University Press.

Jick, Todd D. 1979. "Mixing Qualitative and Quantitative Methods: Triangulation in Action." *Administrative Science Quarterly* 24(4):602–11. doi: 10.2307/2392366.

Kindon, Sara, Rachel Pain, and Mike Kesby. 2007. *Participatory Action Research Approaches and Methods: Connecting People, Participation and Place*. 1st ed.

McDonough, William, and Michael Braungart. 2002. *Cradle to Cradle: Remaking the Way We Make Things*.

Paras, Manoj Kuman, and Curteza Antonela. 2018. "Revisiting Upcycling Phenomena: A Concept in Clothing Industry." *Research Journal of Textile and Apparel* 22(2):00–00. doi: 10.1108/RJTA-03-2017-0011.

Parung, Christabel, and Viviany Viviany. 2022. *Upcycling Design Process and Classification of Upcycling Method as Innovation to Extend Product Lifecycle*. Proceedings of the International Conference on Industrial Engineering and Operations Management. https://doi.org/10.46254/AN12.20220022

Popa, Lavinia Marie, and Antonela Curteza. 2024. "Upcycling in Fashion – A Literature Review." *Buletinul Institutului Politehnic Din Iași, Secția Chimie Și Inginerie Chimică* 70(3):35–46. doi: 10.5281/zenodo.13837849.

Sandin, Gustav, and Greg M. Peters. 2018. "Environmental Impact of Textile Reuse and Recycling – A Review." *Journal of Cleaner Production* 184:353–65. doi: 10.1016/j.jclepro.2018.02.266.

Streubert, Helen J., and Donna Rinaldi Carpenter. 1999. *Qualitative Research in Nursing: Advancing the Humanistic Imperative*.

Sung, Kyungeun. 2015. "A Review on Upcycling: Current Body of Literature, Knowledge Gaps and a Way Forward." International Conference on Environmental, Cultural, Economic and Social Sustainability

Sung, Kyungeun. 2023. "Understanding Upcycling and Circular Economy and Their Interrelationships through Literature Review for Design Education." *Proceedings of the Design Society* 3:3721–30. doi: 10.1017/pds.2023.373.

The OR Foundation. 2021. "Waste Landscape Report."

Vanacker, Hester, Andrée-Anne Lemieux, and Sophie Bonnier. 2022. "Different Dimensions of Durability in the Luxury Fashion Industry: An Analysis Framework to Conduct a Literature Review." *Journal of Cleaner Production* 377(4):134179. doi: 10.1016/j.jclepro.2022.134179.

Vanacker, Hester, Andrée-Anne Lemieux, Sophie Bonnier, Margaux Yost, and Shanon Poupard. 2023. "Circularity, Garment Durability, and Just Transition: Understanding the Trinary Interrelationship through an Integrative Literature Review." *Sustainability* 15(15):11993. doi: 10.3390/su151511993.

Zhuo, Chuanwei. 2014. "Upcycling Waste Plastics into Carbon Nanomaterials: A Review." *Journal of Applied Polymer Science* 131(4): 39931. doi: 10.1002/app.399

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Garment Reuse in Practice - Insights from a Clothing Swap

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Keywords: clothing swap; collaborative consumption; clothing reactivation; clothing reuse; wardrobes.

Abstract: Reuse is a key strategy to intensify the use of goods. Hence, clothing swaps are typically presented as a sustainable alternative to conventional fashion consumption. However, research into the mechanisms and dynamics behind these exchanges remains limited. Using qualitative and quantitative methods to study a swapping event in a city in Belgium, this study explores the potential of clothing swaps to enable the reactivation and reuse of clothing. The mass flow analysis reveals that about half of the garments brought to an in-person swap using an indirect exchange system found new owners. Certain garment types (t-shirts and sweaters) were more easily swapped than others (pants). Survey responses indicated that participants use swaps to hand off dormant clothing that is no longer suited to their needs. Further, participant stated that most of the garments they acquired will substitute the purchase of garments. When comparing the wardrobe composition of swap participants to a general sample, we found that swappers have a similar wardrobe size but a much higher fraction of pre-owned garments. Unexpectedly, swap participants had a slightly higher fraction of dormant garments in their wardrobes. The observed differences cannot be solely attributed to participation in swap events, as participants are likely also engaged in other reuse activities. Meaning it provides an important glimpse into the potential effects society-wide policies focused on increasing garment reuse could have on wardrobes. To summarize, by combining different methods, this study provides new insight into the dynamics behind swapping, and clothing reuse in general.

Introduction

Today, ownership is a prominent norm in consumer culture. However, this leads through overproduction and consumption to negative environmental impacts (Niinimäki et al., 2020). Given the current sustainability crisis, there is an increasing need to shift away from a culture of ownership to one of access (Park & Armstrong, 2017). The circular economy (CE) model supports this transition by promoting the continuous use of resources at their highest utility, considering environmental benefits (Alaerts et al., 2019). CE strategies like refuse, repair, reuse, and recycling aim to extend the life of products and materials (Kirchherr et al., 2023). For consumer goods like clothing, a key strategy is reuse, which extends the product lifetime beyond the initial owner, recognizing that our needs may change before a product's full potential is realized.

It is often assumed that CE strategies will yield environmental benefits, for example by extending product lifetimes (Bączyk et al., 2024). However, these benefits can be offset by circular rebound, for instance when easier access to goods leads to increased consumption (Bączyk et al., 2024). For example, the lower price of second-hand goods could increase total clothing consumption. To fully evaluate the environmental impact of CE strategies, it's essential to understand consumer behaviour in relation to CE strategies (Bączyk et al., 2024).

This paper looks at participation in a clothing swap event as a case study on reuse. The following section gives background on circular clothing consumption and clothing swaps. This is followed by a description of the methods. Finally, we present and discuss the results.

Theoretical Background

Clothing use in a circular economy

A CE aims to avoid the environmental impacts of production and waste treatment processes by elongating and intensifying the use of products and materials (Alaerts et al., 2019).

For clothing, this would mean using and maintaining garments for as long as possible. Research indicates this is currently not the case, with garments going out of use before they become deficient (Laitala, 2014). This is evident in reusable garments ending up in waste streams (Vermeyen et al., 2024), and in the finding that about a fourth of the items in an average wardrobe go unused over a year (de Wagenaar et al., 2022; Vermeyen et al., 2025). There are various reasons for clothing to go out of use prematurely, from boredom to changing body types, or changing needs (Laitala, 2014; Vermeyen et al., 2025). A CE seeks to reactivate reusable garments, for example, by enabling a change of ownership. Reuse through second-hand markets is one way to achieve this, clothing swaps are another.

Clothing swaps

Clothing swaps are a form of collaborative consumption, defined as "an economic model based on sharing, swapping, trading, or renting products and services, enabling access over ownership" (Belk, 2014). The general idea of a swap is a 'one-for-one' exchange, which can essentially be seen as a redistribution of goods (Park & Armstrong, 2017). Clothing no longer relevant to the individual can be swapped, potentially fulfilling a changing need for clothing without the purchase of new items (Lang & Zhang, 2019) .

Clothing swaps can take on different forms, from informal meetings with friends and family, to big public events to permanent swap shops where members exchange garments for free or a small fee, to online platforms (Matthews & Hodges, 2016). This organizational context is important to consider, as the interaction between participants differs based on the format (Camacho-Otero et al., 2020; Lang & Zhang, 2019). A swap can be a direct exchange between two individuals, however, this requires a direct match between the items being offered and looked for. As this is not evident, swaps often facilitate an indirect exchange, using a intermediate good, typically tokens. Tokens received for goods handed in can be used to acquire goods handed in by others. However, using this indirect system means there is no guarantee that all goods will find a new owner.

Previous research on (clothing) swaps is focused on behavior and motivations of participants, such as the barriers and drivers of participating (Henninger et al., 2019; Lang & Zhang, 2019; Matthews & Hodges, 2016), or the broader context of swap events (Camacho-Otero et al., 2020; Philip et al., 2019).

There is a lack of studies employing a quantitative approach to create a more comprehensive understanding of garment dynamics during swap events and their potential for clothing reactivation. Specifically, do garments obtained from swaps replace the purchase of new garments, or do they merely add to existing wardrobes? To summarize, this study seeks to address two key research questions: (1) Which types of garments are best suited for successful swapping?, and (2) To what extent does participation in swaps lead to a more intensive use of garments?

Method

The data discussed in this paper all relate to a swap event that took place in October 2024 in the city of Leuven (Belgium). Data was collected in three different ways: (i) the flow of garments during the event, (ii) an online survey amongst participants following the event, and (iii) a wardrobe audit at the home of a subset of participants following the event.

Case study

This paper discusses a clothing swap organized by an NGO focused on raising consumer awareness and promoting participation in circular clothing initiatives, such as reuse and repair, within the city of Leuven (Belgium). Since 2022 they have organized two clothing swaps each year - one in spring and one in autumn. Participation in the event is free of charge and entirely organized by volunteers. The swap is organized over two consecutive days: On the first day, participants hand in the items they wish to part with, receiving tokens in exchange. Smaller items, such as t-shirts, are worth less tokens than larger items, such as coats. On the second day, participants can use their tokens or pay a small price to acquire garments. The collected clothing is displayed by category (see Figure 1). Participants can freely browse and fitting rooms are present to try on garments. Unused tokens expire after the event. The remaining garments are donated to local charities. A volunteer coordinates this process to ensure that donations align with the needs and capacity of the recipient organizations.

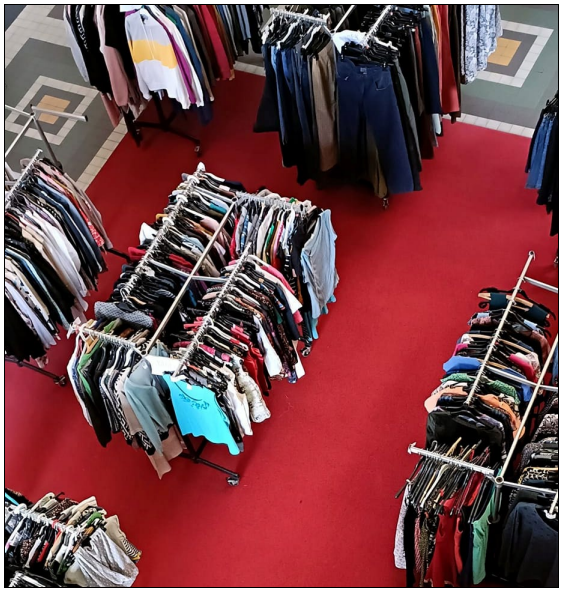


Figure 1. Presentation of clothing during the swap.

Mass flow analysis

To analyze the dynamics of an in-person clothing swap event involving indirect exchanges, data was collected on: (i) the number of items participants' handed in, by garment category, (ii) the total amount of items participants took home, (iii) the number of garments remaining after the event, by garment category.

Online survey

Following the swap, an online survey was distributed to participants through various channels, including QR codes displayed at the event exit, a Facebook and Instagram post, and newsletter email. A total of 44 participants completed the four-part survey. The first part contained general questions about participants' experience with clothing swaps. The second part focused on the clothing participants contributed to the swap. The aim was to gain a better understanding of the characteristics of garments participants chose to hand in. The third part asked about the clothing the participant acquired at the swap. The aim was to gain a deeper understanding of the selection process during the swap. Lastly, the fourth section collected demographic and socio-economic information, and inquired about participants' willingness to take part in a follow-up study on the composition of their wardrobes.

Wardrobe audit

A wardrobe audit uses quantitative or qualitative methods to systematically analyse the content of individuals' wardrobes (Maldini et al., 2023). In this study, the audit consisted of a systematic inventory of all garments within the scope of the study at the participant's home with a researcher present to guide the process. Underwear, swimwear, and accessories such as gloves, scarves, hats, bags, and shoes were outside the scope of the audits. For each garment category, the researcher recorded the total number of items, the number of dormant garments (items not worn in the past 12 months), and the number of pre-owned garments (items previously owned by someone else).

Initially, 27 individuals had expressed interest in participating in further research in the survey. These individuals were contacted and asked if they could make time for a wardrobe audit in November 2024. Ultimately, 15 audits were conducted. The participants were all women, aged between 26 and 71. Their audit results are compared to the 78 audits on women collected in Vermeyen et al. (2025) to assess whether the wardrobes of swap participants differ in terms of total wardrobe size, the fraction dormant, and the fraction pre-owned. These 78 audits are hereafter referred to as the 'baseline sample'. The audit results presented in this paper are preliminary and part of ongoing research. Increasing the sample size and applying statistical methods should bring further insight into the data presented. For instance, further analysis is required to identify and control for confounding variables.

Results and discussion

The results are presented and discussed across four thematic areas to shed light on the dynamics of clothing swaps: (i) garment flow during the swap event (ii) selecting garments to hand in, (iii) selecting garments to take home, and (iv) wardrobe composition.

Garment flows during the swap event

Figure 2 illustrates the flow of garments during the clothing swap. A total of 3,204 garments were handed in, of which 1,717 (54%) were successfully swapped during the event. Shirts - comprising of t-shirts, blouses, or dress shirts with either short or long sleeves - were, with 25%, the garment type most often handed in. Sweaters - comprising of all garments typically worn over shirts but under jackets - are a close

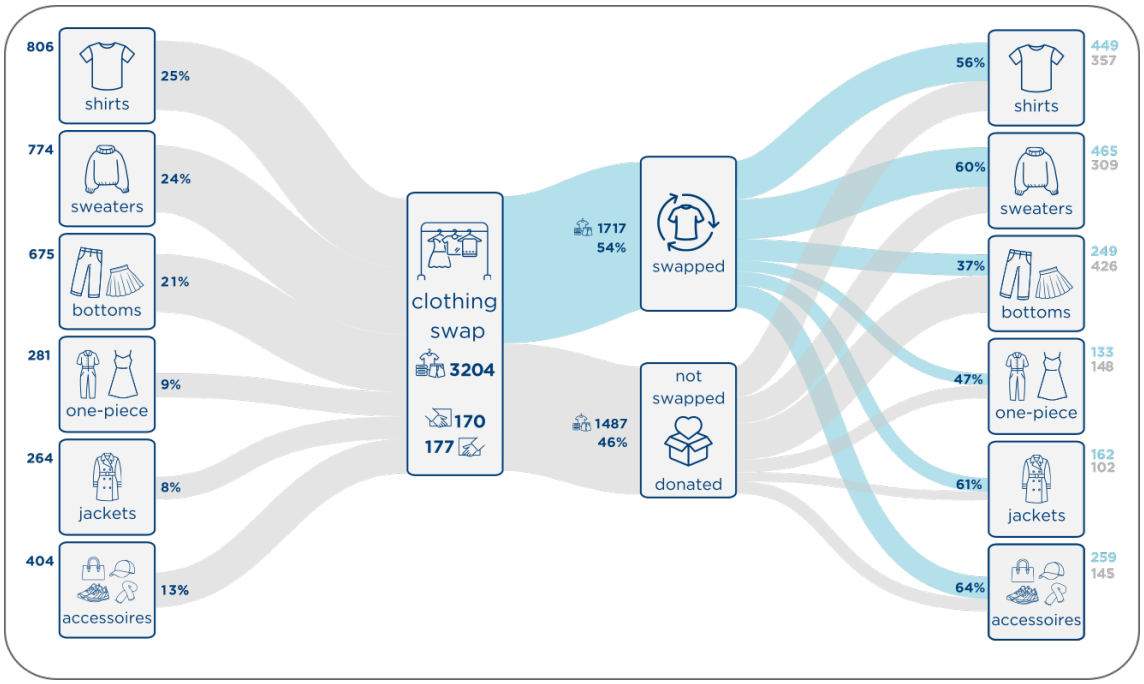


Figure 2. Flow of garments during the *autumn clothing swap*.

second with 24%, . Given the swap took place in autumn, it is likely that more winter-specific items, such as sweaters and jackets, were collected. Follow-up research during the 2025 spring swap will provide insight into this.

Approximately 170 individuals participated in the event, though the exact number of unique participants is unclear. This is because on the inflow side, some participants handed in clothing for multiple individuals, while on the outflow side, some individuals passed multiple times at the clothing check-out during the event. Therefore, the following results are presented in terms of packages handed in and taken out of the swap, rather than individual participants. A total of 170 packages were handed in, and 177 packages were taken out of the event. The size of the packages handed-in varied strongly between 1 and 240 items. Packages containing between 1 and 20 items were most common (75%). The size of the packages taken home varied between 1 and 66 items. Here packages containing between 1 and 10 items were most common (72%).

Based on the above, it can be concluded that most participants brought more items to the swap than they took away. Jackets and sweaters were the most likely to find new owners, with almost two-thirds selected. Bottoms - comprising of pants and skirts - were most likely to remain behind. A possible explanation for this is that sweaters and jackets are easier to try on, as well as, having a more universal fit. Pants, particularly jeans, were observed to be less appealing to participants.

To summarize, the mass flow results show that about half of the garments brought to an in-person swap using an indirect exchange system find new owners. The results further indicate that specific garment categories are more easily swapped than others.

Selecting clothing to hand in

Of the 44 survey responses, 41 reported handing in clothing to the swap. Consistent with the mass flow results, most respondents (n=31, 76%) indicate they handed in between 1 and 20 items. About half (n= 21) indicated all the items handed in were solely theirs, the remaining respondents also handed in items belonging to family or friends.

Next, the survey asked questions pertaining strictly to the garments the respondents owned themselves prior to the swap, thus excluding items they handed in for others. Respondents were asked to describe their garment selection process. Of the respondents, 31 (76%) specified they chose garments they no longer wore. A poor fit was cited by 21 respondents (51%) as the reason for the garment's disuse. This finding is further supported by the fact that, on average, respondents reported that four out of five items handed in had not been worn in the past 12 months. This aligns with Matthews & Hodges (2016), who found that clothing swaps are used to clean out wardrobes. Vermeyen et

al. (2025) found that individuals are more willing to part with garments that are dormant due to a poor fit or an undesirable style.
When asked if they were the first user of the pieces brought to the swap, respondents indicated that this was the case for about half of the items. Only five respondents (12%) indicated bringing exclusively items of which they were the first owner. This suggests that swaps function as a reuse circuit, where garments are repeatedly exchanged. This finding is corroborated by volunteers' observations that some items reappear in subsequent swaps. The survey questions indicate that on the supply side, clothing swaps have the potential to reactivate dormant items and facilitate reuse.

Selecting clothing to take home

All survey respondents indicated that they took clothing home from the swap. Three out of four respondents took between 1 and 10 pieces home, and similarly, three out of four indicated that they still had leftover tokens at the end of the event. The survey findings are in line with the mass flow analysis (Figure 2), which shows that participants brought about twice as many items as they took home.
When asked to what extent they sought specific items during the swap, responses varied widely: one-fourth of respondents indicated they were mainly looking for specific pieces, while another fourth had nothing specific in mind and were just browsing, the remaining respondents fell somewhere in between. Next, respondents were asked to what extent they believed the items taken from the swap would substitute for new purchases. On average, participants believed that eight out of ten items taken from the swap would replace new purchases. Applying this finding to the mass flow analysis suggests that the swap event prevented the purchase of 1,374 garments (1,717*0.8). However, this number is only indicative, and further, from the question posed it is unclear whether the substituted garments would have been new or pre-owned.

Wardrobe composition

Finally, the 15 wardrobe audits conducted among swap participants are compared to a baseline sample taken from Vermeyen et al. (2025). Figure 3 plots for each participant their total wardrobe size against the fraction dormant and the fraction pre-owned, respectively. The mean of each variable for each sample is also shown. It should be stressed that the results presented here are very preliminary and part of ongoing research. Due to the small size of the swap sample caution is advised in interpreting the results.

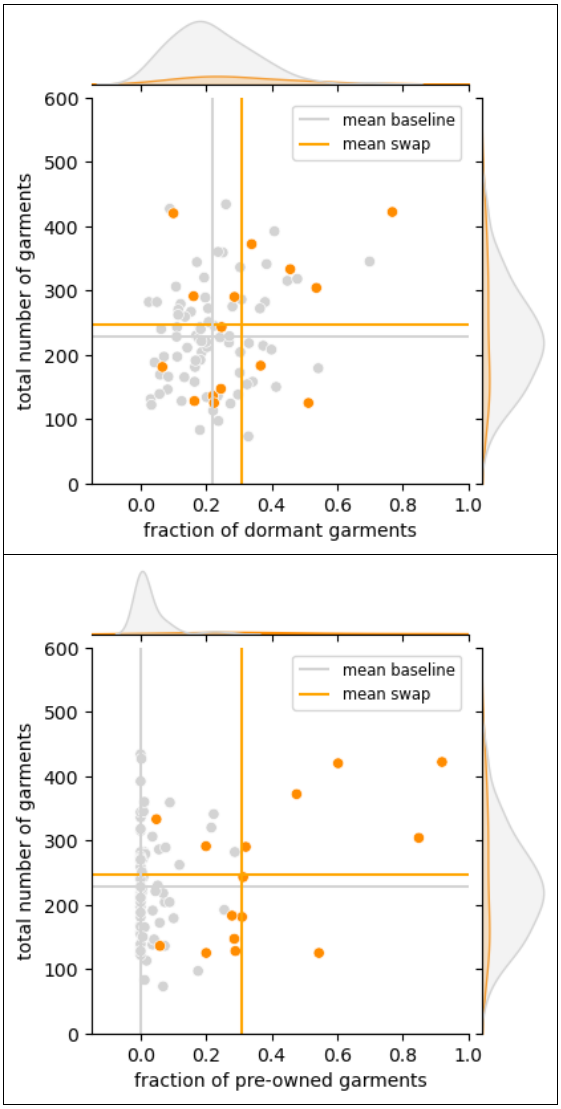


Figure 3. Total wardrobe size vs [1] fraction dormant, and [2] fraction pre-owned, for the baseline sample (n=78) and swap sample (n=15).

A wide variation is observed between individuals in the swap sample. With respect to total wardrobe size, no notable difference between the baseline sample and swap sample is observed. For the fraction of dormant garments, swap participants seem to have a slightly higher average. This is contrary to expectations, as respondents indicated in the survey they specifically selected dormant garments to hand in at the swap event. Lastly, participants in the swap sample have a notably

higher fraction of pre-owned garments in their wardrobes.

The differences between the swap and the baseline sample cannot be solely attributed to participation in swap events, as these individuals likely also engage in other reuse practices, such as secondhand shopping. Rather, the swap sample offers specific insight into the wardrobes of those actively involved in clothing reuse. Hence, the audit results provide a valuable glimpse into the potential outcome of successfully increasing clothing reuse in society on our wardrobes. It indicates to what extent active participation in reuse can be expected to increase the pre-owned fraction in wardrobes, while having a minimal effect on the amount of dormant clothing or overall wardrobe size. This information is crucial to designing effective policies in the transition to a circular and sustainable clothing system.

Limitations and future research

This paper presents the findings from a specific swap event. As noted in the literature review, swaps vary in form, so the results should not be generalized without caution. The online survey and wardrobe study involved a small, self-selected sample, so their findings should be interpreted carefully. Increasing the sample size, conducting qualitative interviews and applying statistical methods can bring further insight into the data. The research will be elaborated on in future swap events.

Conclusions

By combining different qualitative and quantitative methods to study a clothing-swapping event, this research provides a deeper understanding into the dynamics of clothing swaps, garment reuse and reactivation. The mass flow analysis revealed that about half of the garments brought to an in-person swap using an indirect exchange system found new owners. Certain garment types (t-shirts and sweaters) are more easily swapped than others (pants). The survey responses indicated that participants use swaps to hand off dormant clothing that is no longer suited to their needs. They were often not the first owner of the donated garments themselves, indicating that the swap functions as a reuse circuit, where garments are repeatedly exchanged. To a lesser extent, they acquired new garments that better suited them, stating that eight out of ten swapped garments would replace the purchase of garments. When comparing the composition of the wardrobes of 15 swap participants to a general sample, we found that the swappers have a similar wardrobe size but a much higher fraction of pre-owned garments. Further, the swappers had a slightly higher fraction of dormant garments. This comparison provides an important glimpse into the potential effects policies focused on increasing garment reuse may have on our wardrobes.

Acknowledgments

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References

Alaerts, L., Van Acker, K., Rousseau, S., De Jaeger, S., Moraga, G., Dewulf, J., De Meester, S., Van Passel, S., Compernolle, T., Bachus, K., Vrancken, K., & Eyckmans, J. (2019). Towards a more direct policy feedback in circular economy monitoring via a societal needs perspective. *Resources, Conservation and Recycling*, *149*, 363–371. https://doi.org/10.1016/j.resconrec.2019.06.004

Bączyk, M., Tunn, V., Worrell, E., & Corona, B. (2024). Consumer behavior in circular business models: Unveiling conservation and rebound effects. In *Sustainable Production and Consumption* (Vol. 52, pp. 283–298). Elsevier B.V. https://doi.org/10.1016/j.spc.2024.10.022

Belk, R. (2014). You are what you can access: Sharing and collaborative consumption online. *Journal of Business Research*, *67*(8), 1595–1600. https://doi.org/10.1016/j.jbusres.2013.10.001

Camacho-Otero, J., Pettersen, I. N., & Boks, C. (2020). Consumer engagement in the circular economy: Exploring clothes swapping in emerging economies from a social practice perspective. *Sustainable Development*, *28*(1), 279–293. https://doi.org/10.1002/sd.2002

de Wagenaar, D., Galama, J., & Sijtsema, S. J. (2022). Exploring Worldwide Wardrobes to Support Reuse in Consumers' Clothing Systems. *Sustainability*. https://doi.org/10.3390/su14010487

Henninger, C. E., Bürklin, N., & Niinimäki, K. (2019). The clothes swapping phenomenon – when

consumers become suppliers. *Journal of Fashion Marketing and Management: An International Journal*, *23*(3), 327–344. https://doi.org/10.1108/JFMM-04-2018-0057

Kirchherr, J., Yang, N. H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions. *Resources, Conservation and Recycling*. https://doi.org/10.1016/J.RESCONREC.2023.107001

Laitala, K. (2014). Consumers' clothing disposal behaviour – a synthesis of research results. *International Journal of Consumer Studies*. https://doi.org/10.1111/ijcs.12088

Lang, C., & Zhang, R. (2019). Second-hand clothing acquisition: The motivations and barriers to clothing swaps for Chinese consumers. *Sustainable Production and Consumption*, *18*, 156–164. https://doi.org/10.1016/j.spc.2019.02.002

Maldini, I., Haugrønning, V., & De León, L. (2023). Studying clothing consumption volumes through wardrobe studies: a methodological reflection. *Procedia PLATE – Product Lifetimes And The Environment*. https://aaltodoc.aalto.fi/handle/123456789/122687

Matthews, D., & Hodges, N. N. (2016). Clothing Swaps: An Exploration of Consumer Clothing Exchange Behaviors. *Family and Consumer Sciences Research Journal*, *45*(1), 91–103. https://doi.org/10.1111/fcsr.12182

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*. https://doi.org/10.1038/s43017-020-0039-9

Park, H., & Armstrong, C. M. J. (2017). Collaborative apparel consumption in the digital sharing economy: An agenda for academic inquiry. *International Journal of Consumer Studies*, *41*(5), 465–474. https://doi.org/10.1111/ijcs.12354

Philip, H. E., Ozanne, L. K., & Ballantine, P. W. (2019). Exploring Online Peer-to-Peer Swapping: A Social Practice Theory of Online Swapping. *Journal of Marketing Theory and Practice*, *27*(4), 413–429. https://doi.org/10.1080/10696679.2019.1644955

Vermeyen, V., Alaerts, L., Worrell, E., & Van Acker, K. (2024). Threads untangled: Regional mapping of post-consumer textile management. *Cleaner Waste Systems*, *9*, 100181. https://doi.org/10.1016/j.clwas.2024.100181

Vermeyen, V., Alaerts, L., Worrell, E., Van Acker, K., & Germeys, F. (2025). Behind Closed Doors: Examining the Stock of Clothing in Individuals' Wardrobes. *Journal of Circular Economy*, *3*(1). https://doi.org/10.55845/OQEE5977

Research paper
6th PLATE 2025 Conference
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The Laundry Care LCA project

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Keywords: LCA; garment; lifetime; care index; washing cycles

Abstract: The fashion industry is increasingly scrutinized for the environmental footprint it generates. Despite this, less attention is placed on the possibility to reduce part of this footprint thanks to attitudes and daily actions that users can take in their homes. A life cycle assessment of three selected garments was performed to analyze the potential environmental benefits of an extended usage of garments thanks to the utilization of different washing treatments. Results showed that the garment production phase has consistently the highest impact. Within the use stage, the relevance of wash cycles was investigated by comparing various cycles in both the European and North America regions, and by highlighting the contribution of different energy mixes and detergent types. The data demonstrated that washing machine users can reduce the impact of garments by, for example, washing them at lower temperature, as this results in slower deterioration. Therefore, the environmental impacts per wear of garments can be reduced by around 50% by doubling the expected number of garments uses.

Introduction

Impacts connected to garments production are high, thus it is important to keep items in use for longer to postpone the moment when there is a need to purchase new ones. However, in recent years several surveys and research emphasized that people tend to buy more clothes while using them for a lower number of times (Ellen MacArthur Foundation, 2017). Despite these considerations seem to be widely accepted, only limited effort has been made to verify how relevant would it be to extend the lifetime of garment in terms of environmental impact.
This paper presents a life cycle assessment (LCA) based method used by the Group which the authors are part of to quantify the reduction of the garments environmental impacts. This reduction was exclusively achieved through the extension of the garment lifetime due to the use of gentler washing treatments.

Materials and method

Researchers performed a LCA of t-shirt, polo, and jeans to quantify the potential environmental benefits of a prolonged lifetime of garments by comparing two scenarios: a baseline scenario (BS), where the selected garment is worn and then washed X times, and an extended scenario (ES), where the same garment is worn X*t times, with X*t > X. In this context, t represents the Care Index indicator developed by the company R&D department. The developed LCA model (Care LCA) was created using the SimaPro 9.5 LCA software and Ecoinvent 3.9 database.

Garment Longevity Assessment

To measure garment longevity, an internal protocol called the "Care Index method" that provides a numerical output was developed over several years of research and development. Currently, its use is intended solely for internal evaluation of the Group's appliances. The Care Index is an internal indicator that allows to compare the gentleness of two different washing treatments and quantify the corresponding impact on clothes deterioration, affecting their lifespan. In practical terms, the index compares the number of laundry cycles required to reach a specific level of color change - correlated to clothes end of life - against a reference washing program. To run this test, researchers developed a protocol that utilizes a variety of fabrics, each intentionally dyed and printed to mirror different clothing types - i.e. t-shirt, polo-shirt and jeans - and common dye varieties found in the market. The investigation focused on a 4 kg daily load. Through extensive laboratory testing, different scenarios where fabrics underwent a sequence of washing treatments were considered and

color changes were measured at various intervals. The color degradation was evaluated using the standard Gray Scale methodology and regularly monitored during the testing phase. Reference standards for this assessment were the ISO 105-A05:1996 and the ISO 105-J03:2009. The fabrics end-of-life was considered to be reached when the defined level of color degradation was achieved. The definition of the end-of-life threshold was assessed through an internal panel test involving more than 600 panellists worldwide.
The Care Index was then used for comparing the Extended (ES) and the Baseline Scenarios (BS). A garment life is doubled, when the Care Index equals 2.
Assuming that:

Baseline Scenarios = 52 washes
Extended Scenarios = 104 washes
Care Index = 104/52 = 2

The Index is later used as an input for the Care LCA to indicate clothes longevity in the use phase.

Care LCA measurement
The Care LCA was created to model all phases of garments life cycle to quantify the clothes environmental impact. The functional unit was defined by including, for all garments in scope (i.e., t-shirt, polo and jeans), the service provided, garment weight and size, composition (i.e., conventional cotton, organic cotton, and polyester fibers), the expected usage and service duration. All life cycle stages of garment were considered (from cradle to grave), i.e., production of garment raw materials (polyester and cotton fibers), production of finished garment (spinning, knitting, weaving, dyeing, finishing and final assembly process), transports of raw materials and intermediates included, distribution of finished garment, use phase (washing cycles and drying at ambient air), and end of life scenario. Secondary data from PEFCR Apparel and Footwear (2022) and default scenario from EU PEF (Zampori and Pant, 2019) were used for modelling all life cycle stages, while the Group primary data were used for modelling the use phase, as showed in table 1. European Cotton Normal and North America Hot cycle are more intensive (i.e. higher temperature) compered to Cotton Extra Light and Cold cycle in the respective region. Concerning the washing of garments, a mass allocation is used according to the laundry load of washing machine considered (4 kg). The formulation of the liquid detergent was modelled according to the AISE recommendation (AISE, 2019), whilst the powder detergent was modelled according to the AHAM recommendation (AHAM, 2013).

Wash cycle	Elect. [kWh]	Liquid det [ml]	Powder det [g]	Water [L]
Extra Light	0.11	33		37.5
Normal	0.67	44		49.2
Cold	0.23		63	40.3
Hot	1.64		63	56.2

Table 1. Wash cycles, 4 kg laundry load. Cotton Extra Light and Normal are EU wash cycles. Cold and Hot NA cycles.

Four impact assessment categories were considered: Global Warming Potential in kg CO2-eq (GWP100; IPCC, 2021), the water footprint (WF) in m3 water-eq according to the AWARE methodology, the Ecotoxicity freshwater (EcoTox) in CTUe according to the USEtox model 2.1, and Fossil resource use in MJ, according to CML methodology (ADP-fossil).

Results

The environmental impact of garment longevity is reported in the tables below, where the two scenarios are compared via the Care LCA method. For this evaluation, number of wears equals number of washes. Table 2 and 3 report the GWP impact of a cotton T-shirt and Jeans, respectively, both washed with the selected washing cycles, in an EU scenario. Table 4 reports the Ecotoxicity, freshwater impact of cotton jeans washed with the selected washing cycles within a North American scenario.

			GWP [kgCO2eq]			
	N° of wears	EU wash cycle	P	D	U	EoL
BS	52	Cotton Normal	6.18	1.16	0.71	0.10
ES	104	Cotton Extra Light	6.18	1.16	0.53	0.10

Table 2. GWP impacts of life cycle of T-shirt. P=Production; D=distribution; U=Use phase; EoL=End of Life.

			GWP [kgCO2eq]			
	N° of wears	**EU wash cycle**	**P**	**D**	**U**	**EoL**
BS	20	Cotton Normal	22.3	1.28	1.00	0.35
ES	40	Cotton Extra Light	22.3	1.28	0.75	0.35

Table 3. GWP impacts of life cycle of Jeans. P=Production; D=distribution; U=Use phase; EoL=End of Life.

			EcoTox [CTUe]			
	N° of wears	**NA wash cycles**	**P**	**D**	**U**	**EoL**
BS	20	Hot	784.1	10.2	22.0	1
ES	30	Cold	784.1	10.2	23.3	1

Table 4. Ecotoxicty freshwater impacts of life cycle of Jeans. P=Production; D=distribution; U=Use phase; EoL=End of Life.

The production phase of garment presents the highest impact for all impact categories, independently from the type of garment selected. In fact, in all tables above, production values were consistently the highest when compared to the other phases. Depending on the considered impact category, then, distribution (for GWP) or use phase (Ecotoxicty, freshwater) have the second greatest impact.
To better understand where the high impacts of the production are coming from, the relevance of the individual production steps for all impact categories were analyzed. Table 5 shows, as an example, the contribution in percentage (%) of various production processes to the four impact categories for conventional cotton jeans.

	Fiber	Yarn	Fabric	Dyeing Finish.
GWP	16.8	30.3	33.7	19.2
EcoTox	27.7	34.5	33.3	4.5
ADP	13.6	28.3	33.1	25
WF	29.5	36.1	34.3	0.1

Table 5. Contribution analysis (%) of cotton Jeans pant 's production processes.

Based on available secondary data, the fabric and yarn production are the most relevant steps in the jeans manufacturing, because if summed up they contribute more than 60% to the impacts, followed by fiber production.

An insight on the use phase is highlighted in table 6 and 7, based on the NA Cold and Hot wash cycles.

	Elec	Tap water	Det	Water drained
GWP	67.2	4.1	27.1	1.6
EcoTox	26.8	2.7	50.5	20.1
ADP	74	3.2	23	0.9

Table 6. Contribution analysis (%) of use stage. Hot wash cycle.

	Elec	Tap water	Det	Water drained
GWP	23	7.3	66.9	2.9
EcoTox	5.2	2.7	71.6	20.4
ADP	28	6.3	64	1.7

Table 7. Contribution analysis (%) of use stage. Cold wash cycle.

The GWP and ADP fossil impact categories are strongly affected by the electricity when the garment is washed with the Hot wash cycle, followed by the detergent (i.e., the electricity contributes with 67.2% for the GWP, while the detergent contributes with 27.1%). On the contrary, when the garment is washed with the Cold wash, the detergent is more relevant than the electricity (i.e., the detergent contributes 66.9% for the GWP, while the electricity contributes 23.0%). Also, the detergent strongly affects the EcoTox freshwater impact category, as it is responsible for 50.5% of the impact with a Hot cycle, and for 71.6% with a Cold wash cycle.
In the sensitivity analysis, the contribution of different energy mixes was investigated. Figures 1 and 2 show the results of GWP for a conventional cotton Polo shirt when the shirt is used and washed 52 times with Normal cycle (fig. 1) and Extra Light (fig. 2) cycle in selected EU countries (DE, IT, SE, FR and PL) that are market relevant for the Group.

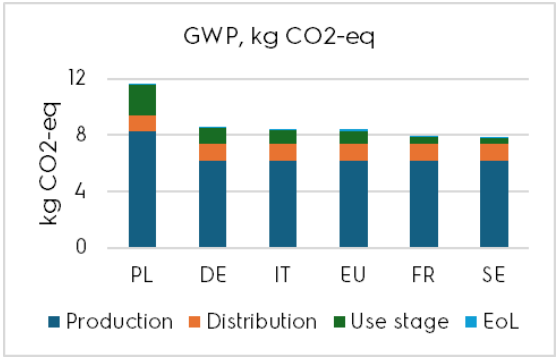


Figure 1. Sensitivity analysis on different energy mix. GWP impacts of conventional cotton Polo shirt, washed 52 times, with Normal wash cycles in different EU countries.

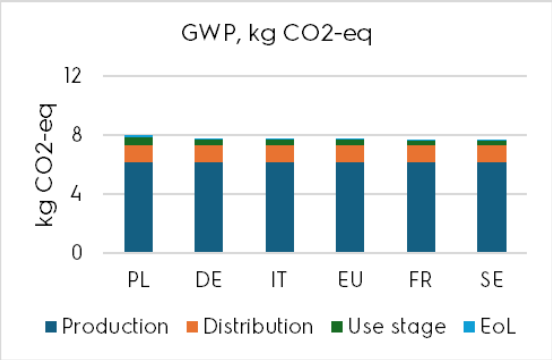


Figure 2. Sensitivity analysis on different energy mix. GWP impacts of conventional cotton Polo shirt, washed 52 times, with extra light wash cycles in different EU countries.

The GWP impact of the Polo shirt is differently affected by the countries when the shirt is washed with the two treatments. For instance, Poland (PL) and Sweden (SE), the two countries with the most different energy mix, when Normal cycle is used, the GWP is equal to 11.66 kg CO2-eq and 7.85 kg CO2-eq, respectively. It means that the overall climate change impact of a Polo shirt is decreased by around 14% when washing in SE compared to washing it in PL. If we compare PL with the average EU, the total climate change impact is 11.66 kg CO2-eq versus 8.39 kg CO-eq (9% of difference). Those changes for the GWP impact are less evident when the Polo shirt is washed with Extra Light cycle, because this cycle is less energy intensive when compared to the Normal cycle, therefore it is less sensible to climate change variations.
In order to understand the benefit on the overall impact of a prolonged use of clothing items, a different parameter was calculated: the *impact per wear*. This parameter takes into consideration the whole contributions of different phases to the impact category together with the number of uses during the use phase. An example of measurement of this parameter is reported below (Figure 3), where the jeans impact per wear for a European scenario is visible. Again, the wash cycles Cotton Normal represents the BS and the Extra Light represents the ES.

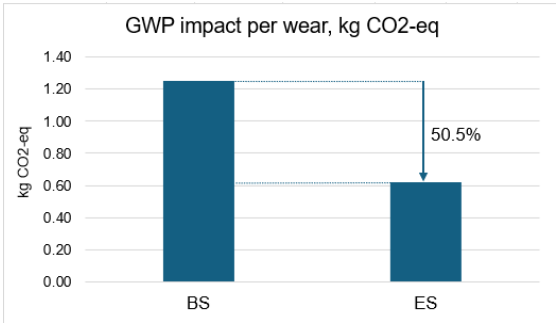


Figure 3. GWP impact per wear for the jeans using EU scenario

As already seen in Table 3, the total GWP is 22.97 kg CO2-eq for the BS, and 22.72 kg CO2-eq for the ES. Assuming that the number of wears until the end of life is 52 in the BS whilst it is 104 in the ES, it means to have a Care Index equal to 2. In other words, this means doubling the life of the item when using the Cotton Extra Light instead of the Cotton Normal.
This type of assessment can be done per each category can be placed in relationship with the number of uses and defined as *impact per wear*. By increasing the number of uses, the environmental burden can be spread over a greater number of uses resulting in a reduction of the overall impact. Similar approaches have been already proposed by institutes and researchers in the field of fashion (Bates Kassatly, 2024). For the jeans in the European scenario, the GWP impact per wear can be reduced by around 50% when the item is worn 52 times more than the BS.

Conclusion

This study illustrates the environmental impacts of the life cycle phases of three garments. It also provides an insight on how much consumers could decrease their garments impact on the planet. Since this LCA approach includes all lifecycle stages, from fiber sourcing to garment disposal, it stresses the importance of extending the life of garments during the so-called *Use Phase*, where washing machines can play a key role. The message is that the longer the garments are used for, the easier it will be to amortize their environmental impact. Indeed, adopting low washing temperatures, such as cold washes, promotes clothes longevity while contemporarily requiring lower energy consumptions. The LCA method presented in this paper was verified by a third-party according to the ISO 14040-44 for

supporting the Group within its sustainability strategy.

References

AHAM, Association of Home Appliance Manufacturers. (2013). *Performance Evaluation Procedures for Household Clothes Washers. AHAM HLW-1-2013*.

AISE, International Association for Soaps, Detergents and Maintenance Products (2019). *Product Environmental Footprint Category Rules (PEFCR). Household Heavy Duty Liquid Laundry Detergents (HDLLD) for machine wash*. September 2019. Version 1.2

Bates Kassatly, V. (2024). Sustainable Fashion - Could it all be in the hands of the Consumer? *Veronica Bates Kassatly.* https://www.veronicabateskassatly.com/read/sustainable-fashion-could-it-all-be-in-the-hands-of-the-consumer

Ellen MacArthur Foundation. (2017). *A new textiles economy: Redesigning fashion's future*. A New Textiles Economy: Redesigning Fashion's Future

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Climate Change 2021: The Physical Science Basis

Quantis. (2022). *Product Environmental Footprint Category Rules (PEFCR) for Apparel and Footwear. Draft. Version 1.3* – First draft PEFCR, 28 March 2022.

Zampori, L., & Pant, R. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method, EUR 29682 EN, Publications Office of the European Union, Luxembourg, 2019, https://dx.doi.org/10.2760/424613. JRC115959*.

Extended Abstract
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Test less, better, faster, cheaper.

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Keywords: Durability; Lifespan; Textile testing; Clustering; Textile industry.

Introduction

One of the major challenges faced by the textile industry is addressing its socio-environmental impact. To tackle this, various strategies derived from circular economy and eco-design have been identified as potential levers:

- Consumption changes through new business models (Fletcher 2012),
- Care (Laitala and Klepp 2020)
- Price perception in relation to sustainability (McNeill et al. 2020; Pires et al. 2024; Wakes et al. 2020),
- Physical durability of products (Degenstein et al. 2020; Fletcher 2012; Wakes et al. 2020).

These approaches offer significant opportunities for mitigating environmental damage, improving resource efficiency, and promoting sustainability throughout the entire lifecycle of textile products (UNEP 2023). However, each face has specific and significant challenges that require collaboration among producers, governances and consumers (UNEP 2023; Pichon et al 2022)

Focusing on physical durability, it is assumed that the evaluation methodologies currently available are based on established frameworks, which could theoretically be implemented. However, these frameworks rely on a variable number of tests depending on product category (from 4 to 20) (AFNOR 2025; European Commission 2021). Considering the size of a collection, it's clear that this represents a significant challenge. The need to perform individual tests for each item within a large textile collection makes the practical implementation of these frameworks both resource-intensive and time-consuming. This complexity underscores the importance of developing more efficient methodologies to facilitate the adoption of physical sustainability measures in the textile industry.

In this context, a central question emerges: for a high number of references, how to simplify and to optimize the process of assessing the physical durability, while guaranteeing relevant and reliable results?

This study proposes a methodology to optimize the durability assessment of textile considering:

- the number of redundant tests
- the number of fabric references to be tested.

This approach aims to identify key features that enable the performance to be predicted, offering a scientifically robust yet practical solution to support manufacturers in their pursuit of more sustainable production.

Methodology

The proposed methodology relies on a clustering-based approach to predict quality test results. In the following, data collection, processing, clustering and prediction are explained.

Data collection

This work is based on the case study of a knitwear manufacturer. A fashion knitted garment is made from: knitting, dyeing, finishing and dressmaking. Given the diversity of yarns and the process parameters, a high variety of process combinations can arise. Thus, a single yarn reference can be used in several scenarios, a single knitted fabric can incorporate different yarns, etc. (Figure 1). At the dressmaking level, a single knitted fabric may be used for the development of multiple designs, while a single design may be created from various fabric references.

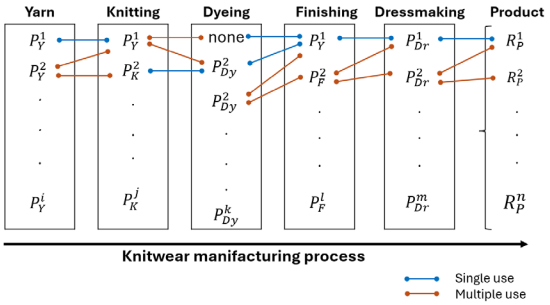


Figure 1. Variety of manufacturing processes for knitted textile products

Features	Type
Knitting structure	Categorical
Structure specification	Categorical
Knit type	Categorical
Mechanical finishing	Categorical
Wool	Numeric
Synthetic	Numeric
Cotton	Numeric
Flax	Numeric
Viscose	Numeric
Elastane	Categorical
Organic cotton	Categorical
Recycled synthetic	Categorical
Knit cut	Categorical
Knitting machine diameter	Numeric
Fabric width	Numeric
Fabric weight	Numeric
Gauge	Numeric
Number of needles on knitting machine	Numeric
Number of knitting feed	Numeric
Yarn count	Numeric
Yarn color (natural, dyeing or mottled)	Categorical
Yarn treatment	Categorical
Twisting	Categorical
Spinning	Categorical
Yarn CSR	Categorical

Table 1. Raw knitwear features

A persistent issue in data collection from textile industry was cross-referencing and standardization (Niinimäki et al. 2024). Thus, the proposed methodology focuses on cross-validated data: the structure fabric's properties from around one hundred raw knitted fabrics. Tables 1 and 2 detail the structure and quality features collected, including composition, machine parameters and dimensional stability.

Features	Type
Dimensionnal stability course	Numeric
Dimensionnal stability wale	Numeric

Table 2. Quality tests

As a first approach, the selected raw knitwear references are those made from a single yarn reference such as rib, jersey or interlock.

This study was carried out using Orange Data Mining software. The methods worked with thereafter, hierarchical clustering and decision trees effectively structure and classify complex datasets, maintaining strong predictive ability and robustness to data variations (Ghattas et al. 2017).

Data cleaning

A clean-up of outliers, based on the results of the Local Outliner Factor method and expert judgement, results in a more homogeneous dataset of 110 knitted fabric. These outliers concern references with unusual stability probably due to production issues or singleton like flax-based reference.

Prediction of dimensional stability according to knitwear features

To demonstrate the benefits of clustering, an investigative step was implemented, based on the direct prediction of dimensional stabilities from knitting features (Figure 2). All predictive models used are based on regressive or classification trees due to their ease of use and accuracy on relatively small datasets.

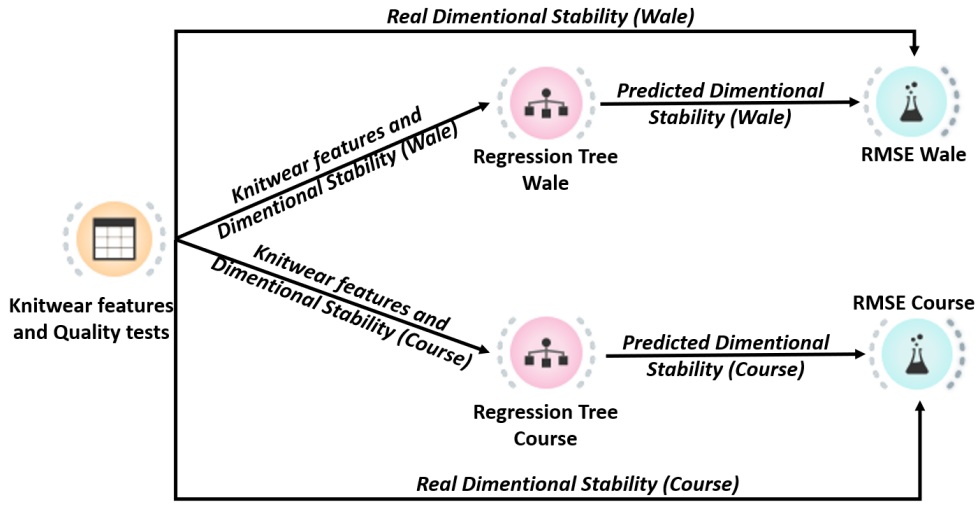


Figure 2. Prediction of dimensional stability based on regression tree

Cluster based prediction and analysis of feature influences

The proposed approach is a two-step method (Figure 3):

1- A hierarchical clustering defines clusters of fabrics with similar dimensional stability behavior.

2- A classification tree assigns a cluster to a fabric according to its knitwear features. The cluster average is considered as the dimensional stability of the fabric assigned to this cluster.

Finally, the obtained tree is analyzed to highlight the knitwear features with the highest influence on their dimensional behavior with the permutation feature importance technique.

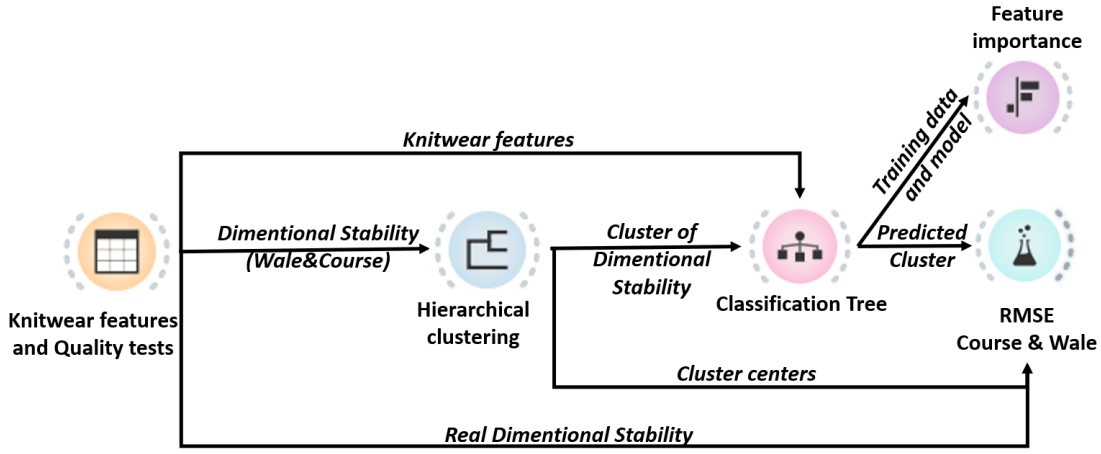


Figure 3. Cluster of dimensional stability and prediction of knitting features based on classification tree

Results

Cluster quality results beforehand confirmed as the most accurate by calculating the root-mean-square deviation (RMSE) between the actual dimensional stabilities and the course and wale dimensional stabilities. RMSE values are reported in Table 3.

RMSE	*Prediction according to features*	*Cluster based prediction*
Course	0,535	0,316
Wale	0,552	0,470

Table 3. RMSE values

The dendrogram of the hierarchical clustering (Figure 4) is used to select 8 clusters considering the balance between separation and compactness. The point distribution (Figure 5) shows distinct groups, validating the segmentation despite the limited data.

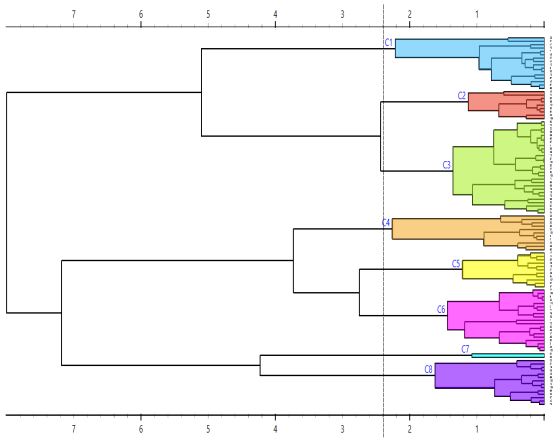


Figure 4. Hierarchical clustering of raw knitwear reference according to dimensional stability

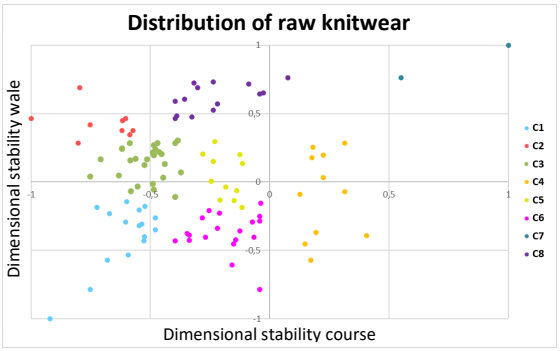


Figure 5. Distribution of raw knitwear according to dimensional stability in course and wale (data normalized and bounded)

The analysis of the attribute importance of the prediction model highlights that fabric width, knit type and fabric weight are the 3 most influential features on knitwear dimensional stability (Figure 6).

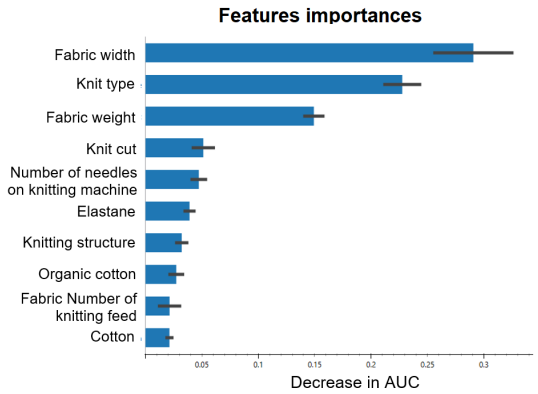


Figure 6. Features importances

At the studied knitwear manufacturer, fabric width has a strong influence, mainly because it is processed either open-width or tubular, causing data variations up to threefold. It is essential to assess the gap between theoretical and actual values to determine its true impact.

Conclusion

This study demonstrates that clustering of fabrics improves the prediction accuracy of quality test results. Furthermore, the proposed methodology highlights the most important features for eco-design. However, a deeper analysis of the results is required to identify the relationship between prediction accuracy and clusters. This further analysis should identify if a fabric requires a test to be performed or if the prediction is enough accurate to qualify its quality.

A limitation of this study is that the influence of finishing was not considered in the fabric features, though it could impact on the dimensional stability. This will be the subject of future works.

Acknowledgments

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References

AFNOR. 2025. “NF G30-113 - Articles Textiles d’habillement et Linge de Maison - Évaluation de La Durabilité.”

Degenstein, Lauren M., Rachel H. McQueen, Lisa S. McNeill, Robert P. Hamlin, Sarah J. Wakes, and Linda A. Dunn. 2020. “Impact of Physical Condition on Disposal and End-of-life Extension of Clothing.” *International Journal of Consumer Studies* 44(6):586–96. doi: 10.1111/ijcs.12590.

European Commission. 2021. “Product Environmental Footprint Category Rules: Apparel and Footwear.”

Fletcher, Kate. 2012. “Durability, Fashion, Sustainability: The Processes and Practices of Use.” *Fashion Practice* 4(2):221–38. doi: 10.2752/175693812X13403765252389.

Ghattas, Badih, Pierre Michel, and Laurent Boyer. 2017. “Clustering Nominal Data Using Unsupervised Binary Decision Trees: Comparisons with the State of the Art Methods.” *Pattern Recognition* 67:177–85. doi: 10.1016/j.patcog.2017.01.031.

Laitala, Kirsi, and Ingun Grimstad Klepp. 2020. “What Affects Garment Lifespans? International Clothing Practices Based on a Wardrobe Survey in China, Germany, Japan, the UK, and the USA.” *Sustainability* 12(21):9151. doi: 10.3390/su12219151.

McNeill, Lisa S., Robert P. Hamlin, Rachel H. McQueen, Lauren Degenstein, Sarah Wakes, Tony C. Garrett, and Linda Dunn. 2020. “Waste Not Want Not: Behavioural Intentions toward Garment Life Extension Practices, the Role of Damage, Brand and Cost on Textile Disposal.” *Journal of Cleaner Production* 260:121026. doi: 10.1016/j.jclepro.2020.121026.

Niinimäki, Kirsi, Anubhuti Bhatnagar, Hella Hernberg, and Malahat Ghoreishi. 2024. *Identifying Data Gaps in the Textile Industry and Assessing Current Initiatives to Address Them. Technical report*. LU: Publications Office.

Pichon, Noémie, Romain Benkirane, and Sébastien Thomassey. 2022. “Obsolescence des vêtements : un effet de mode ?” *Techniques de l’Ingénieur*. doi: https://doi-org.ressources-electroniques.univ-lille.fr/10.51257/a-v1-g7004.

Pires, Paulo Botelho, Cláudia Morais, Catarina J. M. Delgado, and José Duarte Santos. 2024. “Sustainable Fashion: Conceptualization, Purchase Determinants, and Willingness to Pay More.” *Administrative Sciences* 14(7):143. doi: 10.3390/admsci14070143.

United Nations Environment Programme. 2023. *Full Report - UNEP Sustainability and Circularity in the Textile Value Chain A Global Roadmap*.

Wakes, Sarah, Linda Dunn, Dahna Penty, Kayla Kitson, and Tim Jowett. 2020. “Is Price an Indicator of Garment Durability and Longevity?” *Sustainability* 12(21):8906. doi: 10.3390/su12218906.

Extended Abstract
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Connecting transition design and everyday fashion practices: a case of body change and the wardrobe.

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Keywords: Transition design; Fashion; Wardrobe; Body change; Everyday fashion.

Introduction

Garments and fashion items are part of everyday life, and they are objects that accompany people through small and big moments of transition: between contexts, life phases and body changes.
In this work I introduce a connection between phases of the transition process and everyday fashion practices through describing a moment of body change from the perspective of dressing, aiming to offer a foundational reflection towards further empirical and theoretical research.

Transition design

Transition design is a contemporary method elaborated on a framework that incorporates the complexity of the process of change into design methodology, recognizing an active, catalysing role of design in it (Ceschin & Gaziulusoy, 2020). In the words of the founders, it was "inspired by the need for design to be more reliable in the face of increasingly complex problems" (Irwin, Kossoff, & Tonkinwise, 2015, p. 3). Transition design can act as a complementary strategy of any existing design method.
In 2022, an actionable model of transition design was presented (Figure 1), based on change theories and long-term past societal transitions, mainly based on destabilizing environmental events (Hebinck et al., 2022; Loorbach et al. 2017).
The figure represents the encounter of two opposing processes that configure any process of change: one line is composed of the phases that build up to the arrival and stabilization of new elements, and another stream captures steps of the process of phasing the old elements out. These two crossing paths, the build-up and the breakdown processes, cross each other in a moment of stability.

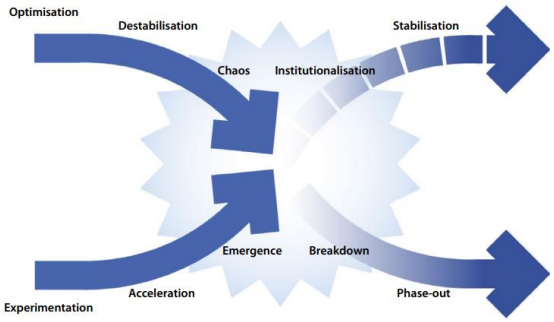


Figure 1. The X-curve model of transitions. (Source: Hebinck et al., 2022, p. 1009.)

While the framework of transition design is more commonly applied to social or institutional design, it is also an informative framework in the case of products such as fashion items.
From a systemic perspective fashion production and transition design have already been connected (Odabasi et al., 2022) and there are examples from the field of fashion that address transitory moments: the Dutch brand Vigga (Petersen, 2019) offers a rental possibility of childrenswear with a subscription package, or the project of Rebecca Early, periodically renews prints on shirts transforming the garments (Early, 2019). However, an analysis of the X-curve model within everyday fashion practice, and a focus on the object level offer further areas to explore.

Pregnancy: Fashion practices

The body changes throughout life, and the garments in the wardrobe follow these changes navigating transitory phases. Fashion offers a dedicated range of products to different ages, body types and activities.
Selecting one example of change, in this work I focus on pregnancy, as a life moment of temporary body transformation, and I reflect on each stage of the X-curve model (Hebinck et al.,

2022). In the example a woman is considered, in young adulthood between the age of 18-29 (Erikson 1993), with a stable body shape.
After the first trimester of pregnancy the body of a woman begins to transform not only internally, but externally as well. The transitory moment includes the period until a new stability begins, expanding to a period after giving birth.

Transitioning wardrobe

Following the phases of the X-curve model (Hebinck et al., 2022), it is possible to reflect on the approach towards the wardrobe when the body changes, and different needs emerge. Reflecting on the patterns of breakdown, a synthesis of key concepts of the process are listed in Table 1.

Pattern of breakdown	The wardrobe: practices and approach
Optimisation - improving the existing	**Curated wardrobe** - multipurpose pieces - adding items occasionally
Destabilisation - a sense of urgency for change	**Fitting issues** - new criteria for garment selection
Chaos - conflict, uncertainties	**Disordered wardrobe** - new, old, fitting and not fitting garments
Experimentation - radical new practices	**Looking for alternatives** - crafting, swapping, shopping, combining
Acceleration - alternatives are visible	**Upcoming event** - urgent need covered relying on new practice
Emergence -new structures become visible	**Transforming wardrobe** - embedding new basic pieces

Table 1. Transition phases explored through notes on dressing practice. (based on: Hebinck et al., 2022)

The process of transition continues after a short moment of stability, following a pattern of build-up (Table 2.). On system-level transitions, in this part of the process of transition breakdown and phasing out are the least considered stages in the context of introducing innovative solutions (Hebinck et al., 2022).

Pattern of build-up	The wardrobe: practices and approach
Breakdown - repelling and releasing former established order	**Rearranged wardrobe** - relocating, putting away garments, towards a new medium-term order
Phase out - dealing with loss	**Refreshed wardrobe** - getting rid of garments
Institutionalisation - the new normal	**Changed wardrobe** - organised spaces - multipurpose pieces
Stabilisation - optimising	**Effortless use** - maintaining the new wardrobe (optimisation)

Table 2. Transition phases explored through notes on dressing practice. (based on: Hebinck et al., 2022)

Body change occurs in life between psychosocial development phases (Erikson, 1997), and for other reasons such as sport, or health issues. In this perspective, the wardrobe is approached shifting between transitory phases, with a shorter or longer duration of each pattern or phase.
Applying the X-curve model (Hebinck et al., 2022) to dress culture reveals adaptation strategies in the context everyday fashion practices. Such perspective is relevant to optimise and evaluate innovation on the level of fashion items, offering valuable insights on larger systemic levels as well.

Further research

This work offers itself as a starting point for future investigations in particular with an empirical focus, that could contribute to a more detailed understanding of implications of adaptive fashion practices.

References

Ceschin, F., & Gaziulusoy, İ. (2020). *Design for sustainability: a multi-level framework from products to socio-technical systems.* Routledge. https://doi.org/10.4324/9780429456510

Early, R. (2019). Shirt stories. University of Arts London Professional platform.

Erikson, E., H. (1993). *Childhood and Society*. Paladin Gafton Books. Imago Publishing Company. (Original work published 1951).

Hebinck, A., Diercks, G., von Wirth, T., Beers, P. J., Barsties, L., Buchel, S., Greer, R., van Steenbergen, F., & Loorbach, D. (2022). An actionable understanding of societal transitions: The X-curve framework. *Sustainability Science*, 17(3), pp. 1009-1021. https://doi.org/10.1007/s11625-021-01084-w

Irwin, T., Kossoff, G., & Tonkinwise, C. (2015). Transition design provocation. *Design Philosophy Papers*, 13(1), pp. 3-11. https://doi.org/10.1080/14487136.2015.1085688

Odabasi, S., von Busch, O., Moon, C., Sansone, L., & Rissanen, T. (2022). Transition Design and Fashion. *Fashion Practice*, 15(2), 349–367. https://doi.org/10.1080/17569370.2022.2133183

Petersen, T., B. (2019) Buying into the future: A case study of a Danish brand of fashionable children's clothing. In Julier, G., Folkmann, M. N., Skou, N. P., Jensen, H.-C., & Munch, A. V. (Eds.). (2023). *Design culture: objects and approaches*. Bloomsbury Visual Arts. pp. 83-95. https://doi.org/10.5040/9781474289856

Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability transitions research: transforming science and practice for societal change. *Annual Review of Environment and Resources*, 42(1), pp. 599-626. https://doi.org/10.1146/annurev-environ-102014-021340

Extended Abstract
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Why Do You Buy? Introducing a Reflective Café Approach to Foster Mindful Clothing Purchases in Generation Z

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Keywords: Impulse buying; post-purchase; guided introspection; reflective thinking; mindful consumption.

Introduction

Owning a wardrobe filled with ever-changing fashionable clothes allows young people to stay trendy, express their individuality, and build a sense of community with their peers. However, this pursuit often comes at the cost of excessive and impulsive purchases that can lead to substantial waste and harm the environment (Morgan & Birtwistle, 2009; Niinimäki et al., 2020). Research indicates that 41% of Generation Z (Gen Z) consumers—those born in the late 1990s and early 2000s—are impulsive buyers (Djafarova & Foots, 2022). A major driver of this behavior is the pervasive use of social media and e-commerce platforms, which provide constant exposure to advertisements and create shortcuts in decision-making (Djafarova & Bowes, 2021; Herzallah et al., 2021; Thangavel et al., 2022).

Impulsive Purchase of Gen Z

Gen Z often faces contradictory situations when reflecting on their impulsive purchasing behaviors (Ayuni, 2019). On the one hand, Gen Z demonstrates strong concern for sustainability challenges and the environmental impacts of their behaviors and lifestyles, as evidenced by their willingness to pay for eco-friendly products (Djafarova & Foots, 2022; Gomes et al., 2023). On the other hand, growing up in the digital era, their consumption habits have inevitably been shaped by shifting cultural trends, the fast fashion boom, and the convenience of online shopping (Rosely et al., 2024). Therefore, for Gen Z, the question of whether to buy inherently reflects a motivational dilemma: balancing their climate awareness and sustainability values with their need for self-expression and social belonging (Chan et al., 2017).

According to Rook and Fisher (1995), impulsive buying can be understood as "*a consumer's tendency to buy spontaneously, unreflectively, immediately, and kinetically*." Persuasive marketing strategies on social networking sites—such as targeted campaigns, time-bound offers, and influencer endorsements—often trigger careless, irrational, heat-of-the-moment purchases (Herzallah et al., 2021; Rosely et al., 2024). The phenomenon of impulsive purchases among Gen Z exemplifies the value-action gap, in which sustainable consumption intentions are often undermined by contextual and social influences on actual purchasing behavior (Carrington et al., 2014; Park & Lin, 2020). This tension, therefore, highlights opportunities for tailored design interventions.

Post-Purchase Reflection

Existing interventions to curb impulse buying have primarily focused on the decision-making process, particularly at the moment of purchase. Previous research has investigated various strategies throughout the shopping process, including but not limited to promoting delayed purchases, incorporating gamified distractions, increasing checkout effort, and reducing product desirability (Moser et al., 2019; Sin et al., 2022; Tobon & Abril, 2024). Despite their diversity, these approaches share common goal: encouraging rational thinking over impulsive decision-making. However, limited attention has been given to the post-purchase stage, where rational and reflective thinking could play a more fundamental role in shaping future purchasing behavior and exerting long-term influence (Dahl et al., 2016; Liu et al., 2019; Obukhovich et al., 2024). This

study aims to address the often-overlooked post-purchase stage by introducing the Reflective Café, a group-based reflection approach designed to encourage mindful clothing purchases among Gen Z.

Methods

The design and development of the Reflective Café unfolded in two phases. The first phase aimed to deepen our understanding of Gen Z's attitudes, behaviors, and characteristics concerning impulsive shopping. To do so, we conducted several research activities, like literature review, introspective studies, and generative sessions with five Gen Z participants using tools adapted from Desmet (2018). After analyzing and synthesizing the research outcomes, we distilled the insights into three primary design criteria to guide the next phase:

- **Group-Based Reflection as a Social Activity**: Gen Z values open conversations and bidirectional feedback (Dolot, 2018). Engaging in group-based reflection may enhance engagement and stimulate deeper reflective thinking.
- **Visual Communication**: Representing thoughts and emotions in a tangible format makes abstract ideas explicit and easier to grasp, facilitating effective communication.
- **Guided Reflection with Room for Creativity**: Open-ended prompts may encourage mindful reflection while allowing flexibility for self-expression and creative exploration.

The second phase included five rounds of concept iteration, which were informed by continuous user testing and evaluation (Figure 1). We explored several design directions to address the identified design criteria, with group-based collage ultimately emerging as the most effective medium. During the concept evaluation, we observed an interesting phenomenon: some participants became more critical when reflecting on their peers' recent purchases. Figure 2 provides two examples. For further details, see Bakker (2023).



Figure 1. Concept evaluation.

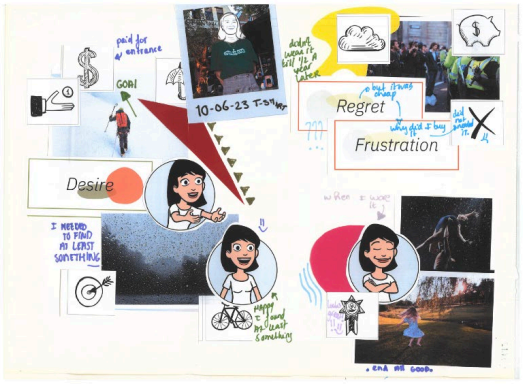




Figure 2. Collages created by two participants reflecting on their recent purchases of a T-shirt and a pair of shoes.

The Reflective Café

The final concept, Reflection Café, is a group-based intervention designed to encourage Gen Z to reflect on their impulsive buying behaviors. As shown in Figure 3, the Reflection Café menu outlines provided stationery, a set of guiding cards with reflective prompts, and clear instructions for implementation.

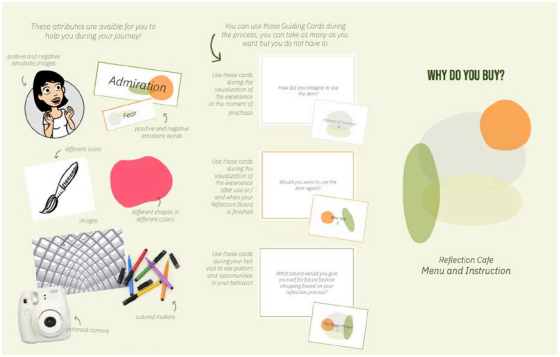


Figure 3. Reflective Café menu.

The reflection process begins by inviting a friend to join on a three-stage reflective journey spanning six months:

- Stage 1: Exploring the most recent purchase.
- Stage 2: Delving deeper into the most recent purchase to generate insights about its context and motivations.
- Stage 3: Discussing both one's own and the peer's purchasing decisions and their associated effects.

Throughout this process, participants are invited to critically examine their wardrobe and consumption patterns, thereby gaining valuable insights into their decision-making, the functional, emotional, and economic value of their purchased items, together with their associated social and environmental impacts (Figure 4).

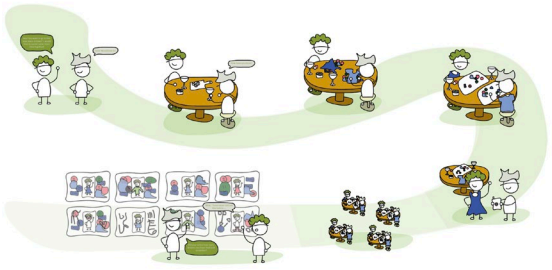


Figure 4. Overview of the Reflective Café process.

Conclusion

The Reflection Café offers Gen Z a creative and collaborative environment to explore the question: "Why do you buy?" Through structured group reflections, participants are guided to openly share and discuss their viewpoints with peers and critically reflect on their recent clothing purchase decisions across three stages. By turning self-reflection into an engaging social experience, this approach aligns with Gen Z's desire for social connection and self-expression. This paper focuses on the conceptualization and initial development of the Reflective Café; the empirical evaluation of its long-term impact on cultivating mindful clothing purchasing behaviors among Gen Z remains an area for future research.

References

Ayuni, R. F. (2019). The online shopping habits and e-loyalty of Gen Z as natives in the digital era. *Journal of Indonesian Economy and Business*, 34(2), Article 2. https://doi.org/10.22146/jieb.39848

Bakker, S. L. (2023). Why do you buy: Reducing fashion consumption together through reflection [Master's thesis, Delft University of Technology]. TU Delft Repository. https://repository.tudelft.nl/record/uuid:a76709fb-ccb8-4500-a437-fc53ba3891c3

Carrington, M. J., Neville, B. A., & Whitwell, G. J. (2014). Lost in translation: Exploring the ethical consumer intention–behavior gap. *Journal of Business Research*, 67(1), 2759–2767. https://doi.org/10.1016/j.jbusres.2012.09.022

Chan, T. K. H., Cheung, C., & Lee, Z. (2017). The state of online impulse-buying research: A literature analysis. *Information & Management*, 54(2), 204–217. https://doi.org/10.1016/j.im.2016.06.001

Dahl, M., Keitsch, M., & Boks, C. (2016). Post purchase experience—A multidisciplinary review. DS 85-1: *Proceedings of NordDesign 2016*, Volume 1, Trondheim, Norway, 10th - 12th August 2016, 103–112. doi:10.20935/AcadMatSci7501.

Desmet, P. (2018). Measuring Emotion: Development and Application of an Instrument to Measure Emotional Responses to Products. *In M. Blythe & A. Monk (Eds.), Funology 2: From Usability to Enjoyment* (pp. 391–404). Springer International Publishing. https://doi.org/10.1007/978-3-319-68213-6_25

Djafarova, E., & Bowes, T. (2021). 'Instagram made Me buy it': Generation Z impulse purchases in fashion industry. *Journal of Retailing and Consumer Services*, 59, 102345. https://doi.org/10.1016/j.jretconser.2020.102345

Djafarova, E., & Foots, S. (2022). Exploring ethical consumption of generation Z: Theory of planned behaviour. *Young Consumers*, 23(3), 413–431. https://doi.org/10.1108/YC-10-2021-1405

Dolot, A. (2018). The Characteristics of Generation Z. *E-Mentor*, 74(2), 44–50. DOI: 10.15219/em74.1351

Gomes, S., Lopes, J. M., & Nogueira, S. (2023). Willingness to pay more for green products: A critical challenge for Gen Z. *Journal of Cleaner Production*, 390, 136092. https://doi.org/10.1016/j.jclepro.2023.136092

Herzallah, D., Muñoz Leiva, F., & Liébana-Cabanillas, F. (2021). To buy or not to buy, that is the question: Understanding the determinants of the urge to buy impulsively on Instagram Commerce. *Journal of Research in Interactive Marketing*, 16(4), 477–493. https://doi.org/10.1108/JRIM-05-2021-0145

Liu, H., Jayawardhena, C., Osburg, V.-S., & Mohiuddin Babu, M. (2019). Do online reviews still matter post-purchase? *Internet Research*, 30(1), 109–139. https://doi.org/10.1108/INTR-07-2018-0331

Morgan, L. R., & Birtwistle, G. (2009). An investigation of young fashion consumers' disposal habits. *International Journal of Consumer Studies*, 33(2), 190–198. https://doi.org/10.1111/j.1470-6431.2009.00756.x

Moser, C., Schoenebeck, S. Y., & Resnick, P. (2019). Impulse Buying: Design Practices and Consumer Needs. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–15. https://doi.org/10.1145/3290605.3300472

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, 1(4), Article 4. https://doi.org/10.1038/s43017-020-0039-9

Obukhovich, S., Sipilä, J., & Tarkiainen, A. (2024). Post-purchase effects of impulse buying: A review and research agenda. *Journal of Consumer Behaviour*, 23(3), 1512–1527. https://doi.org/10.1002/cb.2287

Park, H. J., & Lin, L. M. (2020). Exploring attitude–behavior gap in sustainable consumption: Comparison of recycled and upcycled fashion products. *Journal of Business Research*, 117, 623–628. https://doi.org/10.1016/j.jbusres.2018.08.025

Rook, D. W., & Fisher, R. J. (1995). Normative Influences on Impulsive Buying Behavior. *Journal of Consumer Research*, 22(3), 305–313. https://doi.org/10.1086/209452

Rosely, N., Sakarji, S. R., & Thani, A. K. A. (2024). "Sorry, I Couldn't Give Up Shopping!" How Live Streaming Urge Consumers towards Impulsive Fast Fashion Purchases. *Global Business and Management Research*, 16(2), 330-343.

Sin, R., Harris, T., Nilsson, S., & Beck, T. (2022). Dark patterns in online shopping: Do they work and can nudges help mitigate impulse buying? *Behavioural Public Policy*, 1–27. https://doi.org/10.1017/bpp.2022.11

Thangavel, P., Pathak, P., & Chandra, B. (2022). Consumer Decision-making Style of Gen Z: A Generational Cohort Analysis. *Global Business Review*, 23(3), 710–728. https://doi.org/10.1177/0972150919880128

Tobon, S., & Abril, C. (2024). Game on: Curbing impulse buying and returns in apparel e-tailers. *Review of Managerial Science*. https://doi.org/10.1007/s11846-024-00808-3

Extended Abstract
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Ecolabels in the Textile and Fashion Industry: Strengths, Weaknesses, and Recommendations for Improvement

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Keywords: Ecolabels; Eco-credentials; Sustainability; Textile fashion industry; Transparency.

Opportunities and Challenges for Ecolabels in the Textile and Fashion Industry

The textile and fashion industry (TFI) significantly contributes to environmental degradation, prompting a growing interest in sustainable practices. Voluntary self-regulations, such as ecolabels, have proliferated as part of the industry's response to these concerns. Ecolabels enable firms to signal environmental commitment to key stakeholders, including governments, suppliers, and consumers, reducing information asymmetries in the TFI.

However, the industry's complex global value chains and diverse range of products pose challenges to ecolabel effectiveness. Despite their potential to guide business and consumers toward more sustainable choices, ecolabels in the TFI often suffer from a lack of standardisation, inconsistencies in environmental criteria, and insufficient transparency, limiting their role in fostering trust and sustainable decision-making. This study systematically assesses ecolabels in the TFI, with a focus on UK-specific challenges such as regulatory fragmentation, evolving consumer attitudes towards sustainability, and the growing importance of circular economy policies (e.g., UK Extended Producer Responsibility (EPR) framework). It helps businesses and consumers make informed choices that support sustainability and extend the longevity of garments by promoting responsible purchasing, care practices, and sustainable end-of-life decisions. Our research enhances transparency and comparability, helping allowing stakeholders to better understand the environmental impact of TFI products and their potential to contribute to long-lasting, sustainable wardrobes.

An Iterative, Qualitative Assessment Approach

This exploratory qualitative study focuses on ecolabels relevant to the UK market, drawing from academic and gray literature and ecolabel databases such as the Ecolabel Index (2024), Fashion United (2024), and 'Ecolabel guide' (Global Ecolabelling Network, 2019). We developed a conceptual framework (Figure 1) that builds on and extends theories of information asymmetry and consumer and producer uncertainty in ecolabelling (Cashore, 2002; Darnall et al., 2018; Darnall & Carmin, 2005). Our framework establishes a robust foundation for evaluating ecolabels, defined as: *voluntary self-regulation tools that indicate products (or processes) as environmentally preferable based on life-cycle considerations. Ecolabels signify that a product meet stated environmental and social criteria, claiming to have less negative environmental (and/or social) impacts compared to similar products. Ecolabels, with independently verified, credible, non-misleading information about the environmental impacts of products, differentiate products in the marketplace, aiming to promote more sustainable production and consumption practices* – in a way that enhances transparency and facilitates meaningful comparisons.

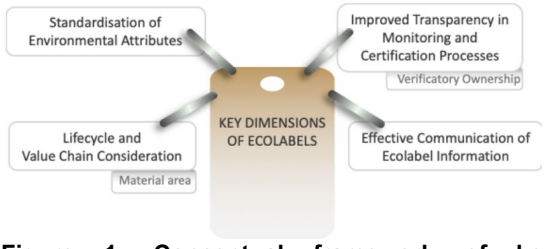


Figure 1. Conceptual framework of key dimensions and sub-dimensions to reduce information asymmetry and uncertainty and enhance ecolabel effectiveness. Source: Authors

Our framework addresses a gap identified by Ranasinghe & Jayasooriya (2021), contributing to more systematic methods for comparing and identifying the optimal ecolabel for specific garment products.

Findings: Strengths and Weaknesses of Ecolabels

We assessed 155 ecolabels, identifying 44 relevant to the UK TFI. Our findings reveal inconsistencies in environmental attributes: nearly half of the ecolabels do not address climate change, while nine focus exclusively on it (Figure 2). Most ecolabels are non-profit, with 43 verified by third parties, but only three meet ISO Type 1 standards (ISO, 2019).

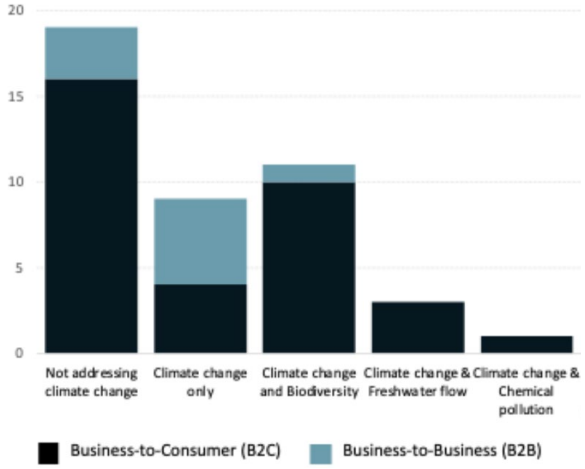


Figure 2. Distribution of ecolabels addressing climate change, either exclusively or in combination with other environmental attributes, showing the number of ecolabels in each category. Source: Authors

Ecolabels span different stages of the value chain, showing variation in sustainability certification approaches. Cradle-to-grave frameworks are increasingly popular in business-to-consumer (B2C) ecolabels, encouraging extended product lifespans through circular design, repairability, and responsible disposal. However, applying life-cycle methodologies presents several challenges, including the choice of system boundaries, ensuring sufficient data granularity, and maintaining consistency across product categories. Policy initiatives (European Commission, 2022; UKRI, 2023; UNSSC, 2020). further drive interest in circularity, but these complexities complicate the implementation of effective ecolabels in the UK textile market. While ecolabels align environmental priorities and promote transparency, fragmented standards, narrow lifecycle perspectives, and complex communication strategies hinder their effectiveness. By analysing the strengths and weaknesses of ecolabels in the TFI, our findings provide key insights into how ecolabels can encourage consumers to make informed choices that extend garment longevity, reduce premature disposal, and minimise the environmental footprint of fashion consumption.

Conclusion and Recommendations

Ecolabels play a critical role in shaping sustainability practices in the TFI by setting benchmarks, promoting transparency, and encouraging lifecycle thinking that supports longer garment use. For the UK textile sector, particularly amid shifting policies around extended producer responsibility and growing regulatory scrutiny, ecolabels can offer a competitive advantage by helping businesses demonstrate environmental commitment, improve consumer trust, and reduce premature disposal, thus supporting garment longevity and circularity. However, several challenges persist for them to remain relevant.

While ecolabels help align environmental priorities and influence consumer decisions, unclear criteria, inconsistent environmental attributes, and limited focus on durability and repairability hinder their impact on garment longevity. Transparency gaps in certifier ownership also contribute to consumer distrust.

To address these issues, we propose a unified definition of ecolabels to reduce confusion and build academic consensus. Current academic and industry approaches focus on fragmented aspects of ecolabelling, despite the clear scientific consensus on the interconnectedness of sustainability issues (Rockström et al., 2009).

For ecolabels to effectively promote sustainable practices, we recommend*:*

- Standardising environmental attributes and aligning them with global frameworks like the UN SDGs.
- Adopting a systems-based lifecycle approach that considers sustainability, across the entire value chain, from material sourcing to garment care and disposal.

- Strengthen standards beyond third-party verification to ensure absolute sustainability, transparency, and accountability.

- Enhancing communication strategies to balance clarity and technical detail, making ecolabels accessible and informative for diverse audiences.

Limitations and Future Research

Our study does not examine the direct relationship between ecolabels and the environmental performance of TFI firms, nor does it explore their social impacts. Future research should investigate the role of ecolabels in encouraging longer product lifespans, including their impact on consumer behaviors such as garment maintenance, repair, and responsible end-of-life decisions.

Additionally, further research should explore the frequency of ecolabel use within the UK TFI and their alignment with broader business sustainability strategies. Understanding how ecolabels influence both production and post-consumer behavior will provide deeper insights into their potential to drive long-term sustainability in fashion.

Acknowledgments

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References

Cashore, B. (2002). Legitimacy and the Privatization of Environmental Governance: How Non–State Market–Driven (NSMD) Governance Systems Gain Rule–Making Authority. *Governance*, *15*(4), 503–529. https://doi.org/10.1111/1468-0491.00199

Darnall, N., & Carmin, J. (2005). Greener and cleaner? The signaling accuracy of U.S. voluntary environmental programs. *Policy Sciences*, *38*(2–3), 71–90. https://doi.org/10.1007/s11077-005-6591-9

Darnall, N., Ji, H., & Vázquez-Brust, D. A. (2018). Third-Party Certification, Sponsorship, and Consumers' Ecolabel Use. *Journal of Business Ethics*, *150*(4), 953–969. https://doi.org/10.1007/s10551-016-3138-2

Ecolabel Index. (2024). *All ecolabels on textiles | Ecolabel Index*. All Ecolabels on Textiles. https://www.ecolabelindex.com/ecolabels/?st=category%2Ctextiles#google_vignette

European Commission. (2022). *EU Strategy for Sustainable and Circular Textiles*. European Commission. https://ec.europa.eu/info/law/better-regulation/

Fashion United. (2024). *Sustainability Certification Organizations in the Fashion Industry*. https://fashionunited.com/i/sustainability-certification-organizations-in-fashion

Global Ecolabelling Network. (2019). Global Ecolabelling Network. https://globalecolabelling.net/

ISO. (2019). *Environmental labels*. ISO.org. https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100323.pdf

Ranasinghe, L., & Jayasooriya, V. M. (2021). Ecolabelling in textile industry: A review. *Resources, Environment and Sustainability*, *6*, 100037. https://doi.org/10.1016/j.resenv.2021.100037

Rockström, J., Steffen, W., Noone, K., Persson, Å, Chapin, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. (2009). Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society*, *14*(2). https://doi.org/10.1038/461472a

UKRI. (2023, August 14). *UKRI funds research for a sustainable fashion and textiles industry*. UK Research and Innovation. https://www.ukri.org/news/ukri-funds-research-for-a-sustainable-fashion-and-textiles-industry/

UNSSC, U. N. S. S. C. (2020). *Circular Economy and the 2030 Agenda*. https://www.unssc.org/courses/circular-economy-and-2030-agenda-november/

Extended Abstract
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Hyper-Local Recirculation of Second-hand Clothing Through Donation-Thrift Networks

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Keywords: Circular Economy; Second-hand Clothing; Sustainable Fashion; Textile Waste Management; Thrift.

Introduction

The amount of post-consumer textile waste has been increasing over the past decades (DeVoy et al., 2021), mirroring the rise in clothing consumption. In Canada, an estimated 1.1 million tonnes of textile waste are generated each year, which amounts to a per capita average of 31.2 kg per person annually (Cheminfo Services Inc., 2022). Textile waste is typically managed through municipal solid waste (MSW) systems, donations to charities, or resale through thrift stores and consignment platforms, depending on factors such as the clothing's condition, age, and style (Laitala, 2014). As clothing production and consumption continue to rise, systems like donation, thrifting, and second-hand clothing (SHC) markets locally and abroad have become mainstream solutions for managing clothing overproduction and supporting circularity within the textile sector. In the shift toward circular economy (CE) frameworks, emphasis on the 'R' principles of reducing, reusing, recycling, and recovery of materials has become increasingly critical (Kirchherr et al., 2017).

However, textile waste diversion in Canada faces a unique set of challenges due to the country's geographic and population distribution. The lack of centralized textile recycling processes in many regions, combined with the logistical difficulties of handling large volumes of clothing across a vast, sparsely populated country, results in inefficiencies in recycling and diversion. As a result, textile diversion programs heavily rely on informal, semi-private networks composed of charitable, not-for-profit, and for-profit organizations. These organizations collect, sort, and resell SHC to mitigate landfill waste. This study aims to explore and characterize the regional diversion networks of SHC thrift retailers in Canada. These networks are collectively defined as "second-hand clothing diversion networks" (SHCDN) and function as informal recycling systems for SHC in Canada.

Research Objective

This research aims to analyze the practices, challenges, and opportunities within regional SHCDNs in Canada, particularly focusing on how local actors (e.g., thrift stores, charitable organizations, and for-profit entities) engage with CE principles to manage textile waste. The study seeks to examine the regionalized nature of SHC diversion, as well as the tensions between centralized, large-scale systems and more localized, high-volume networks. By applying the territorial circular ecosystem (TCE) framework developed by Bourdin and Torres (2024), the study aims to identify how geographic proximity and local collaboration affect the success of diversion networks, ultimately promoting more sustainable and resilient systems for textile waste management.

Methods

This study used a mixed methods approach that included qualitative semi-structured interviews, facility tours, informal conversations, document analysis, and stakeholder analysis and mapping (Aligica, 2006; Brown et al., 2016). Data collection used purposive sampling for the semi-structured interviews with key actors within the SHCDNs, including store managers, sorters, and operations staff from thrift stores across Alberta, Saskatchewan, Manitoba, and Ontario.

A total of 25 interviews were conducted, each lasting between 1 and 2 hours. In addition to interviews, facility tours were conducted to observe the sorting, recycling, and resale processes at various thrift stores. The interviews were audio recorded, transcribed,

and analyzed using NVivo software, which facilitated coding and thematic analysis to identify trends, patterns, and challenges related to SHC diversion practices (Fereday & Muir-Cochrane, 2006).

The research draws on the TCE framework, which emphasizes the interconnectedness of local economic actors, institutions, and practices that together contribute to a CE. By applying this framework, the study aims to explore how local dynamics influence the sorting, repair, repurposing, and resale of SHC in Canadian thrift stores.

Findings

Preliminary findings suggest that there is a significant tension between large-scale, centralized SHC systems and hyper-local, regionalized diversion networks. While centralized systems benefit from economies of scale and can manage large volumes of clothing efficiently, regional networks that emphasize localized collaboration appear to be more effective at recirculating SHC. Thrift stores that leverage regional networks for sorting, repurposing, and resale of SHC report higher rates of clothing recirculation, contributing to reduced waste and better utilization of donated goods.

Hyper-Local Recirculation Strategies for Regional Diversion Networks

One key practice observed among thrift stores that operate successful regional diversion networks is the laundering and minor repair of high-value goods, which enhances the resale value of SHC. Some stores also employ online and in-store auction platforms, enabling them to reach wider customer bases and sell high-value items that may not be suitable for regular sale in-store. Additionally, several stores engage in repurposing and upcycling with the help of local actors, such as small-scale artisans or repair specialists. This localized approach not only adds value to unsellable SHC but also fosters community engagement and collaboration.

Proximity & Regional Diversion Networks

The proximity of thrift stores to local communities plays a crucial role in the success of these diversion networks. By being close to their customer base, these stores are able to build stronger relationships with donors and consumers, facilitating the collection and recirculation of SHC. Furthermore, the proximity allows for easier collaboration among local actors, including municipalities, charities, and small businesses, which supports the development of a CE at the regional level. Greater local recirculation of SHC can potentially reduce the burden of the substantial volumes of SHC exported to international markets where serious environmental harm must be assumed (Brooks, 2013).

Regional Diversion Network Challenges

However, several challenges persist in managing textile waste through regional diversion networks. A primary challenge identified is the transportation costs associated with moving unsellable SHC to textile recycling centers or processing facilities. In Canada, where such facilities are limited, particularly in rural and remote areas, the cost of transportation can be prohibitively high. Additionally, there is the ethical dilemma surrounding the export of excessive volumes of SHC to overseas markets. Some thrift organizations have developed creative solutions to address these challenges by fostering hyper-local recirculation practices. For example, smaller not-for-profit thrift stores have found ways to increase retail floor sale periods and upcycle or repurpose unsellable SHC within their communities, avoiding transportation costs and the negative impacts of overseas exports.

Conclusions

The study underscores the critical importance of geographical proximity and localized collaboration in establishing successful regional SHC diversion networks. By leveraging the strength of regional networks, thrift stores and their partners can substantially enhance resource optimization, drive waste reduction, and foster more resilient circular systems for textile waste management. However, significant challenges remain, particularly concerning transportation costs and the ethical dilemmas tied to the export of SHC.

To effectively address these challenges, the study advocates for the implementation of robust regulations and legislation that govern international textile waste flows. This approach is vital in addressing the concerning surplus of primary and secondary textiles that are often of

poor quality. Furthermore, government investment in cost-effective, low-fi technological solutions for regional recirculation is imperative to cultivate localized CE practices in Canada.

These strategic efforts would improve waste management practices and contribute to a more sustainable fashion industry. One that prioritizes circularity and resource conservation, fundamentally transforming the way we approach textile waste for the betterment of our environment and society.

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References

Aligica, P. (2006). Institutional and Stakeholder Mapping: Frameworks for Policy Analysis and Institutional Change. *Public Organization Review*, *6*(1). https://doi.org/10.1007/s11115-006-6833-0

Bourdin, S., & Torre, A. (2024). Economic geography's contribution to understanding the circular economy. *Journal of Economic Geography*, lbae040. https://doi.org/10.1093/jeg/lbae040

Brooks, A. (2013). Stretching global production networks: The international second-hand clothing trade. *Geoforum*, *44*, 10-22. https://doi.org/10.1016/j.geoforum.2012.06.004

Brown, G., Strickland-Munro, J., Kobryn, H., & Moore, S. A. (2016). Stakeholder analysis for marine conservation planning using public participation GIS. *Applied Geography*, *67*, 77-93. https://doi.org/10.1016/j.apgeog.2015.12.004

Cheminfo Services Inc. (2022, May 31). *Characterizing Reuse, Recycling and Disposal of Textiles in Canada. https://nactr.ca/wp-content/uploads/2022/07/Characterizing-Reuse-Recycling-andDisposal-of-Textiles-in-Canada.pdf*

Degenstein, L. M., McQueen, R. H., & Krogman, N. T. (2021). 'What goes where'? Characterizing Edmonton's municipal clothing waste stream and consumer clothing disposal. *Journal of Cleaner Production*, *296*, 126516. https://doi.org/10.1016/j.jclepro.2021.126516

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods*, *5*(1), 80-92. https://doi.org/10.1177/160940690600500107

Laitala, K. (2014). Consumers' clothing disposal behaviour–a synthesis of research results. *International Journal of Consumer Studies*, *38*(5), 444-457. https://doi.org/10.1111/ijcs.12088

Weber, S., Lynes, J., & Young, S. B. (2017). Fashion interest as a driver for consumer textile waste management: Reuse, recycle or disposal. *International Journal of Consumer Studies*, *41*(2), 207–215. https://doi.org/10.1111/ijcs.12328

Extended Abstract
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Environmental Impact factors for Apparel Products: Generalizing LCAs with Statistical "Market-mix" Modeling

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Keywords: Apparel; LCA; Reuse; second-hand; macro-level; GHG emissions; land use; water

Introduction

Life Cycle Assessment (LCA) is a bottom-up approach widely considered the gold standard for assessing the full lifecycle environmental impacts of products or services (Guinée, 2002). In the apparel sector, process-based LCA is commonly used to quantify the environmental impacts associated with a particular product, and identify environmental hotspots along the full lifecycle. For example, in their seminal paper on fast fashion, Niinimäki et al., 2020 use LCA results for a specific cotton T-shirt and a pair of jeans to highlight how much GHG and water a single fashion item is associated with. As they demonstrate, production typically dominates the full lifecycle impacts of clothing, accounting for roughly 75% of GHG emissions, and 92% of water depletion. Yet while LCA is an extremely useful tool, preforming product base analyses tends to be costly and time-consuming even when the system boundaries focus on production and cradle-to-gate life stages. In practice, the public availability of apparel LCAs is limited and the variety of product types covered is narrow.

As a result, studies exploring the potential benefits of alternative business models in apparel (e.g. clothing libraries), policies (e.g. EPR) or consumption pattern shifts at the mosso or macro level, often base their environmental modeling on specific case studies extrapolating results (Sandin et al., 2019; Roichman et al., 2024; EEA, 2023). For example, Zmani, Sandin, and Peters (2017) use results for three specific garments, to study the potential environmental benefits of collaborative consumption across the entire Swedish population. Similarly, Roichman et al. (2024), use LCA results for two garment types to shed light on the GHG emissions associated with consumer returns more generally. Yet while such efforts help to understand the scope of potential impacts, drawing on specific case studies as the basis for more general analyses may be problematic.

LCAs are typically specific to the products modeled, their weight, material composition, supply chain specifications and modeling assumptions and choices such as the impact assessment methods used. As apparel product weights material composition etc. can vary substantially both within and between product categories, the specificity inherent to LCA makes it challenging to generalize findings from one product to another similar one, let alone draw insights across product categories (see for example Munasinghe, Druckman, and Dissanayake 2021, and differences between Roichman 2024; Niinimäki et al., 2020 and Moon, 2024). The generalizability challenge is particularly relevant in macro level analyses where there is need to assess environmental impacts of entire product populations, or when detailed product specific data is unavailable, too time consuming or too costly to collect. Such instances include, for example, analyses of sustainable business models including sharing or leasing, international trade in second-hand apparel where items are often sold in bulk, or analyses based on Material Flow Analysis (MFA) (Moon, 2024).

In other sectors, such as transport, a market mix approach is often used to estimate typical emissions per passenger-km in a specific region. Put simply, the market mix carbon intensity factor is a weighted average calculated based on the region's automobile fleet composition, the relative frequency of different vehicles within it, and the respective GHG emissions associated with each type of vehicle.

As such a market mix approach allows for a more generalized analysis by considering the typical characteristics and market share of various products within the segment. Here we operationalize the idea of an apparel market mix, to provide robust, data driven impact factors for common apparel product categories (e.g. tops, bottoms, sportswear etc. See Table 1).

	GWP 100 (kg CO_2e)				Land use (m^3)				Water deplation			
Category	Mean	std.	Min	Max	Mean	std.	Min	Max	Mean	std.	Min	Max
Tops	10.71	1.41	6.54	14.48	9.093	1.300	5.626	12.881	4.413	0.649	2.628	6.564
T-shirts, shirts and blouces	3.08	0.20	2.48	3.65	2.134	0.136	1.703	2.467	1.606	0.104	1.319	1.917
Bottoms (full)	10.47	0.81	7.85	12.69	7.544	0.609	5.872	9.114	5.009	0.385	3.954	6.136
Bottoms (short)	4.64	0.29	3.77	5.36	2.953	0.219	2.342	3.555	2.013	0.155	1.564	2.399
Dresses	11.19	2.58	4.78	18.81	4.265	1.122	1.410	7.214	2.999	0.811	0.955	4.973
Accessories (gloves)	1.33	0.22	0.77	1.91	1.428	0.233	0.842	2.016	0.266	0.046	0.151	0.381
Jackets and blazers (anoraks, ski jacktes, raincoats etc.)	15.51	3.02	8.57	23.96	13.608	3.037	5.351	22.210	2.190	0.392	1.214	3.269
Overcoats, car coats, capes, etc.	34.19	4.33	21.75	44.76	34.948	4.477	21.557	47.236	5.606	0.714	3.459	7.423
Scarves, shawls, ties etc.	3.31	0.38	2.26	4.31	3.467	0.440	2.263	4.550	0.781	0.089	0.517	1.053
Sportswear	8.74	0.79	7.02	10.76	5.155	0.479	4.083	6.313	3.906	0.362	3.112	4.799
Suits & ensembles	29.64	2.65	23.26	37.48	33.157	2.982	26.031	42.354	4.682	0.423	3.753	5.911
Swimwear	1.75	0.27	1.06	2.43	0.766	0.130	0.450	1.084	0.598	0.106	0.352	0.848

Table 1: Environmental impacts associated with the production of a single generic unit (i.e. product) by product category.

Methods and results

To generate representative, general cradle to gate environmental impact factors for a typical, generic item in each apparel product category (e.g. tops, underwear, jackets), we constructed a modular, open access LCA tool using Brightway (https://docs.brightway.dev/en). Specifically, for each product category (e.g. Tops) we first modeled the distributions of product sub-categories (e.g. blouse, T-shirts) based on their market frequency. Next for each sub-category, we modeled per item weight distributions and typical material compositions based on a comprehensive report on apparel in the EU (Beton, 2014). Drawing from these distributions using a series of Monte Carlo simulations, we randomly sampled an item weight and used it along with the sub-category's respective material composition to calculate the mass of each material (e.g. silk, cotton, viscose). Next, we modeled all relevant production inputs and processes including weaving, knitting, washing, drying, and finishing according to their relative production prevalence, and calculated the cradle-to-gate impacts associated with materials and item manufacture according to the specified impact category (i.e., GWP100 (IPCC2021), water depletion, and land use (ReCiPe2016(H) midpoint)). We then repeated the process 10^4 times, to generate the typical impact distributions and calculate the mean, standard deviation, and min and max ranges for each product category's market mix. Environmental impact factors per item in each product category are presented in Table 1.

As reflections of the market mix of items, our results can be used as general impact factors for different apparel product categories, in cases where one needs to model the entire population or when detailed, product level data is unavailable. Importantly, all parameters of materials, weights, and relative frequency can be adjusted and updated by users, to reflect aspects such as localize parameters for to a particular region or changes in apparel product populations over time as these become available.

Conclusions

Interest in the environmental impacts of fashion and appeal is rising (EPRS, 2019), and there is growing need for general benchmarks at the product category level and impact factors that can be used for scenario analyses or with aggregate datasets lacking detailed product descriptions. Here we develop a dedicated open access Brightway tool and generate impact factors which represent the market mix of different apparel product categories. By simplifying complex systems, our approach and results enable actionable insights without relying on exhaustive, product-specific analyses.

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References

Beton, A., Dias, D., Farrant, L., Gibon, T., Le Guern, Y., Desaxce, M., Perwuelz, A., Boufateh, I., Wolf, O., Kougoulis, J., Cordella, M., & Dodd, N. (2014). *Environmental improvement potential of textiles (IMPRO Textiles)*. European Commission Joint Research Centre, Institute for Prospective Technological Studies. https://doi.org/10.2791/52624

European Environment Agency. (2023). The destruction of returned and unsold consumer goods in the EU: A legal analysis of possible approaches to prevent waste. *https://www.eea.europa.eu/publications/the-destruction-of-returned-and*

Guinée, J. B. (Ed.). (2002). *Handbook on life cycle assessment: Operational guide to the ISO standards.* Kluwer Academic Publishers.

Moon, D. (2024). Promoting sustainable practices: Exploring secondhand clothing consumption patterns and reductions in greenhouse gas emissions in Japan. Sustainable Production and Consumption, 45, 294–305. https://doi.org/10.1016/j.spc.2024.01.0154o

Munasinghe, P., Druckman, A., & Dissanayake, D. G. K. (2021). A systematic review of the life cycle inventory of clothing. *Journal of Cleaner Production, 318,* 128559. https://doi.org/10.1016/j.jclepro.2021.128559

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment, 1*(4), 189–200. https://doi.org/10.1038/s43017-020-0039-9

Roichman, T., Sprecher, B., Blass, V., Meshulam, T., & Makov, T. (2024). The convenience economy: Product flows and GHG emissions of returned apparel in the EU. *Resources, Conservation and Recycling, 210,* 107811.https://doi.org/10.1016/j.resconrec.2024.107811

Sandin, G., Roos, S., Spak, B., Zamani, B., & Peters, G. (2019). Environmental assessment of Swedish clothing consumption: Six garments. *Sustainable Futures*. Mistra Future Fashion. Retrieved from http://mistrafuturefashion.com/wp-content/uploads/2019/08/G.Sandin-Environmentalassessment-of-Swedish-clothing-consumption.MistraFutureFashionReport-2019.05.pdf

Zamani, B., Sandin, G., & Peters, G. (2017). Life cycle assessment of clothing libraries: Can collaborative consumption reduce the environmental impact of fast fashion? *Journal of Cleaner Production, 162,* 1368–1375. https://doi.org/10.1016/j.jclepro.2017.06.128

European Parliamentary Research Service. (2019). *Environmental impact of the textile and clothing industry*. Retrieved from https://www.europarl.europa.eu

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Can Promoting Fashion Innovativeness Move Traditional Luxury Consumers Toward More Sustainable Fashion Behaviours?

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Keywords: Unsustainability; overconsumption; luxury fashion; consumer behaviour

Introduction

This study examines the individual uniqueness motivations among some fashion consumers in Asian markets, promoting fashion innovativeness as a desirable behaviour, linked to more mindful, circular and sustainable fashion consumption. Additionally, we examine customers desire for uniqueness, versus conformity motivations, are driven by a consumer's sense of self-fulfillment via fashion, rather than social fulfilment (via susceptibility to influence of others and desire for social respect).

Luxury Fashion & Sustainability

From a sustainability perspective, luxury and prestige fashion systems are notable for their insufficient commitment to sustainability aims and support for sustainable initiatives, relative to their market dominance. Further, luxury customers are said to lack awareness of green practice, often via a willful ignorance of the issue (Bhandari et al., 2022). Hence, it is useful to better understand the drivers of continued and increasing demand for these products in their key markets, to examine how consumer perceptions might be shifted toward more sustainable behaviours.

Luxury consumption in Asian markets is often characterized by face-saving and group orientation motivations (Le Monkhouse, Barnes & Stephan, 2012). There is extant evidence that sustainability motivations differ markedly across cultural contexts, and that some cultures may weight other consumption drivers (such as social norms) above sustainability (Amatulli et al., 2021).

Traditionally, Asian cultures were said to focus on luxury as it was a publicly visible means to show conformity with social norms of status and quality. Western consumers, on the other hand, were said to be more concerned with expressions of individual taste and style (Oh & Kim, 2011). However, there is evidence that a steady acculturation toward Western culture is occurring in Asia (Das & Jebarajakirthy, 2019). Some studies note a clear shift in Asian markets from collectivist values to individualist amongst some consumers regarding their shopping behaviour (Wu et al., 2015).

This study posits that, alongside this shift in shopping values, there is potential to capitalize on individual uniqueness motivations among some fashion consumers in Asian markets, promoting fashion innovativeness as a desirable behaviour, linked to more mindful, circular and sustainable fashion consumption. It is our proposition that a desire for uniqueness, versus conformity motivations, are driven by a consumer's sense of self-fulfilment via fashion, rather than social fulfilment (via susceptibility to influence of others and desire for social respect). Hence, we hypothesise that:

H1: *Self fulfilment positively affects desire for uniqueness*

H2: *Self fulfilment positively affects fashion innovativeness*

H3: *Conformity motivations negatively impact fashion innovativeness*

Methods

An online survey was distributed for data collection. The survey development followed a tailored design method (TDM) (Dillman et al., 2014). This study focused on a convenience sample of consumer in Asian markets particularly Singapore and Malaysia. The

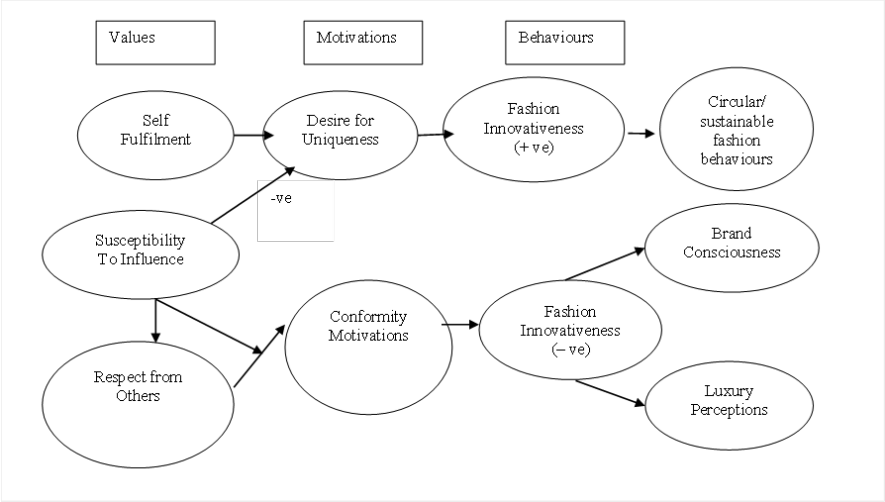


Figure 1. Research Model

sampling frame was individuals over the age of 18 years, present in the central city shopping district of Kuala Lumpur (n=250) and Singapore (n=250).

The original sample 500 respondents, applying the inclusion criteria (Bernerth et al., 2021), we excluded 5 respondents for rapid completion, 7 for incomplete responses, and 3 for failing an attention check (Please choose the strongly disagree from the options below), we obtained a usable sample of 485 respondents.

Of the final sample, 485 respondents were age between 18-25 (56.7%). A t-test revealed no statistically significant differences between these early and late respondents groups in all the constructs or between Singapore and Malaysia samples. Thus, our analysis found no evidence of response bias.

Findings

This study utilised partial least squares structural equation modelling (PLS-SEM) to evaluate the measurement model and test the proposed hypotheses. PLS-SEM was selected due to its capacity to handle complex relationships and mitigate factor ambiguity in moderation-mediation models (Liang et al., 2007). This variance-based technique enhances the prediction of endogenous constructs while providing superior statistical power, making it well-suited for our analysis (Hair Jr. et al., 2014). It is particularly valuable for investigating the intricate effects of self fulfilment, desire for uniqueness, fashion innovativeness (+ve), and susceptibility to influence on Circular/ sustainable fashion behaviours.

Moreover, fashion Innovativeness (FI -ve), respect from others, conformity motivation, susceptibility to influence on brand consciousness or luxury perceptions.. The method's flexibility accommodates diverse measurement models and yields precise insights into variable interactions. By employing PLS-SEM, we rigorously examine the interrelationships among variables and robustly test our hypotheses within a moderated-mediation framework.

Hypothesis 1 proposed that self fulfilment positively affects desire for uniqueness. The results confirm a significant positive relationship between self fulfilment and desire for uniqueness ($\beta = 0.338$, $p < 0.000$, $f2 = 0.125$).

In addition, self fulfilment showed a positive and significant effect on Fashion Innovativeness (FI +ve) ($\beta = 0.080$, $p < 0.000$, $f2 = 0.047$), which supports hypothesis 2.

Hypothesis 3 posited that conformity motivations leads to low fashion innovativeness (FI -ve). This hypothesis was also supported, with the results indicating a significant positive relationship ($\beta = 0.361$, $p < 0.000$, $f2 = 0.150$).

Conclusions

This study provides evidence that there are opportunities in the markets studied to operationalize values-based motivations for consumption to encourage consumers away from traditional conformity patterns of fashion

product preference, towards more sustainable behaviours.

While much sustainability focused public messaging seeks to educate consumers regarding detrimental impacts on the planet of consumption choices, in the context of fashion, this has been largely ineffectual in some markets (despite high uptake of other, non-fashion related sustainable behaviour).

This study offers insight into the importance of values-based messaging, which promotes sustainable methods of fashion consumption as a means to achieve and maintain uniqueness and fashion innovativeness, in changing traditional patterns of value-based fashion consumption behaviours.

References

Amatulli, C., De Angelis, M., Pino, G., & Jain, S. (2021). Consumer reactions to unsustainable luxury: A cross-country analysis. *International Marketing Review*, *38*(2), 412-452. https://doi.org/10.1108/IMR-05-2019-0126

Bhandari, N., Garza-Reyes, J. A., Rocha-Lona, L., Kumar, A., Naz, F., & Joshi, R. (2022). Barriers to sustainable sourcing in the apparel and fashion luxury industry. Sustainable Production and Consumption, 31, 220-235. https://doi.org/10.1016/j.spc.2022.02.007

Das, M., & Jebarajakirthy, C. (2020). Impact of acculturation to western culture (AWC) on western fashion luxury consumption among Gen-Y consumers in the Asia-Pacific region. Journal of Retailing and Consumer Services, 56, 102179. https://doi.org/10.1016/j.jretconser.2020.102179

Dinh, T. M., Le Hoang, Q. C., Vu Hoang, H. D., Lao, T. K. L., & Pham, T. H. T. (2024). Do luxury brands have to trade off for sustainability?. Journal of Global Fashion Marketing, 1-23. https://doi.org/10.1080/20932685.2024.2346845

Le Monkhouse, L., Barnes, B. R., & Stephan, U. (2012). The influence of face and group orientation on the perception of luxury goods: A four market study of East Asian consumers. International Marketing Review, 29(6), 647-672. DOI: 10.1108/02651331211277982

Oh, S., & Kim, J. (2011). Analysis of the Marketing Strategy of a Luxury Brand and its Success in Selected Asian Countries. International Journal of Interdisciplinary Social Sciences, 6(1). DOI: 10.18848/1833-1882/CGP/v06i01/52004

Extended Abstract
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The influence of age, gender and income on Australians' expectations of clothing lifespan

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Keywords: Clothing Longevity; Australia; Consumer Behaviour; Durability; Clothing Lifespan

Introduction

Extending clothing lifespans is a crucial step in advancing the transition to a circular economy. Past studies have highlighted the need to distinguish between social and technical lifespans of clothing (Laitala et al., 2018), as well as how/when to measure lifespan, whether in number of wears or number of years (Klepp et al., 2020). While research has been conducted on clothing lifespans in European contexts (WRAP 2019) and in Europe, Asia and the USA (Laitala & Klepp, 2020), this area remains underexplored in Australia, which presents a unique cultural and economic landscape. This paper investigates the expected lifespans of clothing in Australian households. Factors such as age, gender, and income can significantly impact how long consumers expect their clothing to last. By examining these variables, this research can provide insights into consumer behaviour and preferences, which can inform targeted interventions and educational campaigns to promote sustainable clothing practices.

Theoretical framework

Social practice theory posits that an individual's actions are shaped by everyday practices that comprise of materials, competencies and meanings (Reckwitz, 2002; Shove et al. 2012). In the context of sustainable clothing consumption, extending the lifespan of clothing is a critical component to reduce waste, minimise negative environmental impact, and support sustainable development. A practice theory approach frames durability of clothing as not solely determined by the product's design and materials but also influenced by how they are worn, washed, cared for, and maintained over time.

Methodology

This research presented in this paper draws from a larger study into the practices of Australians' clothing acquisition, use, and disposal (see Payne et al., 2024). The study employs a large-scale survey to generate robust, generalisable data on clothing lifespan, enabling longitudinal measurement over time (Klepp, Laitala & Wiedemann, 2020). The data was collected via an online survey in June 2024 by a market research agency. The survey sample was designed to be nationally representative of the Australian population across age, gender, and geographic location. In total, 3,080 valid responses were collected.

To measure clothing lifespan, two key survey questions were used. First, participants were asked to indicate the last time they acquired an item in each of nine different clothing categories. The nine clothing categories included t-shirts and short-sleeved tops, shirts and long-sleeved tops, jumpers, hoodies, and sweaters, underwear, socks, and hosiery, pyjamas and nightwear, smart bottoms for work, casual bottoms and jeans/denim, outdoor jackets and coats, and suits, ensembles, and dresses. For each category, participants were required to select a response indicating the number of years since acquisition, with options ranging from "less than 12 months" to the number of years (between 1-10), allowing for specific identification of the time elapsed. The second question asked participants to estimate how long they expected the acquired item to last. For this question, participants also chose a response from the same set of options, indicating how many years they expected the item to remain in use. These questions were adapted from consumer surveys conducted in the United Kingdom and Europe by WRAP (2019), allowing for international comparisons.

Findings

The results demonstrate that Australians expect to use their clothing for about four to eight years, with the average across all clothing products being 6.5 years. Expectedly, underwear, socks and hosiery have the shortest expected lifespan of 4.7 years; outdoor jackets and coats, and suits, ensembles and dresses both have the highest expected lifespan of 7.8 years. Compared to Europeans, Australians expect their clothing to last for longer. For example, Danish respondents had the longest expected longevity for their t-shirts at 4.4 years (WRAP 2019), and Australians expect this product category to last 6.1 years.

Age

The Kruskal-Wallis test revealed significant differences in the mean rank lifespan across age groups: 18-34 (mean rank = 1448.67), 35-54 (mean rank = 1501.85), and 55+ (mean rank = 1646.97). The test statistic was H(2, n=3080) = 27.845, with a significant result (p = 0.001), indicating significant differences in average lifespan across age groups. Post-hoc pairwise comparison using Dunn-Bonferroni indicated that there was a significant difference between age groups 18-34 and 55+, and 35-54 and 55+, and age group 55+ have the highest mean rank (clothing lifespan) than that of 18-34, and 34-54 age groups, p<0.001.

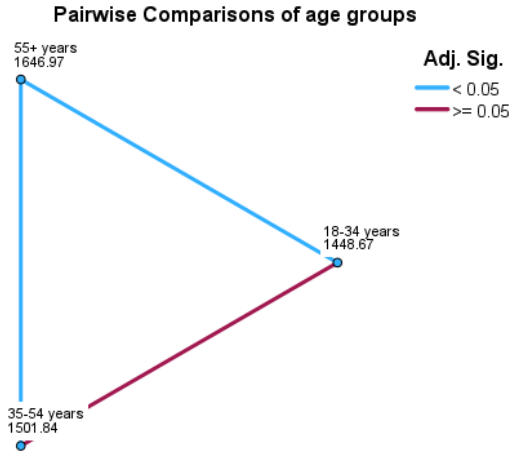


Figure 1 Pairwise Comparisons of Age Groups

Gender

A Mann-Whitney U test pairwise comparison was conducted, and there were statistically significant differences in comparing mean rank differences between average clothing lifespan across genders: female (mean rank=1459.88) and male (mean rank=1627.20). The post-hoc test statistics show H (1, n=3080) =27.224, and the mean rank for males is higher than for females. Post-hoc pairwise comparison (see Figure 2) using Dunn-Bonferroni indicated a significant difference between genders; males have a longer clothing lifespan than females.

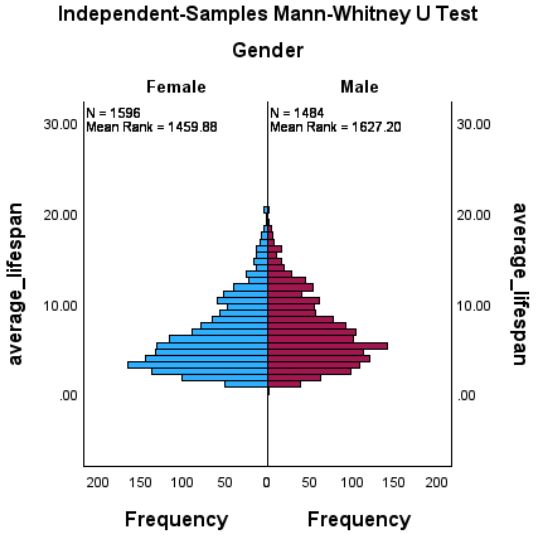


Figure 2 Independent Samples Mann-Whitney U Test

Income

The Kruskal-Wallis test revealed significant differences in the mean rank lifespan across income brackets: Less than $33800 (mean rank = 1655.96), AU$33801-$62400 (mean rank = 1625.24), $62401-104000 (mean rank = 1578.82), AU$104001-$156000 (mean rank = 1444.27), more than $156001 (mean rank = 1334.96), prefer not to say (mean rank = 1525.30). The test statistic was H (5, n=3080) = 41.721, with a statistically significant result (p < 0.001). Figure 3 shows the post-hoc pairwise comparison with the Dunn- Bonferroni method, indicating that there was a significant difference. Household income of more than $156001 has the lowest mean rank of lifespan compared to people's household income of $62401-$104000, $33801-$62400, and less than $33800.

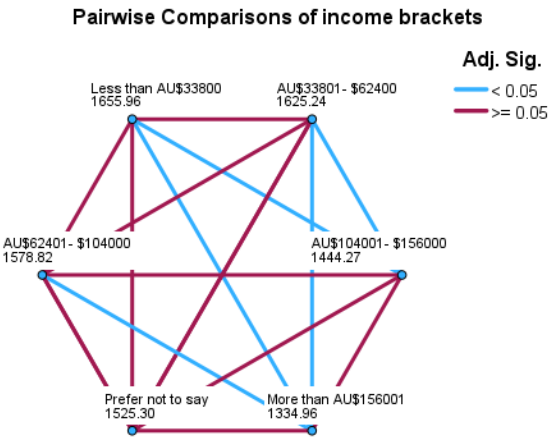


Figure 3 Pairwise Comparison Between Income Level

Acquisition and circular practices:
The relationships between average lifespan and demographic variables, Kendall's tau-b (τb) was conducted to examine the correlations between average lifespan and behavioural metrics, such as acquisition, washing practices, and circular activities.

Acquisition: There is a small negative correlation between monthly spending on new clothing and average lifespan, τb =-0.112, $p<0.001$.

Disposal practices: there is a positive small correlation between the disposal behaviour of no longer wanted yet still wearable clothing - 'I keep clothing even if I have not used it for many years' $\tau b = 0.127$, $p<0.001$. and 'I repair, reuse or repurpose the item at home' $\tau b = 0.158$, $p<0.001$.

Repair frequency activities: There is a small positive correlation between repair clothing frequency and average lifespan, $\tau b = 0.127$, $p<0.001$. There is a positive small correlation relationship between confidence in repairing activities and average lifespan, redesigning an item $\tau b = 0.101$, $p<0.001$, replacing a zip $\tau b = 0.116$, $p<0.001$, changing the fit/size $\tau b = 0.101$, $p<0.001$, and replacing a pocket $\tau b = 0.115$, $p<0.001$.

Discussion and conclusions

The findings reveal that Australians expect their clothing to last an average of 6.5 years, with demographic factors such as age, gender, and income significantly influencing these expectations. Older consumers expect their clothing to last longer compared to younger age groups (18-34 and 35-54). Men report a longer expected clothing lifespan than women. Lower-income groups tend to report longer expected clothing lifespans compared to higher-income groups.

Additionally, there is a small negative correlation between monthly spending on new clothing and expected clothing lifespans, as well as a positive correlation between repair frequency and clothing longevity. The disposal behaviour of retaining wearable but no longer wanted clothing also positively correlates with longer clothing lifespans. These results emphasise the importance of considering demographic factors and clothing use practices in lifespan research. They also underscore how perceptions and expectations of clothing are shaped by individual identity and fashion practice.

The findings of this study contribute to the existing social practice theory studies by illustrating how demographic variables, i.e., age, gender and income, as well as clothing-related acquisition, use, and disposal practices influence the clothing lifespans, provide valuable insights for promoting sustainable practices to extend the lifespan of garments.

This study's findings also offer important practical implications for consumers, industry, and policymakers. One of the key challenges in extending clothing lifespans lies in equipping consumers with the necessary skills and knowledge to maintain and repair their garments. As such, targeted education campaigns and skill-building initiatives could play a crucial role in fostering more resourceful consumption habits. For fashion brands, these findings provide valuable insights into consumer expectations of durability. Understanding the perceived lifespan of different clothing categories can also help brands make informed decisions about material selection, design for longevity, and the provision of aftercare services such as repair, rental or resale programs. At a policy level, these insights could inform the development of durability-focused regulations and incentives.

Acknowledgments

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References

Dempster, A. P., Laird, N. M., & Rubin, D. B. (1977). Maximum likelihood from incomplete data via the EM algorithm. *Journal of the royal statistical society: series B (methodological)*, *39*(1), 1-22.

Klepp, I. G., Laitala, K., & Wiedemann, S. (2020). Clothing lifespans: What should be measured and how. *Sustainability*, *12*(15), 6219. http://dx.doi.org/10.3390/su12156219

Laitala, K., & Klepp, I. G. (2020). What affects garment lifespans? International clothing practices based on a wardrobe survey in China, Germany, Japan, the UK, and the USA. *Sustainability*, *12*(21), 9151. https://doi.org/10.3390/su12219151

Reckwitz(2002). Toward a theory of social practices: A development in culturalist theorizing. *European Journal of Social Theory*, *5*(2), 243-263. https://doi.org/10.1177/136843102222 25432

Rubin, L. H., Witkiewitz, K., St Andre, J., & Reilly, S. (2007). Methods for handling missing data in the behavioral neurosciences: Don't throw the baby rat out with the bath water. *Journal of Undergraduate Neuroscience Education*, *5*(2), A71.

Seamless. (2024). *Seamless National Clothing Benchmark*. https://cdn.prod.website-files.com/6626f3b6b75e22631bdf7c57 /67342188a21a1399698f60f9_Seamle ss_National_Clothing_Benchmark.pdf

Shove, E., Pantzar, M. Watson, M., & (2012). *The dynamics of social practice: Everyday life and how it changes. (1 ed.)*. SAGE Publications, Limited. https://doi.org/10.4135/978144625065 5

WRAP. (2019). *Key Findings Report: Consumer Research for ECAP 2016-2019*. European Clothing Action Plan. http://www.ecap. eu.com/wp-content/uploads/2019/12/Consumer-Research-for-ECAP.pdf

Extended Abstract
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Re-Imagining Garment Cutting Waste: Fashion Hacking, Zero-Waste, and the Power of Negative Spaces

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Keywords: Negative Spaces; Fashion Hacking; Zero-Waste Design; Textile Waste; Garment cutting.

Introduction

The fashion industry generates a significant amount of textile waste, accounting for 10-15% of the total fabric used only during the garment cutting stage (Rissanen, 2007). These offcuts are typically considered useless residues, but they can be reimagined as valuable resources for the creation of new products through an innovative approach that combines Otto von Busch's theory of fashion hacking (2014) with the zero-waste design discussed by Timo Rissanen and Holly McQuillan (2018) as a tool for optimizing the cutting process. The integration of digital tools like Ai-powered tools and digital prototyping software has been widely studied to optimize fabric usage and minimize waste in fashion design to facilitate sustainable production (Salomé, 2024). Research highlights how these technologies enable zero-waste pattern development (McQuillan, 2019), reduce physical prototyping (Vrljanac et al., 2023), and optimize fabric placement through AI-driven solutions for pattern optimization (Glogar et al., 2025; Lee, 2023a), automated fabric placement (Bui et al., 2025), efficiency (Choi, 2024), and cost-efficient digital simulations (Kabakibi et al., 2023). High-end and fast fashion brands have adopted these tools to enhance pattern efficiency and minimize textile waste (Lee, 2023b; Morandi & Tonelli, 2023; Ramzan et al., 2024). Similarly, sportswear companies employ AI-based cutting software and simulations to improve sustainability and resource efficiency (Choi, 2022; Glogar et al., 2025).
These studies collectively underscore the transformative potential of AI and digital prototyping in advancing sustainable fashion practices while their implementation in fashion education enhances waste reduction strategies (Herring, 2025).

Negative Spaces

Purpose of the research

This contribution aims to explore the implementation of the zero-waste design approach in fashion, with a specific focus on the offcuts from the cutting stage, here defined as "negative spaces" of both the pattern and the cut garment. The main scope and priority of this study is to find new use for existing and ongoing cutting waste from industry and, at the same time, is on how design can change approaches in cutting to begin with. The goal is to investigate a new perspective that considers the textile waste generated during the cutting stage as "negative spaces" – "containers" (Torres, 2024) rich in value and meaning – which, instead of being discarded, can be transformed into new textile products for the fashion industry or related sectors. In this context, the designer becomes a "transmuter" of waste, permeating it with economic, social, cultural, and productive value through hacking operations within the design process. Waste material is thus interpreted with a different sensitivity, allowing us to discern "the various visible and invisible components of the cosmos" and to reshape and revalue "the remnants of something we no longer need or want in our lives" (Binotto & Payne, 2016, p.6).

Methodology

The concept of viewing offcuts from a different perspective is central to this exploration. When observing a single offcut, it may appear as an insignificant amount of fabric. However, when the same pattern is reproduced multiple times, the cumulative quantity of discarded fabric becomes substantial. These offcuts represent the negative spaces of both the garment and the fabric. The term "negative" in this context carries a dual meaning: on one hand, it refers to waste generated from the fabric during the cutting process; on the other hand, it carries an artistic connotation, where the negative space

serves as a complementary part of the overall composition, imparting a positive dimension.
This dual perspective raises important questions: How can a designer redefine the value of this waste and shift the way it is perceived? How can these materials be brought from invisibility to visibility? Designers possess a unique capability to make waste visible and assign it new value, but the process behind this transformation warrants closer examination.
From a methodological standpoint, improving the cutting stage and assigning new value to offcuts or "negative spaces" are key objectives. Two approaches are identified as pathways for achieving this: first, modifying garment patterns to align with zero-waste design principles, ensuring that the aesthetic and functional requirements, such as fitting, are preserved to meet consumer expectations. Second, in cases where zero-waste patterns are unattainable, developing a consistent marking system for the cutting stage is proposed. This approach ensures that identical offcuts are produced, enabling their integration into new garments or accessories.
The proposed methodologies could serve as the foundation for workshops aimed at educating students and training professionals. These sessions would disseminate the findings and promote the adoption of sustainable practices in pattern design and fabric cutting.

First outcomes

Initial experimentation was conducted using digital tools, in preparation for working with physical scraps. The first step involved selecting a pattern to study and creating a layout optimized for the cutting table. In the absence of layouts from manufacturing, a pattern from the CLO3D library—a simple white women's shirt in size EU 38—was used as a realistic reference. The focus at this stage was not on the garment's shape but on the optimization of fabric usage (fig. 1). Traditional pattern layering methods were compared to zero-waste design approaches, analyzing the resulting negative spaces.

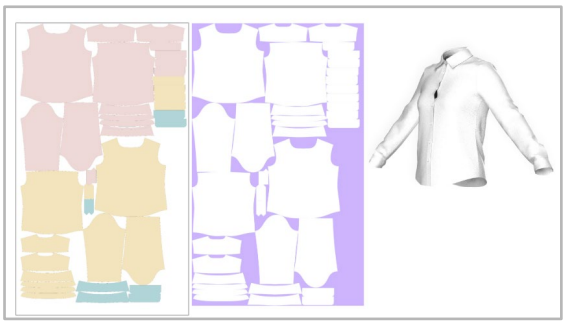


Figure 1. Negative spaces that come out from traditional pattern layering methods. © The author.

Digital tools were employed to generate these negative spaces, which were then draped in CLO3D (fig. 2) to create a visual representation of the fabric's potential for reuse. Subsequently, physical experimentation was conducted using a cutting table, to enable the creation of tangible offcuts, with the support of technicians and researchers at the Science Park's Do-tank Center during a visiting research period at The Swedish School of Textile - University of Borås. For the initial prototype, second-hand cotton bed sheets were selected as the material for testing. The cutting process produced positive spaces, which were used for garment construction, while the negative spaces were retained for further experimentation.

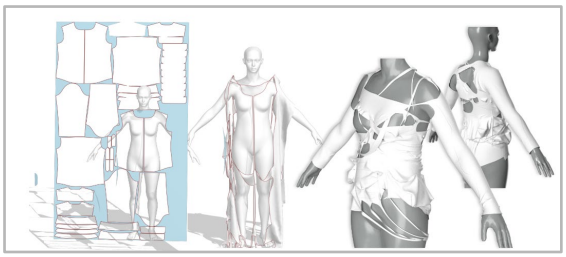


Figure 2. Digital draping session with negative spaces. © The author.

Additionally, a workshop was conducted with first-year BA Fashion Design students of The Swedish School of Textile at University of Borås enrolled in a course focused on form and material. Participants worked with offcuts sourced from previous assignments and waste bins within the Garment Construction Lab (fig. 3). This collaborative exercise provided valuable insights into the creative potential of textile waste and reinforced the importance of integrating these concepts into educational practices.

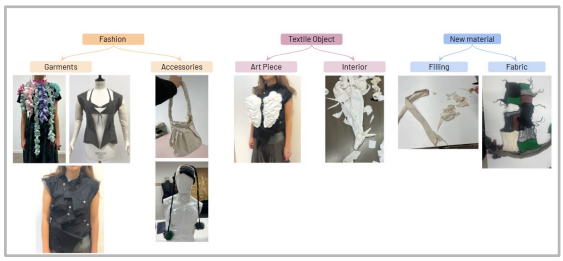


Figure 3. Workshop outcomes. © The Author.

This experiment aims to explore whether it is possible to repurpose fabric scraps to create new items, preserving the value of the cut fabric rather than discarding it as waste. It is based on the idea that designers have the power to reshape how we perceive and engage with materials, transforming offcuts into valuable products.
At the same time, fabric scraps resulting from the cutting process can be seen as "containers" of meaning. As textile artist Marion Baruch observes, "[...] In these leftovers is contained all the industrial and social work from which they derive, and in some way, they reveal the contradictions of this flow involving the social and cultural production of our society" (Torres, 2024). These intrinsic values give fabric scraps a profound significance, making it essential to preserve and communicate their meaning. Educating consumers, workers, and companies to recognize this value is a crucial step toward fostering a more responsible and conscious approach to materials.
Just as hackers, fashion designers can now use their skills to develop new approaches and new methodologies through which to decode fashion and alter the system. Through this approach, designers have the opportunity to transform and give new value to textile materials by giving a new identity to pre- and post-consumer waste.

Conclusions

The contribution aligns with broader reflections on sustainability and the concept of refashioning (Gwilt & Rissanen, 2011), analyzing how waste can be transformed into valuable resources through design. This research highlights the critical importance of exploring innovative approaches to reshape the fashion supply chain and reimagine the way garments are currently produced. By focusing on the cutting stage and pattern placement, the study aims to develop a new methodology that minimizes or eliminates fabric waste during production.
The dual approach, encompassing both digital and physical experimentation, has demonstrated the potential of digital tools while emphasizing the indispensability of manual and artisanal expertise. Without the tactile knowledge gained from working fabric on a mannequin, digital modeling—though creative and artistic—risks failing to meet the practical needs of the fashion industry. It may lack the sensitivity to address critical aspects such as seam positioning, edge preservation during processing, and compatibility with cutting technologies used in industrial workflows.
This integration of digital innovation with hands-on craftsmanship not only enriches the creative process but also ensures that the proposed methodologies align with the operational complexities of the fashion system. By bridging these two worlds, the research contributes to a sustainable transformation of garment production, addressing waste reduction while maintaining the functionality and aesthetic quality demanded by the industry. Finally, the concept of “negative spaces” not only fills the physical void left by offcuts but offers a new creative and sustainable narrative in 21st-century fashion and design. The author is ongoing working on this research as part of her Doctoral research project at University of Florence, and she’s planning to continue the study further to better, and deeply, understand the possibilities of digital tools to improve the fashion design process and the cutting stage.

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Award Number: PE00000004, Concession Decree No. 1551 of 11/10/2022 adopted by the Italian Ministry of University and Research, CUP B83C22004890007. MICS (Made in Italy - Circular and Sustainable).
Spoke 2 Eco-Design strategies: from materials to Product Service Systems – PSS

References

Binotto, C., & Payne, A. (2016). The Poetics of Waste: Contemporary fashion practice in the context of wastefulness. *Fashion Practice,* *9*(1), 5–29. https://doi.org/10.1080/17569370.2016.1226604

Bui, L.T.C., Nguyen, H.T.T., Do, L.T., Huynh, T.V., Ta, T.D., Duong, A.T.B. (2025). The Advancement of Computer-Aided Design and Computer-Aided Manufacturing in the Fashion Apparel Industry: Toward a Sustainable Development. In: Nayak, R., Truong, H., Pal, R. (eds) Use of Digital and Advanced Technologies in the Fashion Supply Chain. *Springer Series in Fashion Business*. *Springer*, Singapore. https://doi.org/10.1007/978-981-97-7528-6_7

Busch, O.v. (2014). Fashion Hacking. In S. Yelavich & B. Adams (Ed.). *Design as Future-Making*, 47–57. London: Bloomsbury Academic. Retrieved October 20, 2024, from http://dx.doi.org/10.5040/9781474293907-0009

Choi, K. (2024). 3D digital technology in upcycling apparel design: the creation of a modular redesign system and designer perspectives. International *Journal of Fashion Design Technology and Education*, 1–14. https://doi.org/10.1080/17543266.2024.2413568

Choi, K. (2022). 3D dynamic fashion design development using digital technology and its potential in online platforms. *Fashion and Textiles,* *9*(1). https://doi.org/10.1186/s40691-021-00286-1

Glogar, M., Petrak, S., & Mahnić Naglić, M. (2025). Digital Technologies in the Sustainable Design and Development of Textiles and Clothing—A Literature Review. *Sustainability*, 17(4), 1371. https://doi.org/10.3390/su17041371

Gwilt, A., & Rissanen, T. (Eds.). (2011). *Shaping sustainable fashion : Changing the way we make and use clothes*. Taylor & Francis Group https://doi.org/10.4324/9780203126172

Herring, M. (2025) *Digital Threads: Fashion Design with Clo3D*. (Theses). 1242.https://digitalcommons.lindenwood.edu/theses/1242

Kabakibi, K., & Eriksson, L. (2023). *The role and use of 3D-simulations in fashion design* (Dissertation). Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-219732

Lee, H. (2023a). The Dual Strategy for Textile and Fashion Production Using Clothing Waste. *Sustainability,* *15*(15), 11509. https://doi.org/10.3390/su151511509

Lee, H. W. (2023b). Development of Sustainable Creative Three-Dimensional Virtual Woven Textiles Using Clothing Waste. *Sustainability,* *15*(3), 2263. https://doi.org/10.3390/su15032263

McQuillan, H. (2019). Hybrid zero waste design practices. Zero waste pattern cutting for composite garment weaving and its implications. *The Design Journal*, 22(sup1), 803–819. https://doi.org/10.1080/14606925.2019.1613098

Morandi, A. & Tonelli, C. (2023). *The Impact of 3D Technology on Sustainability in Fashion Luxury Product Design*. (Thesis) https://www.politesi.polimi.it/handle/10589/204494

Ramzan, M.B., Kanwal, A., Hussain, S.M., Manzoor, H., Zehra, H. (2024). Impact of Digitalization on the Construction of Garments. In: Khan, M.Q., Nawab, Y., Kim, I.S. (eds) *Garment Sizing and Pattern Making. SDGs and Textiles.* Springer, Singapore. https://doi.org/10.1007/978-981-97-7683-2_12

Rissanen, T., & McQuillan, H. (2018). Zero waste fashion design. Bloomsbury Visual Arts. DOI: 10.1111/fcsr.12255

Rissanen, T.(2007) Types of fashion design and pattern-making practice., Nordes 2007: Design Inquiries, 27-30 May, University of Arts, Craft, and Design, Stockholm, Sweden. https://doi.org/10.21606/nordes.2007.038

Salomè, M.A. (2024). Re-think. Re-design. Re-start: New Tools for a More Sustainable Fashion Design Process. In: Gambardella, C. (eds) *For Nature/With Nature: New Sustainable Design Scenarios. Springer Series in Design and Innovation* , vol 38. Springer, Cham. https://doi.org/10.1007/978-3-031-53122-4_49

Torres, A. (2024, February 13). Marion Baruch: Humans Made Textile Before writing. *Lampoon.* https://lampoonmagazine.com/article/2024/02/13/marion-baruch-exhibition-viasaterna-textiles-humanity/

Vrljanac, M., Šikman, K., Simić, M., Naumović, T., & Despotović-Zrakić, M. . (2023). Application of 3D Modeling in the Fashion Industry. *E-Business Technologies Conference Proceedings,* *3*(1), 176–184. Retrieved from https://ebt.rs/journals/index.php/conf-proc/article/view/172

Extended Abstract
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Circulating History; Design Agency and the case of Museum Uniforms.

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Keywords: Design for Circularity; Design for Longevity; Collaborative Design Processes; Circular Uniforms, Cultural Heritage of Textiles.

Introduction

The empirical data of this paper will showcase a series of workshops held with management and staff at a museum that ensured ownership of the process and willingness to engage with the development of a circular uniform concept. The paper will further showcase how how cultural heritage and historical circular practices stored in museum collections can help inform design for prolonging use phases (Hasling & Ræbild 2017).

Background and context

Rosenborg castle is a unique organization affiliated under the Royal Danish Collection that caretakes a series of Danish castles and exhibition spaces. In 2023, the research team and the management of Rosenborg together decided to develop a concept for circular uniforms, here understood as a collection wheel (Ræbild, 2015) that considers how the various elements fit the brief and offer opportunities for the circular principles of 9R (Kirchheiner, 2023). This contributes to existing literature on circular workwear and public procurement as a pivotal topic of inquiry within longevity research (see i.e. Huulgard et al, 2022; Petersen & Riisberg, 2016).

The brief had multiple constraints; it should match the existing budget; it should be sensitive to the cultural heritage and significance of Rosenborg; it should be adaptable to a variety of functional needs spanning from guards to custodians, conservation staff, museum sales staff, or educational staff for the school service; finally, it should include principles of layering since the castle itself has no heating system so that the temperature varies dramatically during seasons.

These constraints would require a high level of sensitivity to needs and ideas. Acknowledging how the success criteria of designers working with sustainability or circularity lies in their ability to nest their work at organizational level (Karell and Niinimäki 2020), the research team would need to facilitate common understandings and engagement in a collaborative design process (Friis, 2016; Binder & Brandt, 2018).

For this, a workshop toolbox was developed containing ‘boundary objects’ (Star, 2010), that is, visual and tactile artifacts through which participants can obtain shared understandings in design dialogues for opening what Schön (1983) names 'as-if-worlds' in iterative and abductive processes (Dorst, 2015). Based on this, three workshops were facilitated by the research team.

Workshop 1 - Staff

This workshop aimed to uncover staff experiences and visions regarding the uniforms' functionality and aesthetics. Participants were asked to take photos of their uniforms in use and bring worn uniforms illustrating practical challenges. The workshop included three key exercises:

Photo analysis and reflection: Staff were divided into groups (security and service personnel) to analyze their photos, identifying positive and negative aspects. These reflections, supported by visual materials, were shared with the larger group.

Visions for future uniforms: Groups discussed preferences regarding functionality, identity, maintenance, and gender considerations. Findings were documented on posters and presented in plenary.

Toolbox introduction: A dialogue tool consisting of garment sketches, color charts, and fabric samples was introduced. Groups used these materials to collaboratively design visual and conceptual prototypes, which were later shared and refined (see figure 1).

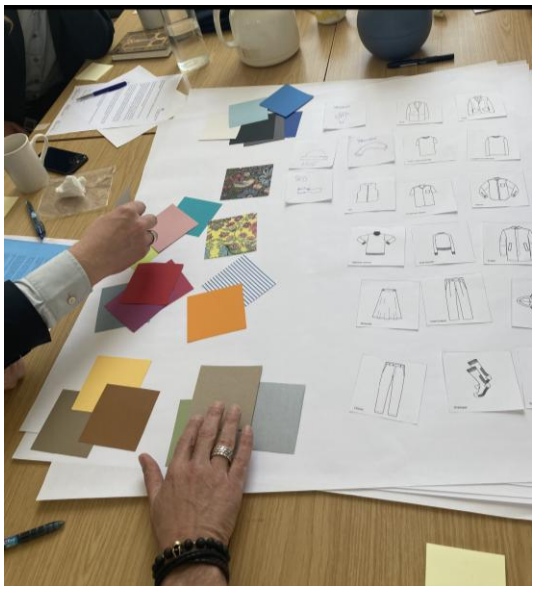


Figure 1. Staff working with the toolbox kit in workshop 1. © Rikke Stetter.

The insights from this workshop illustrated several issues regarding lack of functionality and comfort in the current staff uniforms. And, how staff members felt proud to work at the museum and wished to wear uniforms that better represented the heritage and values of Rosenborg with regards to aesthetics, stylistic references, and choice of materials.

Workshop 2 - Management

The second workshop focused on refining staff insights and exploring management's visions for the uniforms' symbolic and functional roles. Key activities included:

Presentation of staff input: Findings, including critique points and proposed ideas, were presented to management.

Visual identity exploration: Management worked with image cards of uniforms to investigate potential directions for the uniforms' aesthetics and symbolism. Footage from historical uniforms of Rosenborg were included, representing both aesthetic, functional and material aspects, as well as principles of circularity - i.e. traces of size adjustments, mending and repairs, decorative and replaceable ribbons for protection of wear and tear etc.. This process facilitated open discussions, enabling a shared understanding of the uniforms' role within the organization (see figure 2).



Figure 2. Image card from toolbox 2: a uniform worn by custodians at Rosenborg castle in the early 20th Century with visible traces of mending and adjustments in the lining. © Else Skjold.

Bringing staff insights together with various images of uniforms to the management group brought awareness of the fact that the Rosenborg collection of historical custodian uniforms holds manifold examples of ways in

which historical circular uniform concepts hold a multitude of inspiration for the aesthetics and functionalities required for a new concept.

Workshop 3 – Final presentation

This workshop had the purpose of ensuring alignment between research team and staff + management on aesthetic, practical, circular, and economical aspects of the uniform concept. For this the research team presented a full collection draft with material samples for suggested colors and fabric qualities, and a suggested concept for a dynamic and circular collection wheel that answered the initial brief. The concept displayed in a collection wheel (see figure 3), illustrates principles for multiple ownership between shifting staff employees, repair concepts, and considerations for how to ensure a secondary life for styles that leave the museum with the user, or because it is discarded. Several historical circular design principles were included such as i.e. how in the more expensive collection styles, the logo is stitched on hereby providing opportunity for resale without damaging the original garment.

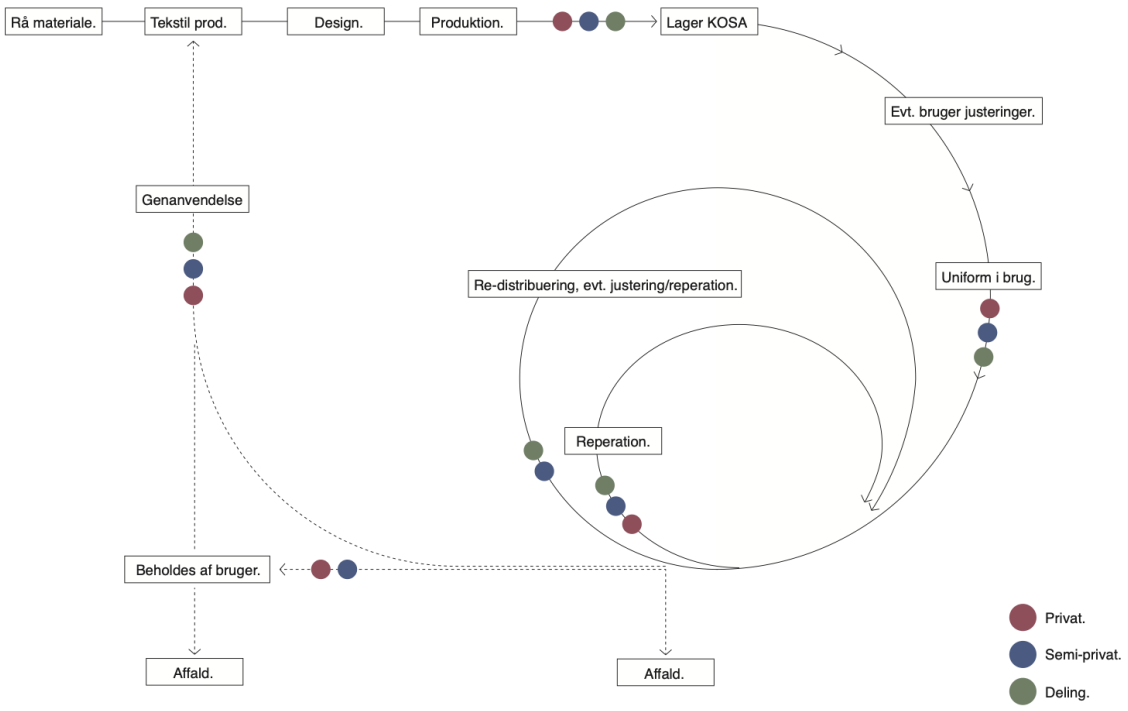


Figure 3. The circular uniform concept was introduced through this collection wheel © Kjetil Aas.

Conclusions

Through a series of workshops, supported by visual and tactile boundary objects, a foundation was established for developing a circular uniform concept that balances economic framework, practical needs, and cultural and organizational identity.

This highlights how designers can obtain more agency by being nested thoroughly within an organizational context, and it further showcases how historical textile collections at museums might inform circular design for longevity going forward.

Acknowledgments

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References

Binder, T., & Brandt, E. (2018). Hvad har design med samskabelse at gøre? Foggaard, M.K. and ongh, M. (Ed) *Ledelse og samskabelse I den offentlige sektor,* Dansk Psykologisk Forlag, p. 327-355.

Dorst, K. (2015). Frame creation and design in the expanded field. She Ji: *The journal of design, economics, and innovation*, 1(1), p. 22-33. DOI: 10.1016/j.sheji.2015.07.003

Friis, S.A.K. (2016), The 6C model. The contribution of design to open, complex, problem solving. *The International Journal of Design in Society,* 10(3), p. 13-30.

Huulgaard, R.D., Kristensen, H.S., Remmen, A. and Smink, C.K. (2022), Circular Public Procurement: A Case Study of Workwear and Laundry Services. Bals, L., Tate, W.L. and Ellram, L.M. (Ed) Circular Economy Supply Chains: From Chains to Systems, Emerald Publishing Limited, Leeds, p. 329-341. https://doi.org/10.1108/978-1-83982-544-620221017

Karell, E. & Niinimäki, K. (2020). A mixed-method study of design practices and designers' roles in sustainability-minded clothing companies. *Sustainability*, 12(11), 4680; https://doi.org/10.3390/su12114680

Kirchherr, J., Yang, N.N., Schulze-Spüntrup, F., Heerink, M.J. & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions. *Resources, Conservation and Recycling*. 194, 10700. https://doi.org/10.1016/j.resconrec.2023.107001

Petersen, T.B. & Riisberg, V. (2016). Pockets, Buttons and Hangers: Designing a New Uniform for Healthcare Professionals. *DesignIssues* 32(1), p.60-71.

Ræbild, U. & Hasling, K.M. (2019). Sustainable Design Cards: A Learning Tool for Supporting Sustainable Design Strategies. Niinimäki, K. (Ed) *Sustainable Fashion in a Circular Economy*. Lahti: Aalto ARTS Books ©Kirsi Niimäki and the authors, p. 128-151.

Ræbild, U. (2015). *Uncovering fashion design method practice. The Influence of Body, Time and Collection.* Unpublished doctoral dissertation. © Design School Kolding. DOI: 10.13140/RG.2.1.2432.6163

Schön, Donald A. (1983) *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books. https://doi.org/10.4324/9781315237473

Star, S.L. (2010). This is not a boundary object: Reflections on the origin of a concept. *Science, Technology & Human Values*, 35(5), 601-617. https://doi.org/10.1177/0162243910377624

Extended Abstract
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Analyzing Durability and Failures of Workwear Rain Jackets

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Keywords: Rain jacket; End-of-life; Durability; Functionality; Workwear.

Introduction

Rain jackets are common items included in technical workwear where the user is expected to spend some or most of their time outdoors, with the primary function to keep the wearer dry when working in rainy and wet weather. The form or design of workwear rain jackets is pre-determined based on roles, geographical location, job activities, size and gender and may have specific features such as reflectors, epaulettes, and radio loops. In common with consumer jackets, features such as breathability, waterproofing, and maintenance are important.

The end-of-life for a consumer rain jacket is often determined by wear and tear, functional degradation, design, color and component failure, whereas end-of-life of a workwear rain jacket often occurs at an earlier stage and may mark the end of service rather than an actual end-of-life. For example, features such as retroreflectors, which are common in workwear, are often subject to a maximum number of washing cycles (ISO, 2013). Sometimes, the features of the jacket cause a jacket to be retired early, but the actual garment may still be good to use.

According to the EU Textiles Strategy, by 2030 all textile products placed on the EU market should be durable, repairable, recyclable, and largely made from recycled fibers, free of hazardous substances, and produced in line with social and environmental standards (European Union, 2022). Procurement processes play a key role in the acquisition of rain jackets. The European Union's Green Public Procurement (GPP) for textiles, (Dodd & De Oliveira Gama Caldas, 2017) emphasizes durability and lifespan extension as essential factors in reducing the environmental impact of textiles, setting benchmarks on physical and functional durability.

Durability is particularly important in workwear, as it involves items that are subjected to challenging conditions in professional settings, and rain jackets are especially interesting in this regard as garments with high technical function, and a high purchase cost.

There are currently no universally agreed-upon methods or standards to quantify the durability of textiles, and the debate over how to test and assess durability continues. In this paper, we will consider how procurement processes, failure areas, and the determination of end-of-life workwear rain jackets affect the sustainability, durability and overall performance of these garments.

Methodology

A visual inspection protocol to assess the end-of-life of consumer rain jackets was developed by (Nilsson et al., 2024). In this study, additional criteria related to construction and technical features specific to workwear were incorporated, providing a structured framework for evaluating visible damage in workwear rain jackets. The inspection was performed using a five-point scale, with 1 representing poor, and 5 representing excellent condition.

Observable defects were then correlated with garment performance, through physical tests, including hydrostatic head, air permeability and water repellency measurements. These tests were also used to confirm the presence of a functional defect and its effect on jacket performance.

Results

38 Police rain jackets were collected from three different countries for analysis. The sample sizes varied, with 9 jackets from Country A, 4 from Country B, and 25 from Country C. The sample included 13 jackets with two-layer and lining construction, and 25 jackets with three-layer constructions.

Despite the different constructions of the tested jackets, we observed membrane delamination, as shown in Figure 1, left. Through delamination the garment has lost its primary functionality of waterproofness, and such a defect marks a definitive end-of-life for the product. Reflective elements, commonly present across many garments designed for workwear frequently showed signs of degradation and peeling, such as shown in Figure 1, right, which can be a contributing factor leading to early garment retirement. These garments are often still waterproof, so only part of the total garment functionality is lost, demonstrating the potential to extend service life through improved design.

Comparison criteria	Consumer Rain Jacket	Workwear Rain Jacket
Purchasing scenario	Individual's decision, based on budget and available options	Organizational decision based on tender; garment selected according to list of specifications
Investment in jacket	Involves personal money, knowledge, and trust	Funded by the organization, product is accepted as provided
Emotional connection	Often has an emotional connect	Often lacks emotional attachment
Functional features	Basic additional functional requirements	Requires more features based on job roles, e.g. radio loops and epaulettes
Wash, care and maintenance	Self-organized	Either self-organized or service provided by employer
Determination of end-of-life	Subjective, depends on individual preference	Based on service completion
Quality of product	Varies according to specifications	Fixed quality as per organizational standards

Table 1: A basic comparison of consumer and workwear rain jacket

Hydrostatic head and water repellency tests showed that visual wear did not always correlate with functional loss; some visibly damaged jackets remained waterproof, while others with minimal visible damage failed testing.

Table 1 shows some of the basic contrasts between consumer rain jackets, where the individual is highly invested in the product and workwear rain jackets, which are provided by employers, selected to meet workplace requirements within a predefined budget, and typically lack any emotional attachment from employees. Workwear rain jackets prioritize functional features and must meet fixed quality standards *(Swedish Institute for Standards, SIS, 2019)*



Figure 1-Left: Faded and Peeled Reflector Element | Right: Delaminated Coating

Conclusions:

Estimation of durability is an ongoing challenge in both consumer and workwear domains. This study identified a range of critical and non-critical failures in police rain jackets through visual inspection and physical testing.
We found that the visual inspection results do not always correlate with the physical tests carried out, highlighting that visual inspection alone cannot guarantee jacket performance. Critical failures significantly compromise the jacket's performance; while some of these failures such as broken zippers and sewn reflective elements are repairable or replaceable, they still pose challenges in maintaining the jacket's overall condition. Non-critical failures, while having minimal impact on the jacket's performance, may affect its visual integrity, which may affect its usability in certain roles. Interestingly, some jackets remained waterproof despite visible wear, improving technical specifications and garment design, particularly waterproofing and seam integrity, while repairing and replacing reflectors can enhance durability and reduce premature end-of-life.

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References

Dodd, N., & De Oliveira Gama Caldas, M. (2017). Revision of the EU Green Public Procurement (GPP) Criteria for Textile Products and Services: Technical Report with final criteria. https://doi.org/10.2760/906174

European Union. (2022). Sustainable and Circular Textiles by 2030. https://doi.org/10.2779/07199

ISO. (2013). High visibility clothing – Test methods and requirements (ISO 20471:2013, Corrected version 2013-06-01).

Nilsson, L., Björklund, A., Waller, J. H., & Bäckström, M. (2024). Is It Worth Buying a Second-Hand Shell Jacket? An Evaluation of Shell Jackets' Functionality and Price over Time. Sustainability, 16(8), 3451. https://doi.org/10.3390/su16083451

Swedish Institute for Standards, SIS. (2019). Standard—Protective clothing—Protection against rain SS-EN 343:2019—Swedish Institute for Standards, SIS. https://www.sis.se/en/produkter/environment-health-protection-safety/protective-equipment/protective-clothing/ss-en-3432019/

Extended Abstract
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Customer Engagement – When do Circular Business Models Pay Off?

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Keywords: Circular Business Models; Fashion Retail; Customer Engagement; Buy-Back

Introduction

The apparel industry is under increasing scrutiny for its linear business model, which rapidly depletes natural resources, drives overconsumption, and generates waste. The rise of fast fashion in recent decades has further exacerbated these challenges by accelerating production volumes, lowering price points, and shortening the average usage time of apparel (Coscieme et al., 2022; Niinimäki et al., 2020; Peters et al., 2021). This state of overproduction and overconsumption, where raw materials are assumed to be abundant (Kjellberg, 2008; Trudel, 2019), is causing irreversible damage to our ecosystem (Richardson et al., 2023; Rockström et al., 2009).

In response to growing awareness of the apparel industry's unsustainable practices, policymakers are emphasizing the urgent need for systemic change. In alignment with United Nations Sustainable Development Goal 12, the European Commission seeks to spearhead the sustainability transition by adopting circular economy principles. *The Strategy for Sustainable and Circular Textiles,* for example, introduces nearly twenty proposals to support the transition toward a circular textile economy (COM 141 final, 2022).

The Sustainability Dilemma of Circular Business Models

While the circular economy and the sustainability transition are closely linked, they are not interchangeable. Circular economy practices have a long history (Belk, 2014; Belk et al., 1988), yet the precise sustainability benefits of these practices remain contested (Geissdoerfer et al., 2016; Geissinger et al., 2019; Kirchherr et al., 2017; Köhler et al., 2019). The sustainability potential of circularity lies in decoupling value creation from waste generation and resource depletion. However, this outcome is not guaranteed, particularly when customer engagement is considered (Ackermann & Tunn, 2024; Geissinger et al., 2019; Parguel et al., 2017). Circular business models engaging the customer, such as buy-back and resale, could contribute to the sustainability transition if they effectively extend the lifespan of clothes and alter consumption patterns, ultimately decreasing demand for new production (Peters et al., 2021; Wiedemann et al., 2023). Yet, emerging research suggests that the availability of buy-back and resale may, paradoxically, accelerate consumption. This rebound effect is driven by an oversupply of goods at a lower price point, the urgency created by the unique availability of individual pieces, and the perception of resale as an attractive investment opportunity (Dion et al., 2024; Henninger et al., 2021).

With policy incentives and regulatory frameworks promoting a circular textile economy and previous research highlighting both its potential and limitations, a critical question arises: When do circular business models pay off - both in regards to sustainability transitions and being able to sustain the business?

Buy-back and Resale Models in Fashion Retail

A buy-back and resale model, in which retailers incentivize customers to return worn clothes by offering compensation, is an increasingly common circular business strategy in fashion retail. Retailers may offer discounts for returned items, which are then resold, upcycled, or recycled (Hvass & Rahbek Pedersen, 2019; Rahbek et al., 2018; Thorisdottir et al., 2024). Despite the growing interest in buy-back and resale, empirical insights remain scarce. This gap stems from a restricted data pool and difficulties in accessing relevant datasets (Hvass & Rahbek Pedersen, 2019; Nielsen & Skjold, 2024).

Method and Data

To address this challenge, we collaborated with a Nordic apparel retailer to examine customer engagement in buy-back programs. Our dataset consists of transaction-level data collected over a period of more than four years, spanning from January 1, 2020, to May 31, 2024. The introduction of the retailer's buy-back program took place in June 2021. During our period of analysis, we observe 367,097 purchases made by 177,007 distinct customers.

Table 1: Descriptive Statistics for Orders

	Regular customer	*Buy-back customer*
Sales, €	169	182
Sales, units	2.41	2.60
Returns, €	44	55
Returns, units	0.52	0.63
N, customers	175,990	1,017
N, orders	357,747	9,350

The descriptive statistics in Table 1 show that only a minor fraction of customers have engaged in the buy-back program since its inception (1,017 customers or 0.6%). However, order values are 8% higher for buy-back customers (€182) compared with all other (regular) customers (€169). With an overall return rate of 26% of the order value, the retailer experiences moderate return rates. We remark though that buy-back customers exhibit a slightly higher return rate, returning approximately 30% of the order value. Interestingly, buy-back customers exhibit a much higher order frequency, placing an average of nine orders compared with just two orders for regular customers over the analysis period. This indicates that customers engaging in the buy-back program may differ considerably from the average customer. Since this may cause bias from self-selecting into treatment (i.e., engaging in the buy-back program), we apply a rolling matching approach (Unal & Park, 2023). This technique lets us overcome the difficulties of different pre- and post-treatment periods as suitable control customers are matched to the treated at the time of treatment, which provides a fairer comparison between customers participating in the take-back program with those who do not.

We identify suitable control customers for 799 out of the 1,017 buy-back customers (79%) in our data. This is because, for many of the customers engaging in the program, we do not observe any subsequent purchase activity. We then applied a fixed effects panel regression model to examine changes in purchase behavior between the treated and control customers. The results of this analysis are shown in Table 2 below.

Table 2: Regression Results

	Sales (€)	*Returns (€)*
Treatment	-76.97***	-41.36**
Constant	756.85	217.05
N, observations	1,598	1,598
R^2	0.82	9,350

Note: ***p<0.01; **p<0.05

Discussion

Contrary to previous literature, our preliminary findings indicate that customers reduce their spending by an average of €76.97 after participating in the retailer's buy-back program, even after accounting for any discounts. Additionally, returns decreased by, on average, €41.36. Forthcoming analyses explore potential explanatory factors, such as customer heterogeneity, to identify conditions under

which buy-back programs in general may reduce overall consumption. In our case, allowing customers to sell back worn items through a buy-back program could potentially extend product lifespans and lower the demand for newly produced items.

References

Ackermann, L., & Tunn, V. S. C. (2024). Careless product use in access-based services: A rebound effect and how to address it. *Journal of Business Research*, *177*, 114643. https://doi.org/10.1016/J.JBUSRES.2024.114643

Belk, R. (2014). You are what you can access: Sharing and collaborative consumption online. *Journal of Business Research*, *67*(8), 1595–1600. https://doi.org/10.1016/J.JBUSRES.2013.10.001

Belk, R., Sherry, J., & Wallendorf, M. (1988). A Naturalistic Inquiry into Buyer and Seller Behavior at a Swap Meet. *Journal of Consumer Research*, *14*(4), 449–470. doi:10.1086/209128

COM 141 final. (2022). EU Strategy for Sustainable and Circular Textiles. In *European Commission* (52022DC0141). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0141

Coscieme, L., Akenji, L. A., Latva-Hakuni, E., Vladimirova, K., Niinimäki, K., Nielsen, K., Henninger, C., Joyner-Martinez, C., Iran, S., & D´Itria, E. (2022). *Unfit, Unfair, Unfashionable: Resizing Fashion for a Fair Consumption Space*.

Dion, D., Pavlyuchenko, R., & Prokopec, S. (2024). The Enrichment Economy: Market Dynamics, Brand Strategy, and Ethics. *Journal of Marketing*. https://doi.org/10.1177/00222429241275 01

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2016). The Circular Economy - A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geissinger, A., Laurell, C., Öberg, C., & Sandström, C. (2019). How sustainable is the sharing economy? On the sustainability connotations of sharing economy platforms. *Journal of Cleaner Production*, *206*, 419–429. https://doi.org/10.1016/J.JCLEPRO.2018.09.196

Henninger, C. E., Brydges, T., Iran, S., & Vladimirova, K. (2021). Collaborative fashion consumption – A synthesis and future research agenda. *Journal of Cleaner Production*, *319*, 128648. https://doi.org/10.1016/J.JCLEPRO.2021.128648

Hvass, K. K., & Rahbek Pedersen, E. (2019). Toward circular economy of fashion Experiences from a brand's product take-back initiative. *Journal of Fashion Marketing and Management*, *23*(3), 345–365. https://doi.org/10.1108/JFMM-04-2018-0059

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/J.RESCONREC.2017.09.005

Kjellberg, H. (2008). Market practices and over-consumption. *Consumption Markets & Culture, 11*(2), 151–167. https://doi.org/10.1080/10253860802033688

Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., Mcmeekin, A., Mühlemeier, M. S., … Wells, P. (2019). *An agenda for sustainability transitions research: State of the art and future directions.* https://doi.org/10.1016/j.eist.2019.01.004

Nielsen, M. D., & Skjold, E. (2024). Does resale extend the use phase of garments? Exploring longevity on the fashion resale market. *International Journal of Sustainable Fashion & Textiles*, *3*(The Future of Sustainable Clothing Use Practice), 29–48. https://doi.org/10.1386/SFT_00038_1

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews: Earth and Environment*, *1*, 189–200.

https://doi.org/10.1038/s43017-020-0039-9

Parguel, B., Lunardo, R., & Benoit-Moreau, F. (2017). Sustainability of the sharing economy in question: When second-hand peer-to-peer platforms stimulate indulgent consumption. *Technological Forecasting and Social Change*, *125*, 48–57. https://doi.org/10.1016/J.TECHFORE.2017.03.029

Peters, G., Li, M., & Lenzen, M. (2021). The need to decelerate fast fashion in a hot climate - A global sustainability perspective on the garment industry. *Journal of Cleaner Production*, *295*, 126390. https://doi.org/10.1016/J.JCLEPRO.2021.126390

Rahbek, E., Pedersen, G., Wencke Gwozdz, Kerli, & Hvass, K. (2018). Exploring the Relationship Between Business Model Innovation, Corporate Sustainability, and Organisational Values within the Fashion Industry. *Journal of Business Ethics*, *149*, 267–284. https://doi.org/10.1007/s10551-016-3044-7

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., … Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, *9*(37). doi: 10.1126/sciadv.adh2458

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., De Wit, C. A., Hughes, T., Van Der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. https://doi.org/10.1038/461472a

Thorisdottir, T. S., Johannsdottir, L., Rahbek, E., Pedersen, G., & Niinimäki, K. (2024). Social, environmental, and economic value in sustainable fashion business models. *Journal of Cleaner Production*, *442*, 141091. https://doi.org/10.1016/j.jclepro.2024.141091

Trudel, R. (2019). Sustainable consumer behavior. *Consumer Psychology Review*, *2*(1), 85–96. https://doi.org/10.1002/arcp.1045

Unal, M., & Park, Y. H. (2023). Fewer Clicks, More Purchases. *Management Science*, *69*(12), 7317–7334. doi:10.1287/mnsc.2023.4716

Wiedemann, S. G., Clarke, S. J., Nguyen, Q. V, Cheah, Z. X., & Simmons, A. T. (2023). Strategies to reduce environmental impacts from textiles: Extending clothing wear life compared to fibre displacement assessed using consequential LCA. *Resources, Conservation & Recycling*, *198*, 921–3449. https://doi.org/10.1016/j.resconrec.2023.107119

Extended Abstract
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Modular Fashion: Sustainable Potential and Challenges for the Industry

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Keywords: Modular fashion; Modular design; Sustainable fashion; Longer garment lifetime.

Introduction

With increasing discussion about rethinking and redesigning the fashion system toward a transition to a circular economy, incorporating modularity in fashion design is gaining attention as a creative and promising possibility (Fletcher & Grose, 2012; Vaid, 2021; Sahimaa et al.,2023). Modular design in fashion not only could bring a sustainable potential for extending garment longevity through versatility (Fletcher & Grose, 2012; Gwilt & Pal, 2017) but also may offer the possibility of a systematic transition from complete garments to detachable clothing parts, thus, meeting diverse needs while reducing consumption (Zhang et al., 2024). Modular garments are clothing assemblages composed of individual and detachable garment modules (e.g., sleeves, main bodies and hoods) that are connected through closure interfaces (e.g., zips, buttons and ribbons). To accommodate a systematic development of modular garments, modular fashion (MF) is proposed accordingly as a business model featuring modularity throughout all garment lifecycles (Zhang et al., 2024).

Due to the modular structure, individual garment modules can be washed and repaired separately, adapted for different occasions and even mixed and matched or reused (Chen & Li, 2018; Fletcher & Grose, 2012). Thus, MF could potentially reduce washing frequency, simplify repairs through module replacement, and meet consumers' evolving needs of being fashionable and on-trend through mixing and matching individual components (Fletcher & Grose, 2012; Gwilt &Pal, 2017; Zhang et al., 2024). Therefore, MF is seen as a sustainable strategy that could potentially extend garments' longevity and reduce overall consumption by encouraging customers to consume and dress in a modular manner (Zhang et al., 2024). Additionally, it is even indicated as "the next big thing" to reshape the fashion industry toward a sustainable fashion future (Vaid, 2021).

Yet, it is still unknown to what extent MF can be an effective sustainable initiative and/or alternative and how it may affect the industry's future. Maldini and Balkenende (2017) suggest the need for verifying sustainable initiatives like MF to move the research toward the empirical level, such as studying long-term buying behaviours of consumers engaging with modular dressing manners. While it is critical, it is premature and challenging to validate such behaviours, given that MF is not yet widely adopted. Meanwhile, as a potential pathway for systematic transition, modularity is more than a shift in consumer purchase decisions and behaviour. Such a radical change necessitates a fundamental mindset shift among all other actors in the fashion industry, from designers, suppliers and manufacturers to retailers (Seixas et al., 2021). This crucial perspective is lacking and addressed within this research, which focuses on the industry's perceptions to explore the sustainable potential and industry challenges of MF. This study aims to provide novel insights into the systemic challenges and opportunities of MF through the lens of industry, contributing to a deeper understanding of MF and its broader implications for shaping a sustainable fashion system.

Methods

This study is exploratory as it seeks to understand industry experts' perceptions of MF in terms of sustainable potential and especially challenges and barriers to its adoption. This is an ongoing project, which study started in April 2024 and aims to purposively recruit twelve experts online, each with a minimum of two years of work experience in the fashion industry,

to conduct in-depth semi-structured interviews. A pre-prepared interview guide is used, with questions developed around themes identified from the literatures, including complexity and sustainability. To ensure a shared understanding of MF between each interviewee and the researcher, Figure 1 is presented for explanation before any questions are asked. All interviews are audio recorded, transcribed and analysed using thematic analysis on NVivo. Initial *a priori codes* were created. Discrepancies were discussed and a coding protocol established that allowed themes to be categorized.

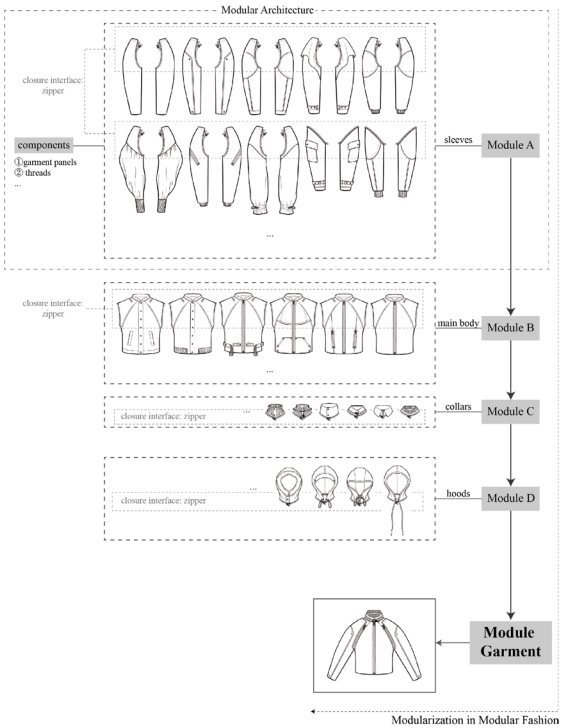


Figure 1. Image used in the semi-structured interview to provide a visual explanation of MF. (Source: Zhang et al., 2024, p.6).

So far, six semi-structured interviews, each lasting a minimum of 50 minutes, have been conducted. Table 1 is a summary of the data collection and showcases the diverse expertise of the participants, including fashion designers with experience in modular design, manufacturers, and retailers.

Participant ID	Occupation	Expertise
P1	Fashion designer	*Individual designer with 5+ years of industry experience & MF experience*
P2	Fashion designer	*Employed at a well-known fashion company with 2+ industry experience & MF experience*
P3	Operation Direction	*with 25+ years of industry experience*
P4	CEO of a sustainable fashion consultancy	*with 20+ years of industry experience in manufacturing*
P5	Academic	*with 3+ years of industry experience in design and retailing*
P6	Academic	*with 30+ years of industry experience from design, retailing to manufacturing*

Table 1. Summary of Participants.

Findings

Sustainable Potential

When asked to provide their initial impression after being shown Figure 1 and explaining the idea of MF, interviewees indicated that “it's a brilliant idea…if it can be done. I think the idea […] being able to […] create, um, something that's unique to the individual and even beyond doing that, being sustainable” (P5). Overall, data from these six semi-structured interviews suggest that MF is a creative, interesting and customisable novel concept that has sustainable potential through its modular structure. This early finding aligns with the theoretical assumptions regarding the sustainable potential of MF because of its interchangeability.

Industrial Challenges

Although data highlight the sustainable potential of MF and its commercial value to varying degrees, it also reveals multiple challenges in its industrial adoption. These are mainly caused by the complexity of modular design, a common concern expressed by all six interviewees.

Designers feel that modular design conflicts with the creative experiment process, emphasising that "we expect designers to experiment and to identify through play […] not pre-planning […] if you want to conceptualise the modularity […] it needs rules that have to follow in the design process" (P1). Manufacturers indicate that it brings challenges of ensuring compatibility across garment modules, which requires a longer developing process and more sewing time "to (be) 100% sure that what you've put together is going to work […] and look really good at every size" (P3). Retailers think MF could be an interesting marketing strategy, but it is risky due to the unclear consumer attitudes and higher costs compared to conventional clothing.

The initial findings reveal that these challenges primarily fall into three areas: early adopters (Table 2a), the design stage (Table 2b), and the production stage (Table 2c). This reflects the inherent complexity involved in designing modular systems (Baldwin & Clark, 2000).

Angle of View: **Early Adopter (mainly due to the complexity of MF)**	
Theme	*Explanation (partial)*
Market uncertainty & consumer engagement	• uncertainty about market acceptance • costumers might get bored with the modular dressing one day
Insufficient motivation	• lack of awareness from brands (benefits of MF) • market pressure is not huge enough (consumer still buy anyway)
Higher costs and risk of profit reduction	• interests prefer to protect profits over sustainability • higher cost of developing and manufacturing (complex and longer process)

Table 2a: Emerging themes concerning early adopters.

Angle of View: **Design (more challenging and complex design)**		
Theme		*Explanation (partial)*
Creative design with an engineering mindset		• Conflict: design experimentation & pre-planning (MF) • precise planning, measurement and design for compatibility(pattern) • to design thoughtful, effortlessly and very beautiful
Initial Design Stage	**Segmentation and garment module design**	• category and design garment modules reasonably (quantity and silhouette, cost) • design garment module in a flattering shape and size
	Optimised design in closure interface	• hard to make perfect choice for closure interface
Mid-Design Stage	**Complexity in material sourcing and compatibility**	• suitable materials to be able be puzzled together • complexity in the fabric shading when puzzling
	Versatile and compatible design	• create versatile pieces across collections
	Increased complexity in team communication	• add complexity for team communication
	Balancing creativity, wearability and inclusivity	• difficult to be wearability, practicality and comfort & playfulness • build modular fashion system with inclusive size • standardise length help anticipate size but don't guarantee fit
Later Design Stage	**Creativity constraints post-system setup**	• restrict designers' creativity after the system is built

Table 2b: Emerging themes concerning design.

Angle of View: **Production (is able to produce but might reluctance to alter)**	
Theme	*Explanation (partial)*
Higer operational costs	• a risk of upscaling and scaling • might cost more than profit if make change
Greater skills and effort required	• more manufacturing skills needed • too much extra work dealing with complex pattern and sizes to ensure right fit
Reluctance to change (status quo bias)	• might resist change to maintain contracts and suit designers
insecurity about employability	• conflict between less production and employability

Table 2c: Emerging themes concerning production.

Conclusions

This study explores the sustainable potential and challenges of MF from the viewpoints of industry experts through empirical data collected by semi-structured interviews. By moving the discussion toward the empirical level, it extends existing research on MF. Early findings reveal that despite recognition of its sustainable potential, MF adoption faces some hurdles, mainly due to the complexity of modular design itself. Challenges have been identified in three key areas: early adopters, the design stage, and the production stage. At present, the findings are based on only six semi-structured interviews. It suggests that fashion designers take a significant role in MF development throughout all stages. Future research could explore consumer perceptions to encourage early adoption and explore identified challenges to address the complexities of modular design in fashion.

References

Baldwin, C. Y. (2000). *Design rules, Volume 1: The power of modularity*. MIT Press.

Chen, Y., & Li, M. M. (2018). Modular design in fashion industry. *Journal of Arts and Humanities,* 7(3), 27-32.

Fletcher, K. (2012). *Fashion and sustainability: Design for change.* Laurence King.

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational research methods,* 16(1), 15-31. https://doi.org/10.1177/1094428112452151

Gwilt, A., & Pal, R. (2017). Conditional garment design for longevity. In *PLATE: Product Lifetimes And The Environment* (pp. 149-153). IOS Press. http://doi.org/10.3233/978-1-61499-820-4-149

Maldini, I., & Balkenende, A. R. (2017). Reducing clothing production volumes by design: a critical review of sustainable fashion strategies. *PLATE: Product Lifetimes And The Environment*, 233-237. http://doi.org/10.3233/978-1-61499-820-4-233

Sahimaa, O., Miller, E. M., Halme, M., Niinimäki, K., Tanner, H., Mäkelä, M., ... & Hummel, M. (2023). The only way to fix fast fashion is to end it. *Nature Reviews Earth & Environment*, *4*(3), 137-138. https://doi.org/10.1038/s43017-023-00398-w

Seixas, S., Montagna, G., & Félix, M. J. (2021). Materials matters in textile and fashion design education. In *Advances in Industrial Design: Proceedings of the AHFE 2021 Virtual Conferences on Design for Inclusion, Affective and Pleasurable Design, Interdisciplinary Practice in Industrial Design, Kansei Engineering, and Human Factors for Apparel and Textile Engineering, July 25-29, 2021, USA* (pp. 681-688). Springer International Publishing. https://doi.org/10.1007/978-3-030-80829-7_84

Vaid,M. (2021, June 30). *Modular Fashion – the next big thing?* Ecotextile News. https://www.ecotextile.com/2021063028006/features/modular-fashion-the-next-big-thing-2.html

Zhang, X., Le Normand, A., Yan, S., Wood, J., & Henninger, C. E. (2024). What is modular fashion: Towards A Common Definition. *Resources, Conservation and Recycling*, *204*, 107495. http://dx.doi.org/10.1016/j.resconrec.2024.107495

Digital Longevity



Research paper
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Navigating Trends and Ecological Sustainability Needs in Germany and Europe's ICT Industry

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Keywords: ecological sustainability; information and communication technology (ICT); microelectronics; trends; energy efficiency.

Abstract: The Information and Communication Technology (ICT) industry significantly impacts the environment across various life cycle stages, including material sourcing, energy use, and waste. To mitigate these effects, the German Ministry for Education and Research established the Competence Center Green ICT @ FMD, focusing on applied research to reduce the environmental footprint of ICT technologies. This paper identifies five emerging areas within the microelectronics sector that are key for ecological sustainability and the economic future in Germany and Europe to address the negative environmental impact of the rapidly growing demand of ICT: (i) Circularity in microelectronics, (ii) Green data centers, (iii) Green power electronics, (iv) Green quantum technologies, and (v) Green procurement and supply chains. These areas were identified through a systematic approach involving surveys, expert interviews, roadmap analysis, literature review, and market research. Criteria such as geographical relevance, time-related relevance and leverage were used to assess the feasibility of each area. Circularity in microelectronics addresses resource efficiency and product lifetime extension, while green data centers focus on hardware, software, and infrastructure optimization to reduce environmental impact. Green power electronics aims to enhance energy efficiency in critical sectors like electromobility and data centers. Green quantum technologies explore innovative applications in sensors and chemical processes, and green supply chains emphasize reducing CO_2 emissions throughout value chains.

Introduction

The information and communication technology (ICT) industry is one of the fastest growing industries and is linked to numerous environmentally critical aspects across all life cycle stages (OECD, 2024). These include the sourcing of critical raw materials, the use of toxic substances, as well as water, resource, and energy consumption during production. Moreover, significant energy consumption during the usage phase and a lack of recyclability contribute to non-compliance with circular economy principles.

To reduce the environmental impact of ICT, the German Ministry for Education and Research established the Competence Center *Green ICT @ FMD*[1]. The center's current focus is on conducting applied research to reduce the carbon footprint and environmental impact of sensor, edge computing, and cloud systems, communication infrastructures, and the production of microelectronic components. Nevertheless, many other technologies fall under the umbrella of ICT, and there are numerous tangential topics of future relevance that are not yet addressed by the competence center. Therefore, an additional key task of the competence center is to identify emerging areas of interest beyond the three already mentioned, to ensure long-term sustainability and innovation in these sectors.

In this paper we introduce five emerging areas in the context of microelectronics and evaluate their feasibility based on different criteria, such as industrial demand and leverage in Germany or Europe, and ecological urgency.

[1] https://greenict.de/en/

Methods

To identify the topics, we conducted different steps, summarized as follows:

1. Development of a Questionnaire
2. Expert Interviews and Roadmap Analysis
3. Identification of Emerging Topics
4. Literature Review, Market Research, and screening of Funding Programs
5. Evaluation of the findings
6. Validation with Experts

We first created a comprehensive questionnaire to assess the current structure in the competence center and ensure demand-driven development aligned with industry needs. This questionnaire evaluated the relevance of the current three topics sensor, edge and cloud systems, communication infrastructures and microelectronics production. The survey includes additional elements to identify further topics, for instance on which inquiries were received from the industry, but could not be covered by the current research focus. Also, we included future research topics that the consulted experts suggested emerging from their current research fields.

In the second step, we conducted interviews with industry and academic experts. The interview was supplemented by a composed questionnaire. Additionally, we reviewed green ICT-relevant roadmaps specified to microelectronics to align with future trends and opportunities.

Insights from the questionnaires, expert interviews, and roadmap analysis were consolidated to identify key topics requiring attention in sustainable ICT microelectronics.

After specifying our key areas, we conducted a literature review and market analysis to break down the identified topics into subtopics.

The identified topics and subtopics were evaluated based on their feasibility within the existing technological and industrial environment. Criteria included industrial demand, ecological urgency, and ecological potential. This evaluation was based on our findings from market research, literature review and an additional screening of funding programs on the German and European level.

In a last step, we verified the completeness of the identified topics and subtopics through consultations with additional experts in the respective fields. This step ensured a comprehensive assessment.

Results

We identified five key emerging areas in the microelectronics sector: (i) circularity in microelectronics, (ii) green data centers, (iii) green power electronics, (iv) green quantum technologies, and (v) green supply chains. The areas and their assessment in terms of geographical and temporal relevance and leverage are summarized in Table 1 and discussed further in the following sections.

Area	Time relevance	Geographical relevance (GER, EU)	Leverage
Circularity in Microelectronics	**very high**	**very high**	**very high**
Circular design approaches			
Reduction of chemicals, gases, energy and materials			
Reduction & substitution of chemicals, gases and materials			
Ultrapure Water reuse and recycling			
Reliability			
Extension of product and component lifetime through reuse, repair, refurbishment and remanufacture			
Recycling			
Green Data Centers	**very high**	**high/very high**	**high**
CPU			
GPU			
AI-Acceleration			
Advanced Packaging & Memory			
Alternative storage medium			
Chip-Level-Cooling, Board-Level-Cooling			
Neuromorphic Computing			
Load Managment			
Virtualisation			
Power & performance measurment and benchmarks			
Water consumption			
Waste heat utilisation			
Alternative cooling technologies			
Power supply units			
Green Power Electronics	**high**	**very high**	**high**
Increasing power density through miniaturisation by using WBG and UWBG semiconductors			
Further development of ultra-low-power circuit technologies			
New circuit concepts and topologies			
New components and circuit architectures for the efficient support of AI algorithms			
New packaging			
Cognitive power electronics			
Alternative cooling technologies - direct liquid cooling			
Life cycle assessment, eco-design, cycle management and increased reliability			
Green Quantum Technologies	**medium**	**high**	**medium**
Q-accelerators can be used in data centers (QC-HPC) and possibly Q-coprocessors			
Hardware-Software Co-Design			
Life cycle assessment			
Upgradeable Hardware infrastructure (QPU) and reusable peripherals			
Substitution of toxic materials and components			
Closed cryogenic cooling circuits			
Green Procurement and Supply Chains	**high**	**high**	**high**
Quantification of GHG emissions from materials, components and systems along the value chain			
Evaluation of emission reduction options, e.g. energy efficiency & material reduction potentials			
Determination of measurable and achievable improvements through eco-design			

Table 1. Identified Key Areas and Their Time-Related Relevance, Geographical Relevance, and Leverage.

Circularity in Microelectronics

Circularity in microelectronics encourages the efficient use of resources by extending the product and component lifetime through reuse, repair, refurbishment and recycling at the end-of-lifetime. It also encompasses circular design approaches, increasing material efficiency and minimizing environmental impact throughout the entire value chain.

Integrated circuits (ICs) are among the most environmentally critical components in ICT, as

their production is energy-intensive and involves numerous toxic chemicals (Boyd, 2011). As an example of circular economy practices within the ICT sector, the reuse of ICs represents a notable opportunity to reduce the environmental footprint of chip manufacturing. Due to the significant economic value of ICs, reuse provides a technique to prolong the lifespan of valuable components while also easing constraints on semiconductor supply chains. Nevertheless, further research is necessary to advance recovery technologies and standards, conduct a comprehensive life cycle assessment as well as to establish appropriate market incentives, in order to facilitate the reuse of ICs (Stoddard, 2024).

If lifetime extension is not possible, responsible disposal and recycling are essential to recover valuable materials (e.g. copper and palladium). Although ICs play an extensive role as they contain valuable and critical materials, it is also important to consider other parts of ICT devices. This will help to mitigate the impact of the growing demand for ICT and reduce overall material consumption, while taking into account the criticality of these materials in terms of their strategic importance and scarcity, as outlined in the list of critical raw materials (European Commission, 2025). However, e-waste is a highly complex and heterogeneous waste. At present, only a few precious elements present in integrated circuits are recovered by current recycling techniques, such as silver, gold, palladium and copper (Umicore, 2025).

Circularity is also crucial in ultrapure water (UPW) reuse and recycling to reduce the water footprint since major semiconductor factories require up to 99 million liters (L) of water per day for cooling and cleaning during manufacturing (TSMC, 2021, Den et al., 2018). Moreover, the development of more efficient material deposition processes, the utilization of more environmentally friendly chemicals, and the incorporation of exhaust gases or fluids within the fabrication process have the potential to address the significant impact of fluorinated gases in manufacturing, which account for 80–90% of direct emissions in industrial facilities and possess a high global warming potential (Raoux, 2021).

Recent technological advancements, including 3D printing for microelectronic devices and bio-based materials for packaging, are being investigated and developed with the objective of enhancing the circularity of ICT components (Zhang et al., 2025, Raskin et al., 2023). Nevertheless, it is essential to undertake additional fundamental and practical research on materials, in addition to conducting a comprehensive life cycle assessment.

In recent years, the European Union has implemented several legislative frameworks promoting circular economy practices such as the Circular Economy Action Plan (European Commission, 2025). To comply with these frameworks, the ICT sector must adopt circular economy approaches.

In addition to the present legislative pressures, it is inevitable that there will be an increased demand in the long term for the ICT sector to reduce its overall environmental impact throughout its entire value chain, in relation to the growing consumption of ICT (Wang and Chiu, 2014).

Overall, the issue of circularity in microelectronics is becoming increasingly important in order to address the scarcity of raw materials and the global dependency and bottlenecks on these resources in order to strengthen Europe's sovereignty.

Green Power Electronics

As electrification of the automotive and energy sectors will further play a key role in decarbonizing our society, power electronics will be crucial. Consequently, the power electronics market is projected to grow at a CAGR of 7%, increasing from a market value of $28.89 billion in 2023 to $35.7 billion by 2029 (Yole, 2024).

Power electronics involve various metallic raw materials such as aluminum and copper, presenting significant environmental improvement opportunities. Thus, currently a particular ecological focus lies on circular economy principles, emphasizing reuse and recycling, which result in reduced use of critical raw materials, extended product lifetimes and enhanced reliability (Huber et al., 2024, Sangwongwanich, 2024).

Another approach of reducing the use of new critical raw materials is via increasing material efficiency through miniaturization of wide bandgap (WBG) semiconductors, e.g. SiC and

GaN. The miniaturization of converter systems and increased power density enabled by these semiconductors lead to substantial savings in copper and aluminum (ECPE, 2018).

However, the selection of material poses a sustainability challenge. While silicon carbide (SiC) results in lower losses and energy consumption during use, its production is associated with significantly higher environmental impacts (Morra, 2024). At the same time, SiC and GaN devices are significantly more efficient in operation than silicon components (Mishra, 20239. Therefore, a comprehensive comparison of different technologies necessitates detailed life cycle assessments for accurate conclusions.

Promising technological trends in the long term, although still requiring further research, include ultra-wide bandgap semiconductors such as Ga_2O_3, AlGaN, AlN, or diamond (Xu et al., 2022). These materials exhibit excellent electrical characteristics but are not yet market-ready. Specifically, advancing research on switching characteristics of materials like Ga_2O_3 is essential to enable future competition with silicon (Si), SiC, or GaN (Yole, 2024).

Packaging in power electronics is also undergoing transformation. With decreasing semiconductor prices, the focus is shifting from the smallest chip size to other trends. This shift involves integrating functions into single components, especially for wide bandgap components, drivers, sensors, and capacitors, leading to new assembly and connection techniques.

Digitalization and artificial intelligence can facilitate cognitive power electronics concepts that expand traditional power electronic functions through new sensor and motor functionalities. This intelligent power electronics can lead to significant energy savings at the system level as functions of separate components are integrated into a single system (Köllner, 2024).

Overall, power electronics are an essential and well-established pillar of the European semiconductor industry, with 25% of global power electronics originating from Europe (Grand View Research, 2023). Therefore, the geographical and timely relevance is very high, as a sustainable transition of the power electronics markets can significantly enhance the competitiveness in the global market through innovation and ecological sustainability.

Green Data Centers

The rapid adoption of technologies like AI and 5G, along with an increase in digital services, is expected to significantly boost data volume in the coming years (IEA, 2024). This increase will lead to higher electricity consumption by data centers, with estimates indicating a 54% rise in energy use from 2023 to 2033 in Germany alone (Stobbe et al., 2024).

Green data centers require advancements in hardware, software, and infrastructure. Key hardware focuses include GPU, CPU, and AI (Yole, 2022) acceleration while software improvements should target load management and virtualization (Leiserson, 2020). Infrastructure considerations must address water consumption, waste heat utilization, cooling technologies, and energy supplies (Aslan et al., 2025)

Innovations in CPU acceleration are critical, with advancements like increasing core counts, new processor architectures, and modern memory technologies (e.g., DDR5 and PCIe5). Additionally, chiplets present potential benefits but face challenges due to non-standardized interconnects, necessitating research into application-specific connections.

The demand for AI accelerators is growing for both inference and training, driven by AI application and further technologies including photonics, neuromorphic, and quantum computing (McKinsey, 2024). For more efficient data transmission in AI applications, silicon photonics stand out for their ability to reduce energy consumption in data transmission (Yole, 2022).

In networking, the use of smart Network Interface Cards (NICs) and Data Processing Units (DPUs) is increasing, alongside the disaggregation of data centers through DPU processors and the deployment of passive optical and point-to-point networks.
In advanced packaging and memory, innovations such as Through Silicon Via (TSV), chiplets, and 2.5D-3D packaging are becoming essential as the pace of advancements slows (Yole, 2022).

As a notable amount of resource use and GHG emissions is due to the production of IT hardware (Busa and Hegemann, 2019), it is also key to focus on circularity aspects and product lifetime increasing measures for data centers and IT hardware (Hoosain et al., 2023). These include numerous circularity approaches including hardware refurbishment, component reuse, recycling of critical parts, and modular systems.
With increasing performance of computing systems, direct-to-chip cooling and board-level cooling strategies are being explored, focusing on waste heat utilization and energy harvesting (Brady, 2024, Forschungszentrum Jülich, 2024). On infrastructure level efficient waste heat utilization and alternative cooling methods, such as immersion cooling, are crucial (Hintemann et al., 2024, Geary, 2024).

Additionally, research into new storage solutions, including glass-based (Anderson, 2025), ceramic-based, and DNA-based storage technologies (Fraunhofer INT, 2020; Beil, 2021, is ongoing, potentially offering significant advantages in efficiency and capacity. Nevertheless, these technologies are currently not commercially available and still at an earlier technological readiness level (TRL).

Green data centers are increasingly important for Germany and the EU, as their geographical advantages attract more data center operators (Hintemann et al., 2024). Additionally, numerous regulations emphasize energy efficiency and climate neutrality commitments. Hence, focusing on green data centers is not only necessary to meet sustainability goals, it is also a locational advantage for Europe in global competition.

Green Quantum Technologies

The fourth area focuses on green quantum technologies. Potential applications for quantum technologies (QT) include the creation of more efficient sensing, simulation, computing and communication. The application fields for QT are diverse, encompassing navigation, precise measurements, data storage, material research, artificial intelligence, biotechnology, medical applications, as well as quantum cryptography and communication.
Quantum technologies are based on the principles of quantum mechanics, providing higher computing power and more energy-efficient operations compared to current computing.

The manufacturing of individual components and assembly processes for QT are energy and material intensive. Therefore, it is essential to develop sustainable solutions for the production and operation of quantum technologies to minimize environmental impacts. A more sustainable use could be achieved through the adoption of renewable energy sources and by optimizing the use of materials.
Opportunities for green quantum technologies include waste heat utilization, usage of more environmentally friendly chemicals and materials, energy efficiency, recycling, and cooling solutions.

The integration of quantum technologies with enabling technologies has the potential to yield substantial advancements. An optimized hardware-software co-design results in enhanced performance and energy efficiency of quantum technologies and their applications. Furthermore, Q-accelerators offer the potential to enhance performance and energy efficiency in data centers.

However, challenges remain. The energy accounting and predictions for future quantum technologies require a comprehensive understanding including life cycle assessment of the fundamental components and foundational technologies is required.

Quantum technologies are becoming increasingly important on a global scale (Riedel, 2019). The quantum computing market is expected to grow at a compound annual growth rate (CAGR) of 56.0% to USD 64,988.3 million between 2020 and 2030 (Research and Market, 2020). While this area is heavily dependent on the continued advancement of quantum technologies and their applications, it offers considerable potential for disruptive innovation (Coccia, 2022). Europe has a strong starting position in the global innovation competition, with half of all scientific publications and approximately 40% of researchers in the quantum computing field originating from Europe (VDI Technologiezentrum GmbH, 2022). To maintain Europe's current position in this cutting-edge sector, Europe must continue to invest in knowledge-based industry and technology. Given the anticipated operationality

of many QTs in the upcoming decades and the rise in financing for quantum innovation, now is a critical time to address ecological sustainability and influence the direction of quantum innovation (Root, 2025).

Green Supply Chains

The fifth area, focusing on environmentally friendly procurement and supply chains, involves quantifying greenhouse gas emissions and assessing opportunities for emissions reduction throughout the entire value chain. Sustainable procurement enhances transparency regarding the environmental impact of components and aids companies in making informed decisions about sustainable practices.

While there will be tremendous predicted growth of the ICT sector, it faces several challenges, including highly complex and opaque supply chains, resource planning under uncertainty, unpredictable fluctuations in demand, and global crises. In the microelectronics industry in particular, supply chains are highly complex, involving numerous players from all over the world. It is therefore essential to optimize the design of the logistics network and use environmentally friendly transport methods, even though these long-term measures require additional investment and may result in higher costs in the short term.

Supplier and material selection can help to increase transparency, mitigate risks, and ensure responsible production in the long term and can serve as an incentive mechanism for producers to manufacture under socially and environmentally better conditions. Increased transparency can further reveal opportunities for emissions reduction, through energy efficiency and material optimization.

Overall, green supply chains are becoming increasingly important due to the global supply chains of the microelectronics industry and regulatory obligations in the EU relating to ESG requirements and supply chains, such as the European Corporate Sustainability Due Diligence Directive (CSDDD) (European Commission, 2025, European Commission, 2024). Combined with circular economy approaches, green supply chains represent a key opportunity for environmental sustainability and help reduce dependence on raw material suppliers, contributing to Europe's technological sovereignty. As a result, both geographic and time relevance are considered high.

Conclusions

The ICT sector is growing rapidly, but also has a significant environmental impact that must be taken into account in all life cycle phases.

Our research emphasizes the importance of (i) Circularity in Microelectronics, (ii) Green Data Centres, (iii) Green Power Electronics, (iv) Green Quantum Technologies and (v) Green Supply Chains. While these areas have a particularly high potential for environmental improvements, they are also vital for Europe's technological sovereignty and competitiveness in the global market in the future. Therefore, it is essential to address both environmental and economic challenges.

To shape a more economically and ecologically sustainable future, it is particularly important to foster collaboration between industry, research organizations and policy makers in Europe to develop innovative solutions and create the necessary framework conditions. As many of these areas are interrelated, it will be crucial that different sectors collaborate on implementing sustainable practices and solutions.

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References

Anderson, P., Aranas, E., Assaf, Y., Behrendt, R., Black, R., Caballero, M., Cameron, P., Canakci, B., Chatzieleftheriou, A., Clarke, R., Clegg, J., Cletheroe, D., Cooper, B., Carvalho, T. de, Deegan, T., Donnelly, A., Drevinskas, R., Gaunt, A., Gkantsidis, C., Winzeck, S. (2025). Project Silica: Towards Sustainable Cloud Archival Storage in Glass. *ACM Transactions on Storage*, *21*(1), 1–31. https://doi.org/10.1145/3708996

Aslan, T., Holzapfel, P., Stobbe, L., Grimm, A., Nissen, N. F., & Finkbeiner, M. (2025). Toward climate neutral data centers: Greenhouse gas inventory, scenarios, and strategies. *IScience*, *28*(1), 111637. https://doi.org/10.1016/j.isci.2024.111637

Beil, L. (2021). *DNA-Speicher: Gigantische Datenmengen auf DNA*. https://www.ardalpha.de/wissen/speichermedien-der-zukunft-dna-speicher-daten-100.html

Boyd, S. B. (2012). *Life-Cycle Assessment of Semiconductors*. Springer New York. https://doi.org/10.1007/978-1-4419-9988-7

Brady, S. (2025, March 24). *Optimizing data center efficiency with direct-to-chip liquid cooling*. https://www.datacenterdynamics.com/en/opinions/optimizing-data-center-efficiency-with-direct-to-chip-liquid-cooling/

Bundesministerium für Arbeit und Soziales. (2023). *Supply Chain Act*. https://www.bmas.de/EN/Europe-and-the-World/International/Supply-Chain-Act/supply-chain-act.html

Busa, A., & Hegemann, M. (2019). *Life Cycle Assessment of Dell R740*. thinkstep.

Coccia, M. (2022). Disruptive innovations in quantum technologies for social change. *Journal of Economics Bibliography*, *9*(1), 21–39. https://doi.org/10.1453/jeb.v9i1.2287

Den, W., Chen, C.-H., & Luo, Y.-C. (2018). Revisiting the water-use efficiency performance for microelectronics manufacturing facilities: Using Taiwan's Science Parks as a case study. *Water-Energy Nexus*, *1*(2), 116–133. https://doi.org/10.1016/j.wen.2018.12.002

ECPE European Center for Power Electronics eV. (2018). *Topics & Trends*. https://www.ecpe.org/research/topics-trends/

Ernst, T., & Raskin, J.-P. (2023). Towards circular ICT: From materials to components. Advance online publication. https://doi.org/10.5281/zenodo.7462003

European Commission. (2024). *Corporate sustainability due diligence*. https://commission.europa.eu/business-economy-euro/doing-business-eu/sustainability-due-diligence-responsible-business/corporate-sustainability-due-diligence_en

European Commission. (2025). *Circular economy action plan*. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

European Commission. (2025). *Corporate sustainability reporting*. https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

European Commission. (2025). *Critical raw materials*. https://single--market--economy-ec-europa-eu.translate.goog/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en?_x_tr_sl=en&_x_tr_tl=de&_x_tr_hl=de&_x_tr_pto=sc

Forschungszentrum Jülich. (2024). *New Material Paves the Way to On-Chip Energy Harvesting*. https://www.fz-juelich.de/en/pgi/pgi-9/news/all-news/new-material-paves-the-way-to-on-chip-energy-harvesting

Fraunhofer INT. (2020). *DNA-Datenspeicher*.

Geary, B. (2024, March 6). Revolutionizing Data Center Sustainability: The Power Of Liquid Immersion Cooling Technology. *Forbes*. https://www.forbes.com/councils/forbestechcouncil/2024/03/06/revolutionizing-data-center-sustainability-the-power-of-liquid-immersion-cooling-technology/

Grand View Research. (2023). *Europe Power Electronics Market Size & Outlook, 2023-2030*. https://www.grandviewresearch.com/horizon/outlook/power-electronics-market/europe

Hess, J. C. (2024). *Chip Production's Ecological Footprint: Mapping Climate and Environmental Impact*. https://www.interface-eu.org/publications/chip-productions-ecological-footprint

Hintemann, R., Hinterholzer, S., & Progni, K. (2024). *Bitkom-Studie Rechenzentren in Deutschland: Aktuelle Marktentwicklungen – Stand 2024.*

Hoosain, M. S., Paul, B. S., Kass, S., & Ramakrishna, S. (2023). Tools Towards the Sustainability and Circularity of Data Centers. *Circular Economy and Sustainability*, *3*(1), 173–197. https://doi.org/10.1007/s43615-022-00191-9

Huber, J., & Kolar, J. W., Imperiali, L. (2024, September 9). *Circular Economy Compatible Power Electronics*. ETH Zürich. https://www.ams-publications.ee.ethz.ch/uploads/tx_ethpublications/workshop_publications/5_FEPPCON_Sustainability_Huber.pdf

International Energy Agency (Ed.). (2024). *Electricity 2024: Analysis and Forecast to 2026.*

Köllner, C. (2024, July 17). On the Road to Cognitive Power Electronics. *Springerprofessional.De*. https://www.springerprofessional.de/en/automotive-electronics---software/automotive-

industry/on-the-road-to-cognitive-power-electronics/27329494

Leiserson, C. E., Thompson, N. C., Emer, J. S., Kuszmaul, B. C., Lampson, B. W., Sanchez, D., & Schardl, T. B. (2020). There's plenty of room at the Top: What will drive computer performance after Moore's law? *Science (New York, N.Y.)*, *368*(6495). https://doi.org/10.1126/science.aam9744

McKinsey. (2024). *Generative AI: The next S-curve for the semiconductor industry?* https://www.mckinsey.com/industries/semiconductors/our-insights/generative-ai-the-next-s-curve-for-the-semiconductor-industry

Mishra, U. K. (2023, March 26). Gallium Nitride and Silicon Carbide Fight for Green Tech Domination. *IEEE Spectrum*. https://spectrum.ieee.org/silicon-carbide

Morra, J. (2024). *Figuring Out the Carbon Footprint of an Individual Chip*. https://www.electronicdesign.com/blogs/the-briefing/article/55089074/electronic-design-figuring-out-the-carbon-footprint-of-an-individual-chip

OECD (Ed.). (2024). *OECD Digital Economy Outlook 2024. The growth outlook of the ICT sector* (Volume 1). OECD Publishing.

Raoux, S. (2023). Fluorinated greenhouse gas and net-zero emissions from the electronics industry: the proof is in the pudding. *Carbon Management*, *14*(1), Article 2179941. https://doi.org/10.1080/17583004.2023.2179941

Research and Markets. Worldwide Quantum Computing Market (2019 to 2030) - Drivers, Restraints and Opportunities. *Research and Markets*. https://www.globenewswire.com/news-release/2020/04/06/2011932/0/en/Worldwide-Quantum-Computing-Market-2019-to-2030-Drivers-Restraints-and-Opportunities.html

Riedel, M., Kovacs, M., Zoller, P., Mlynek, J., & Calarco, T. (2019). Europe's Quantum Flagship initiative. *Quantum Science and Technology*, *4*(2), 20501. https://doi.org/10.1088/2058-9565/ab042d

Root, D. (2025). Quantum Technologies in the Context of Climate Change: Emphasizing Sustainability in a Responsible Innovation Approach to Quantum Innovation. *NanoEthics*, *19*(1). https://doi.org/10.1007/s11569-025-00468-x

Sangwongwanich, A., Stroe, D.-I., Mi, C., & Blaabjerg, F. (2024). Sustainability of Power Electronics and Batteries: A Circular Economy Approach. *IEEE Power Electronics Magazine*, *11*(1), 39–46. https://doi.org/10.1109/MPEL.2024.3356248

Stobbe, L., Nissen, N., Proske, M., Schulz, A., & Aslan, T. (2024, June 18 - 2024, June 20). Methodical Challenges of Prognostic Lifecycle Assessment - an Exemplary Study of ICT's Environmental Impact in Germany 2030. In *2024 Electronics Goes Green 2024+ (EGG)* (pp. 1–9). IEEE. https://doi.org/10.23919/EGG62010.2024.10631248

Stoddard, N., Peterson, L., Schaffer, M., Etheridge, T., Mathur, N., Morris, K. C., Laurin, L., & Ncube, A. (2024, June 18 - 2024, June 20). Towards Sustainable Electronics: Exploring IC Reuse for Circular Economy Transformation. In *2024 Electronics Goes Green 2024+ (EGG)* (pp. 1–8). IEEE. https://doi.org/10.23919/EGG62010.2024.10631235

TSMC (2021). TSMC 2021 Sustainability Report. https://esg.tsmc.com/download/file/2021_sustainabilityReport/english/e-all.pdf

Umicore. (2025). *E-scrap recycling I Precious Metals Refining*. https://pmr.umicore.com/en/recyclables/e-scrap/#:~:text=Umicore%20works%20with%20an%20assay-based%20settlement%20and%20typically,removing%20these%20fractions%20beforehand%20as%20much%20as%20possible

VDI Technologiezentrum GmbH. (2022). *Quantentechnologien*. https://www.quantentechnologien.de/qt-in-deutschland.html

Wang, C.-T., & Chiu, C.-S. (2014). Competitive strategies for Taiwan's semiconductor industry in a new world economy. *Technology in Society*, *36*, 60–73. https://doi.org/10.1016/j.techsoc.2013.12.002

Xu, M., Wang, D., Fu, K., Mudiyanselage, D. H., Fu, H., & Zhao, Y. (2022). A review of ultrawide bandgap materials: properties, synthesis and devices. *Oxford Open Materials Science*, *2*(1), Article itac004. https://doi.org/10.1093/oxfmat/itac004

Yole Intelligence. (2022). *Computing and AI technologies for data center 2022: Market and technology report*.

Yole Intelligence. (2024). *Status of the Power Electronics Industry 2024*.

Zhang, N., Wang, Z., Zhao, Z., Zhang, D., Feng, J., Yu, L., Lin, Z., Guo, Q., Huang, J., Mao, J., & Yang, J. (2025). 3d printing of micro-nano devices and their applications. *Microsystems & Nanoengineering*, *11*(1), 35. https://doi.org/10.1038/s41378-024-00812-3

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Digital Degrowth – From Rebound to Regeneration

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Keywords: Digital Rebound; Sustainable Digitalisation; Sufficiency; Twin Transition.

Abstract: Digitalisation plays a central role in the transition to more sustainable futures. However, it also has negative impacts, such as rebound effects, significantly undermining digitalisation's efficiency gains. Digital degrowth is a relatively new concept in discourses on sustainable digitalisation. Building forth on the concept of degrowth, first proposed in 1972 and gaining strength in the past 20 years, digital degrowth refers to realigning digital technologies to become regenerative; ecological sound and socially just, while simultaneously contributing to resource efficiency in digitalisation efforts. This exploratory paper reflects on digital degrowth and the rebound effects of digitalisation.

Introduction

Digitalisation is the application and use of digital information and communication technologies and includes devices, data centres, and the digital infrastructures that make their communication and networking possible. Digitalisation is widely seen as central to the transition to a more sustainable economy. This is especially clear in discourses on the *twin transition*, the coupling between the digital transition and the green (energy) transition. The two transitions are seen as mutually influencing each other, while the digital transition is perceived as an important enabler of the green transition (Dæhlen, 2023; Lange & Santarius, 2022).

At the same time, digitalisation is contributing to a "technological sprawl", the proliferation of digital devices and the growing demand for cloud computing and data centres (Fix, 2024). Natural resource use continues to grow on average by more than 2.3% per year (United Nations Environment Programme, 2024). The increasing application of artificial intelligence (AI) is resulting in rising energy demands because of data centre power needs. There are doubts that even the so-called green data centres can access enough non-fossil energy on time to meet their demand (O'Brien, 2024).

Digitalisation is thought to increase resource use efficiency, but rebound effects undermine these efficiency gains. The most common understanding of the rebound effect is increased consumption due to products and services becoming cheaper because of more effective resource use.

Based on a literature review, Lange and Berner (2022) identified 21 rebound mechanisms and 14 of them resulted in increased growth and, as a result, increased energy consumption, while none resulted in negative growth. On an economy-wide level, the authors implemented an econometric study using EU data to quantify the change in energy consumption due to rebounds, the so-called *growth rebound effect* (GRE). They estimate the GRE to be between 20% and 47% but believe that it is likely much higher. They conclude that the only way to prevent rebound effects is to implement rebound-proof policies that would initiate a post-growth economy.

Post-growth and degrowth are central concepts in proposals to address the ecological impacts of our economic system in the Global North. Degrowth is not a call for less economic growth but for less throughput, i.e., less energy and resources, to bring "the economy back into balance with the living world in a way that reduces inequality and improves human well-being" (Hickel, 2021b, p. 1106).

Degrowth is proposed to address a variety of rebound effects (Lange & Berner, 2022; Schneider, 2008; Sutherland, 2022). Rebound effects, lower-than-expected gains from efficiency policies and strategies, are also the result of efficiency improvements in digital technologies, so-called digital rebound. This paper explores whether digital degrowth is proposed as a strategy to counter digital rebound effects.

Digital Rebound

In a review of various studies, Coroama and Mattern (2019) conclude that "one of the main flaws of existing assessments [of the environmental impact of digital technologies] is their disregard of rebound effects". The concept of rebound was first mentioned in the context of coal in the 19th century and became known as the Jevon paradox, but has gained renewed attention in the 1980s and shows significant increase in research in the past 10 years (Lange et al., 2021). This has led to a deeper understanding of the different types of digital rebound effects.

Based on a literature review, Lange et al. (2021) developed a typology of rebound effects and mechanisms, consisting of four economic levels – *micro*, *meso*, *macro* and *global* – and two time frames – *short run and long run* (Lange & Berner, 2022). The effects can be direct or indirect:

- Direct rebound effect refers to the relationship between efficiency, price, and consumption. If the resource efficiency of a digital product increases, its price will decrease, which can lead to a rise in consumption. As a result, the efficiency gains are eroded by increased demand. For example, increased energy efficiency in blockchain hashing for bitcoin mining enabled miners to expand their operations tremendously (Fix, 2024). The Bitcoin mining network grew 90% in 2023 (CoinShares, 2024).

- Indirect rebound effects are the result of, for example, *consumer rebound*, savings from cost reductions enable more income to be spent on other products (Maxwell et al., 2011), *time rebound*, when the time saved through digitalisation is used on other resource-intensive activities (Coroamă & Pargman, 2020), and *skill rebound*, when digitalisation lowers the level of skill needed to perform an activity, making it accessible to larger groups of potential users who didn't have the necessary skill before (Coroamă & Pargman, 2020).

Kunkel and Tyfield (2021) argue that digital rebound should also be explored as a sociopolitical process. For example, Santarius and Soland (2018) explore rebound effects from a behavioural science perspective and identify a *motivational rebound* mechanism: "an increase in energy service demand due to a change in consumer preferences that can be attributed to an increase in technological energy efficiency".

While most of the research focuses on consumers and individual companies and microeconomic rebound mechanisms, mesoeconomic rebound focuses on how sectors and markets react to energy efficiency improvements (Santarius et al., 2018). What is called the *circular economy rebound* (Zink & Geyer, 2017) may fall under this category. Circular economy rebound is based on the understanding that repaired, used or refurbished digital products often don't compete in the same market as new products. For example, refurbished mobile phones which are sold to consumers in the Global South who would otherwise not be able to buy a phone.

Macro-level economy-wide rebound research focuses on national economies while global rebound research focuses on the global economy. Globally, one can identify a m*aterial rebound*, which is the result of digital technologies becoming smaller, but more resource intensive, as well as an increased production and use (Santarius, 2017). In addition, the more efficient a device becomes in its digitalisation performance, the less efficient it becomes in its material resource use (Valero et al., 2021). The idea that digitalisation would lead to dematerialisation never materialised (Taffel, 2024).

In the period 2013-2023, the digital economy grew about three times faster than the total economy across OECD countries as a result of further digitalisation and use of artificial intelligence, with an average growth rate of 7.6% in 2023 (OECD, 2024). The UN Trade and Development report on the digital economy (2024) describes an up to a four-fold increase in minerals demand in the period 2020 – 2025. Resource extraction for minerals needed to meet the growing demand for low-carbon technologies, such as graphite, lithium and cobalt, could see a production increase by nearly 500 per cent by 2050 (ibid.).

Data extractivism, the massive extraction and commodification of user data by private companies, is another driver of the digital economy. The never-ending quest for more data, also termed data colonialism (Couldry &

Mejias, 2019) or surveillance capitalism (Zuboff, 2019), and the development and application of AI models to analyse and use the data, require the exponential growth of data centres and associated ICT systems and infrastructures, which will increase the demand for minerals, water, and energy. Castro et al. (2024) show that the increase in renewable energy production is insufficient to cover the increasing energy needs of digital data.

In the current economic system based on GDP-led economic growth, addressing digital rebound effects is not a priority. Decoupling economic growth from consumption is, therefore, a major challenge (Laurenti et al., 2016). Incremental innovation and different forms of obsolescence create an "engine of growth" and lead to what Laurenti et al. call a "consumption rebound effect".

Decoupling economic growth from natural resource use forms the basis of green growth policies, such as the EU's Green Deal and the UN's Sustainable Development Goals. Digitalisation is perceived as central to decoupling as its technologies provide increased efficiency in resource use. Research has pointed out the contradictions between 'green' and 'growth' (Lerpold & Sjöberg, 2023; Santarius et al., 2020; Ward et al., 2016). Research also shows that, until now, digitalisation has not decoupled economic growth from energy consumption (e.g., Lange et al., 2020; Ren et al., 2021; Salahuddin & Alam, 2016).

Degrowth

"How can the digital revolution be reconceptualised to serve a sufficiency revolution?" asks Santarius (2017). Sufficiency is a central aspect of degrowth and is conceptualised as both a means and an end. As an end, sufficiency is about "'enoughness' of human doings in relation to ecosystems—an end in itself and a means for sustainable consumption and production" (Jungell-Michelsson & Heikkurinen, 2022). Sufficiency as a means to combat rebound effects should be implemented on a collective and institutional level (Sachs & Santarius, 2013). Such sufficiency policies can be defined as "policies for less, lighter, slower, closer, and more personal modes of consumption and production (iii) to comply with planetary boundaries (i) while satisfying fundamental human needs (ii)" (Iten et al., 2024). In terms of economic growth, sufficiency thus results in less growth or no growth (Jungell-Michelsson & Heikkurinen, 2022). Sufficiency is called the missing ingredient for sustainable digitalization (Cologna et al., 2020). The concept of digital sufficiency is proposed to understanding how ICT can become part of the essential environmental transformation (Santarius et al., 2023)

Degrowth is "a planned reduction of energy and resource use designed to bring the economy back into balance with the living world in a way that reduces inequality and improves human well-being" (Hickel, 2021b, p. 1106). Hickel further specifies that degrowth is not about less GDP, but less energy and resource use. In that sense, degrowth is GDP-agnostic, but will often result in less GDP.

Degrowth was first mentioned in the 1972, by Austrian/French philosopher André Gorz (Kallis et al., 2015), in a discussion about the proposal for zero growth in the Club of Rome report (Meadows et al., 1972). Discourses on degrowth gained renewed strength in the past decennia (Escobar, 2015; Hickel, 2021a; Kallis, 2011; Kothari et al., 2014; Zoellick & Bisht, 2018).

The role of technology is perhaps the most controversial question in degrowth theory and practice and answers varies from primitivism to techno-optimism (Heikkurinen, 2018; Kerschner et al., 2018). Degrowth doesn't necessarily mean less technology. "[D]egrowth scholarship embraces technological change and efficiency improvements, to the extent (crucially) that these are empirically feasible, ecologically coherent, and socially just" (Hickel, 2023, p. 1).

Digital Degrowth and Digital Rebound

Digital degrowth is a more recent concept in discourses around sustainable digitalisation. Digital degrowth refers to degrowth specific to the digital economy or digital sector. According to España et al. (2023), digital degrowth can mean *degrowth of ICT*, the reduction of the production and consumption of ICT through, for example, repair and a ban on planned obsolescence or *ICT for degrowth*, the use of ICT to create degrowth in other sectors, for

example, the use of ICT to facilitate the circular economy or to further dematerialisation.

Aanestad (2023) describes digital degrowth as "digital solutions that support continuous on earth […]. It requires a deeper awareness of the intricate relations of the web of life integral to holistic/systems perspectives" (p. 59). Kwet (2024) discusses digital degrowth in the context of digital colonialism and sees a connection between digital justice and environmental justice. The basis for Kwet's digital degrowth proposal are *People Tech* and the ecosocialist *Digital Tech Deal*. People Tech is about the democratisation of technology and is based free software licenses and the interoperability of different applications. The Digital Tech Deal is based on a ten-point programme that "covers many of the core principles and objectives essential to averting tech-driven ecocide" (p. 212).

In *Strategies for Degrowth Computing*, Sutherland (2022) discusses several practical applications that will lead to less resource use while increasing efficiency. Rather than extending their lifespan, Sutherland looks at how digital technologies can be used more intensively. Sutherland gives the example of a shared distributed computer system of one million devices, faster than the top 100 supercomputer, that was able to simulate the Covid protein structure and its potential interaction with antiviral drugs without the need to produce new supercomputers.

Does digital degrowth address digital rebounds? An initial exploration of the literature on digital rebounds shows that eliminating certain technologies can prevent digital rebound effects. Sharma et al. (2023) discuss the role of digital design in rebound effects and propose to "undesign design", e.g., prevent the certain use of a technology, limit the use of a technology, or eliminate a technology, to limit rebound effects. Also Selwyn (2023) discusses eliminating destructive technologies, such as cryptocurrency and blockchain, and so-called sustainable technologies that, because of their zero emissions promise, will result in market expansion. One of the alternatives Selwyn discusses is *permacomputing*, "which seeks to extend permaculture approaches into digital domains, thereby encouraging principles of re-use, repair, maintenance, non-waste, dramatic decreases in the use of artificial energy, and an interdependent and co-operative relationship with natural systems".

Santarius (2017) discusses several digital rebound effects: material, economic, psychological, and structural, and concludes: "The only unambiguous way using digital technologies for sustainability reasons is not for pursuing greater efficiency, but for enabling greater *sufficiency* in human action and *degrowth* in material consumption". In their discussion of digital rebound effects, Coroama and Mattern (2019) argue that these effects are not the result of technology but of economics and human behaviour. They present some examples in which digitalisation does not result in rebounds, such as a distributed conference using video-conferencing, which resulted in less CO_2 emissions than a conference in which everyone attended in person. The authors disagree with the conclusion of Santarius (2017) that digitalisation should only be used for enabling sufficiency and degrowth. They argue that more efficiency through digitalisation will result in less digital rebounds.

Discussion

Techno-optimism and technosolutionism are the main ideologies guiding sustainability policies and implementations. In addition, when it comes to digital technologies, a small group of tech companies, Alphabet, Amazon, Apple, Meta, Microsoft, Nvidia (chipmaker), Tesla, also called Big Tech, have become global monopolies. Their ever-increasing economic power enables control over resources, markets, and now also politics. It may be hard to see how digital degrowth alone, with its connotations of sufficiency and ecosocialism, could make enough inroads in current digitalisation policies to make a real difference. In order to break up tech monopolies and prohibit their surveillance capitalism, radical regulation of the tech sector is needed, as well as other measures, such as requirements for interoperability (Doctorow, 2024), sharing of data and computer power, and implementation of democratic processes for deciding what parts of a society or community would benefit from digitalisation. In addition, radical regulation of the design of the digital technologies can extend the lifetime of digital products. In particular, a ban on planned obsolescence and the design of durable products and systems need to be considered, as incentives to reuse, repair, and refurbishing, as the latter may trigger rebound effects

(Bisschop et al., 2022; Bubinek et al., 2025; Makov & Font Vivanco, 2018).

Digitalisation can result in more efficiency, but this leads to economic growth, which increases energy and material resource consumption. Is digitalisation possible without these rebound effects? The degrowth literature implicitly accepts digital degrowth as a remedy against digital rebounds. Digital degrowth is not about less digitalisation but a different digitalisation, one that is ecologically coherent and socially just (Hickel, 2023). Or as Aanestad writes, different kind of solutions that enable "reducing energy and material resource use while maintaining wellbeing and collective sufficiency" (p. 59). There is a growing amount of literature that provides alternative frameworks for technology and system designs that support such values (e.g., Heikkilä, 2021; Howson et al., 2021; Kerschner et al., 2018; Vetter, 2018; Zoellick & Bisht, 2018b). Further research is needed to understand how digital degrowth can enable sustainable digitalisation without rebound effects.

Concluding Remarks

Pansera et al. (2019) asked members of the Degrowth community to imagine wise and unwise futures of digitalisation in 2068. They summarised their findings as follows: "Key concerns of unwise futures include increasing disconnection of humans from the natural environment and from one another as individuals, the use of digital technology for optimising the allocation of scarce resources to the benefit of the wealthy few and authoritarian governance of technologies and life itself. Wise technological futures, in turn, allow people to freely access digital technologies that are convivial, just, environmentally sustainable and guided by democratic deliberation".

I believe that wise technological futures need to be regenerative, consisting of "a system of technologies and strategies based on an understanding of the inner working of ecosystems that generates designs that regenerate socio-ecological wholes (i.e., generate anew their inherent capacity for vitality, viability, and evolution) rather than deplete their underlying life support systems and resources" (Mang & Reed, 2012, p. 116). Regenerative futures become possible if we embrace the interaction and the co-evolution of the human and natural worlds in a whole systems and living systems perspective.

However, having breached the 1.5° C. ceiling established by the Paris Accords (Peters, 2024) and an average material resource use growth of 2.3% per year (United Nations Environment Programme, 2024), we are on the path towards a very unwise future. To find ways to get off that path, I suggest we start asking the following questions to any, old or new, digitalisation project or digital technology design: Does it "(1) promotes justice; (2) restores reciprocity; (3) confers divisible or indivisible benefits; (4) favors people over machines; (5) whether its strategy maximises gain or minimises disaster; (6) whether conservation is favored over waste; and (7) whether the reversible is favored over the irreversible?" (Franklin, 1999, p. 126). Taking a systems perspective to address these questions is a good start on the path to regenerative technological futures.

References

Aanestad, M. (2023). Digital Degrowth – Beyond Solutionism. In M. R. Jones, A. S. Mukherjee, D. Thapa, & Y. Zheng (Eds.), *After Latour: Globalisation, Inequity and Climate Change* (Vol. 696, pp. 55–60). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-50154-8_6

Bisschop, L., Hendlin, Y., & Jaspers, J. (2022). Designed to break: Planned obsolescence as corporate environmental crime. *Crime, Law and Social Change*, *78*(3), 271–293. https://doi.org/10.1007/s10611-022-10023-4

Bubinek, R., Knaack, U., & Cimpan, C. (2025). Reuse of consumer products: Climate account and rebound effects potential. *Sustainable Production and Consumption*, *54*, 190–201. https://doi.org/10.1016/j.spc.2024.12.019

Castro, V., Georgiou, M., Jackson, T., Hodgkinson, I. R., Jackson, L., & Lockwood, S. (2024). Digital data demand and renewable energy limits: Forecasting the impacts on global electricity supply and sustainability. *Energy Policy*, *195*, 114404. https://doi.org/10.1016/j.enpol.2024.114404

CoinShares. (2024). *CoinShares Mining Report 2024*. https://coinshares.com/fr/resources/research/2024-mining-report/

Cologna, V., Creutzburg, L., & Frick, V. (2020). Sufficiency: The missing ingredient for sustainable digitalisation. *SocietyByte*, 6.

Coroamă, V. C., & Pargman, D. (2020). Skill rebound: On an unintended effect of digitalization. *Proceedings of the 7th*

International Conference on ICT for Sustainability, 213–219. https://doi.org/10.1145/3401335.3401362

Coroama, V., & Mattern, F. (2019). *Digital Rebound – Why Digitalization Will Not Redeem Us Our Environmental Sins*. 10. https://ceur-ws.org/Vol-2382/ICT4S2019_paper_31.pdf

Couldry, N., & Mejias, U. A. (2019). Data Colonialism: Rethinking Big Data's Relation to the Contemporary Subject. *Television & New Media*, *20*(4), 336–349. https://doi.org/10.1177/1527476418796632

Dæhlen, M. (2023). *The Twin Transition Century: The role of digital research for a successful green transition of society?* (No. 5). The Guild of European Research-Intensive Universities. https://boris.unibe.ch/184458/

Doctorow, C. (2024). *The Internet Con: How to seize the means of computation*. Verso.

Escobar, A. (2015). Degrowth, postdevelopment, and transitions: A preliminary conversation. *Sustainability Science*, *10*(3), 451–462. https://doi.org/10.1007/s11625-015-0297-5

España, S., Hulst, W., Jansen, N., & Pargmam, D. (2023). Untangling the Relationship Between Degrowth and ICT. *2023 International Conference on ICT for Sustainability (ICT4S)*, 1–12. https://doi.org/10.1109/ICT4S58814.2023.00010

Fix, B. (2024). *A Tour of the Jevons Paradox: How Energy Efficiency Backfires*. https://doi.org/10.59350/155kj-52e89

Franklin, U. (1999). *The real world of technology*. House of Anansi Press.

Heikkilä, V.-M. (2021). Permacomputing update 2021. *Viznut*. http://viznut.fi/textsen/permacomputing_update_2021.html

Heikkurinen, P. (2018). Degrowth by means of technology? A treatise for an ethos of releasement. *Journal of Cleaner Production*, *197*, 1654–1665. https://doi.org/10.1016/j.jclepro.2016.07.070

Hickel, J. (2021a). *Less is More: How Degrowth Will Save the World*. Penquin Group.

Hickel, J. (2021b). What does degrowth mean? A few points of clarification. *Globalizations*, *18*(7), 1105–1111. https://doi.org/10.1080/14747731.2020.1812222

Hickel, J. (2023, July 1). On Technology and Degrowth. *Monthly Review*. https://monthlyreview.org/2023/07/01/on-technology-and-degrowth/

Howson, P., Crandall, J., & Balaguer Rasillo, X. (2021). Digital degrowth innovation: Less growth, more play. *Political Geography*, *88*, 102415. https://doi.org/10.1016/j.polgeo.2021.102415

Iten, T., Seidl, I., & Pütz, M. (2024). Sufficiency policy: A definition, conceptual framework, and application to municipalities. *Sustainability Science*, *19*(5), 1709–1734. https://doi.org/10.1007/s11625-024-01534-1

Jungell-Michelsson, J., & Heikkurinen, P. (2022). Sufficiency: A systematic literature review. *Ecological Economics*, *195*, 107380. https://doi.org/10.1016/j.ecolecon.2022.107380

Kallis, G. (2011). In defence of degrowth. *Ecological Economics*, *70*(5), 873–880. https://doi.org/10.1016/j.ecolecon.2010.12.007

Kallis, G., Demaria, F., & D'Alisa, G. (2015). Introduction to 'Degrowth: A Vocabulary for a New Era' (2015) PDF. *Degrowth: A Vocabulary for a New Era*, 1–17.

Kerschner, C., Wächter, P., Nierling, L., & Ehlers, M.-H. (2018). Degrowth and Technology: Towards feasible, viable, appropriate and convivial imaginaries. *Journal of Cleaner Production*, *197*, 1619–1636. https://doi.org/10.1016/j.jclepro.2018.07.147

Kothari, A., Demaria, F., & Acosta, A. (2014). Buen Vivir, Degrowth and Ecological Swaraj: Alternatives to sustainable development and the Green Economy. *Development*, *57*(3), 362–375. https://doi.org/10.1057/dev.2015.24

Kunkel, S., & Tyfield, D. (2021). Digitalisation, sustainable industrialisation and digital rebound – Asking the right questions for a strategic research agenda. *Energy Research & Social Science*, *82*, 102295. https://doi.org/10.1016/j.erss.2021.102295

Kwet, M. (2024). *Digital Degrowth: Technology in the Age of Survival*. Pluto Press. https://www.plutobooks.com/9780745349879/digital-degrowth

Lange, S., & Berner, A. (2022). The growth rebound effect: A theoretical–empirical investigation into the relation between rebound effects and economic growth. *Journal of Cleaner Production*, *371*, 133158. https://doi.org/10.1016/j.jclepro.2022.133158

Lange, S., Kern, F., Peuckert, J., & Santarius, T. (2021). The Jevons paradox unravelled: A multi-level typology of rebound effects and mechanisms. *Energy Research & Social Science*, *74*, 101982. https://doi.org/10.1016/j.erss.2021.101982

Lange, S., Pohl, J., & Santarius, T. (2020). Digitalization and energy consumption. Does ICT reduce energy demand? *Ecological Economics*, *176*, 106760. https://doi.org/10.1016/j.ecolecon.2020.106760

Lange, S., & Santarius, T. (2022). *Digital Reset. Redirecting Technologies for the Deep*

Sustainability Transformation. Technische Universität Berlin. https://doi.org/10.14279/DEPOSITONCE-16187

Laurenti, R., Singh, J., Sinha, R., Potting, J., & Frostell, B. (2016). Unintended Environmental Consequences of Improvement Actions: A Qualitative Analysis of Systems' Structure and Behavior. *Systems Research and Behavioral Science*, *33*(3), 381–399. https://doi.org/10.1002/sres.2330

Lerpold, L., & Sjöberg, Ö. (2023). Decoupling and redistribution in realising the Sustainable Development Goals. In *Interlinkages between the Sustainable Development Goals* (pp. 16–36). Edward Elgar Publishing.

Makov, T., & Font Vivanco, D. (2018). Does the Circular Economy Grow the Pie? The Case of Rebound Effects From Smartphone Reuse. *Frontiers in Energy Research*, *6*. https://doi.org/10.3389/fenrg.2018.00039

Mang, P., & Reed, B. (2012). Regenerative Development and Design. In R. A. Meyers (Ed.), *Encyclopedia of Sustainability Science and Technology* (pp. 8855–8879). Springer. https://doi.org/10.1007/978-1-4419-0851-3_303

Maxwell, D., Owen, D., McAndrew, L., Muehmel, K., & Neubauer, A. (2011). *Addressing the rebound effect, a report for the European Commission DG Environment* (p. 133). European Commission DG ENV.

Meadows, D., Meadows, D., Randers, J., & Behrens, W. (1972). *The Limits to Growth: A report for the Club of Rome's project on the predicament of mankind*. Potomac Associates. https://clubofrome.org/publication/the-limits-to-growth/

O'Brien, I. (2024, September 15). Data center emissions probably 662% higher than big tech claims. Can it keep up the ruse? *The Guardian*. https://www.theguardian.com/technology/2024/sep/15/data-center-gas-emissions-tech

OECD. (2024). *OECD Digital Economy Outlook 2024 (Volume 1): Embracing the Technology Frontier*. OECD. https://doi.org/10.1787/a1689dc5-en

Pansera, M., Ehlers, M.-H., & Kerschner, C. (2019). Unlocking wise digital techno-futures: Contributions from the Degrowth community. *Futures*, *114*, 102474. https://doi.org/10.1016/j.futures.2019.102474

Peters, G. P. (2024). Is limiting the temperature increase to 1.5°C still possible? *Dialogues on Climate Change*, 29768659241293218. https://doi.org/10.1177/29768659241293218

Ren, S., Hao, Y., Xu, L., Wu, H., & Ba, N. (2021). Digitalization and energy: How does internet development affect China's energy consumption? *Energy Economics*, *98*, 105220. https://doi.org/10.1016/j.eneco.2021.105220

Sachs, W., & Santarius, T. (2013). *Rethink rather than rebound: A sufficiency revolution must precede the efficiency revolution*.

Salahuddin, M., & Alam, K. (2016). Information and Communication Technology, electricity consumption and economic growth in OECD countries: A panel data analysis. *International Journal of Electrical Power & Energy Systems*, *76*, 185–193. https://doi.org/10.1016/j.ijepes.2015.11.005

Santarius, T. (2017). *Digitalization, Efficiency and the Rebound Effect | degrowth.info*. https://www.degrowth.info/en/2017/02/digitalization-efficiency-and-the-rebound-effect/

Santarius, T., Bieser, J. C. T., Frick, V., Höjer, M., Gossen, M., Hilty, L. M., Kern, E., Pohl, J., Rohde, F., & Lange, S. (2023). Digital sufficiency: Conceptual considerations for ICTs on a finite planet. *Annals of Telecommunications*, *78*(5), 277–295. https://doi.org/10.1007/s12243-022-00914-x

Santarius, T., Pohl, J., & Lange, S. (2020). Digitalization and the Decoupling Debate: Can ICT Help to Reduce Environmental Impacts While the Economy Keeps Growing? *Sustainability*, *12*(18), Article 18. https://doi.org/10.3390/su12187496

Santarius, T., & Soland, M. (2018). How Technological Efficiency Improvements Change Consumer Preferences: Towards a Psychological Theory of Rebound Effects. *Ecological Economics*, *146*, 414–424. https://doi.org/10.1016/j.ecolecon.2017.12.009

Santarius, T., Walnum, H. J., & Aall, C. (2018). From Unidisciplinary to Multidisciplinary Rebound Research: Lessons Learned for Comprehensive Climate and Energy Policies. *Frontiers in Energy Research*, *6*. https://doi.org/10.3389/fenrg.2018.00104

Schneider, F. (2008). *Macroscopic rebound effects as argument for economic degrowth*. 1st Degrowth Conference for Ecological Sustainability and Social Equity,. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=7c4d1f92ea5e9d2cfb0a1d6c46dbca58ad4e1f0b

Selwyn, N. (2023). Digital degrowth: Toward radically sustainable education technology. *Learning, Media and Technology*, *0*(0), 1–14. https://doi.org/10.1080/17439884.2022.2159978

Sharma, V., Kumar, N., & Nardi, B. (2023). Post-growth Human–Computer Interaction. *ACM Trans. Comput.-Hum. Interact.*, *31*(1), 9:1-9:37. https://doi.org/10.1145/3624981

Sutherland, B. (2022, June 21). Strategies for Degrowth Computing. *Eighth Workshop on Computing within Limits 2022*. Eighth Workshop on Computing within Limits 2022, Virtual. https://doi.org/10.21428/bf6fb269.04676652

Taffel, S. (2024). Fantasies of dematerialization: (Un)sustainable growth and digital capitalism. In *Digital Technologies for Sustainable Futures*. Routledge.

UN Trade and Development. (2024). *Digital Economy Report 2024: Shaping an Environmentally Sustainable and Inclusive Digital Future*. United Nations. https://doi.org/10.18356/9789213589779

United Nations Environment Programme. (2024). *Global Resources Outlook 2024: Bend the Trend – Pathways to a liveable planet as resource use spikes* (p. 181). International Resource Panel. https://wedocs.unep.org/20.500.11822/44902

Valero, A., Valero, A., & Calvo, G. (2021). *The Material Limits of Energy Transition: Thanatia*. Springer International Publishing. https://doi.org/10.1007/978-3-030-78533-8

Vetter, A. (2018). The Matrix of Convivial Technology – Assessing technologies for degrowth. *Journal of Cleaner Production*, *197*, 1778–1786. https://doi.org/10.1016/j.jclepro.2017.02.195

Ward, J. D., Sutton, P. C., Werner, A. D., Costanza, R., Mohr, S. H., & Simmons, C. T. (2016). Is Decoupling GDP Growth from Environmental Impact Possible? *PLOS ONE*, *11*(10), e0164733. https://doi.org/10.1371/journal.pone.0164733

Zink, T., & Geyer, R. (2017). Circular Economy Rebound. *Journal of Industrial Ecology*, *21*(3), 593–602. https://doi.org/10.1111/jiec.12545

Zoellick, J. C., & Bisht, A. (2018). It's not (all) about efficiency: Powering and organizing technology from a degrowth perspective. *Journal of Cleaner Production*, *197*, 1787–1799. https://doi.org/10.1016/j.jclepro.2017.03.234

Zuboff, S. (2019). *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power* (1 edition). PublicAffairs.

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Utilising Digital Technology for Garment Longevity

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Keywords: Garment Longevity; Digital Archives; Circular Economy; Digital Fashion; Sustainable practices.

Abstract: This research explores methods for repurposing both physical resources and contextual specialist knowledge, offering insights that can inspire and enhance future fashion design and re-manufacturing and archival practices within the industry. It questions whether digital fashion design tools, such as CLO3D can expand from facilitating faster production and consumption to enhancing the use and potential longevity of garments. The study employs an ethnographic approach to practice-based research, where the authors focus on the interaction between the physical and digital worlds, to understand the wider application of CLO3D that promotes the value and lifespan of a garment. Two case studies were investigated to explore the impact of CLO3D on longevity: a historical garment archive that examined historic pattern cutting approaches; a contemporary collection of 30 deadstock sportswear garments. This research aims to enhance the designers understanding and accessibility of archival and sustainable practices by exploring ways to expand the use of a garment through existing digital tools.

Introduction

Technology has had a profound influence on fashion over the last two decades. Digital pattern cutting and simulation technologies, such as CLO3D have recently impacted the way that garments can be designed, sampled and produced. This technology has been proven to reduce waste caused by physical sampling and enable adjustments and experimentation in the digital realm (Business of Fashion, 2020). This research aims to understand how this technology can be repurposed to enhance garment longevity of archival fashion and deadstock collections. By adopting creative design tools such as CLO3D, this study uses an ethnographic approach to explore two case studies that address gaps in both past and present fashion practice.

Due to the speed of current trends of fast and instant fashion the time spent considering the fit, cut and manufacturing methods is often vastly reduced. Kent (2024) highlights how recycling isn't keeping up with consumption, with material-to-material recycling accounting for only 2% of recycled fabric used in 2023. This emphasises that the focus on recycling alone will not address environmental degradation. Therefore, it is imperative that we find alternate solutions and use what we have for longer.

Present-day manufacturing often leads to overproduction and large amounts of deadstock (Tonti 2024), creating a waste stream that designers and brands could potentially utilise.

Currently, remanufacturing is viewed as time-consuming and labor-intensive (Stahel 2019), however, earlier research suggests that technology can streamline this process (Wetherell et al. 2023). By examining the current challenges of present-day fashion, this research aims to explore how technology could enhance the efficiency and accessibility of redesigning and remanufacturing, ultimately extending the life of clothing.

New developments in the field of digital archiving have revolutionised the preservation and conservation of valuable historical artefacts. Digital technology affords the researcher opportunities to broaden access to past collections, both historical and contemporary, and its innovative use allows a sharing of previously unmined resources and innovative design solutions, often overlooked in modern-day fashion. However, these artefacts are often inaccessible due to the controlled

environments where the garments are stored, their often-singular geographic locations (Pecorari, 2019) and lack of physical space (McNulty, 2019, p.239). In a generation where knowledge of clothes-making has become lesser known, the fashion industry and fashion design education can benefit from promoting a slower approach to design; pausing to look back, before we move forward.

By exploring new ways to utilise existing technology, we can begin to hypothesize applications that could educate and empower designers to work in a less linear fashion. This approach is aiming to provide tools to encourage slower, thoughtful design elements and create a space to explore alternative starting points, such as deadstock garments. Consequently, two key questions underpin this research: first, how can technology be used to promote garment longevity? Second, how can tools like CLO3D facilitate this process?

Contextual Review

Speed and Environmental degradation

The speed of clothing production and consumption has grown rapidly in recent years, creating billions of excess unworn and unsold items of clothing (WRAP, 2022). Tonti (2024) reveals that the fashion industry is set to double its emissions in the next ten years, highlighting the importance of sustainable change. Niinimäki et al. (2020) notes how our levels of consumption are often outpacing the sustainability efforts undertaken by brands, propelling us towards the 2030 deadline with limited promise. Technology however can pose a threat to such sustainable goals, with fast fashion brands, such as Shien, using technology to accelerate their systems, allowing them to bring new products to their online stores daily. Pucker (2024) demonstrates how Shein are rapidly outpacing the production of brands once considered 'fast', such as H&M, selling over 1.3 million new garment options in 12 months. This significant growth is accompanied by a 52% increase in carbon emissions (Pucker, 2024). This shift to overproduction and underutilisation of garments remains one of the key challenges within fashion:

"The available statistics suggest that between 80bn and 150bn garments are made every year and that between 10% and 40% of these are not sold. So, it could be 8bn or 60bn excess garments a year" (Tonti, 2024).

Fashion brands are predicted to become increasingly dependent on technology, with investments in the tech sector predicted to rise 3-3.5% by 2030 (Business of Fashion, 2022), enabling this problematic shift from fast fashion to instant fashion, causing significant environmental and social impacts (Pucker 2024). It is to be acknowledged that the faster the system of production and consumption, the less consumers use and value each garment in their wardrobes. This increasing volume of garment production is causing widespread environmental damage, especially when garments reach the end of their useful life (Askiner and Gupta 1999).

Digital technology has enabled the fashion industry to reduce waste, particularly during the sampling stages, by utilising digital garment samples created with 3D software (Business of Fashion, 2020). Additionally, it has facilitated automated made-to-order systems. However, these advancements do not appear to be decreasing the production or consumption of garments (Kent, 2024), indicating that there is still significant potential for further improving sustainability.

Today, designers are increasingly incorporating 3D design tools, such as CLO3D, into traditional fashion design processes. This shift creates opportunities to expand these existing 3D skills and transform the linear design process into one that promotes greater longevity by reconsidering how we use the technology that is available to us.

Garment Longevity

In this research, garment longevity refers to the prolonged use and utilisation of existing clothing, which is part of the broader system of circularity and sustainability. As highlighted by the Ellen MacArthur Foundation (2017; 2021) clothing production has surged since the early 2000s, yet the average wear per garment has significantly decreased. This trend underscores the importance of longevity in fostering a more sustainable fashion industry.

The concept of longevity in fashion archives encompasses several key aspects. Access to collections are often limited by geography, restricting the range of garments available for study. Additionally, repeated handling over time

can compromise the condition of fragile artefacts. The opportunities that technology presents could be optimised to create replicas of these garments enabling a greater reach. This potential of online availability beyond the constraints of the object's physical location (Pecorari, 2019) also has the ability to revolutionise access. By uncovering historical pattern cutting and manufacturing techniques, which may otherwise be lost, we can draw from past knowledge to positively impact future approaches to garment sustainability.

Due to present day over-manufacturing there are large number of unused and unsold garments, often referred to as deadstock, that could be reevaluated. Unfortunately, these garments are frequently sent to landfill, shipped to the Global South, or incinerated (Chan 2024). Brands like Patagonia, The North Face, and Nike are exploring creative remanufacturing solutions for their excess stock; however, the current processes remain largely analogue and operate at a micro scale (Patagonia, The North Face, Nike 2025). Due to the scale of deadstock in the fashion industry, there are often multiple garments available in the same size, fabric type, and colour. By leveraging technology, we can identify ways to reduce the challenges associated with redesigning and remanufacturing deadstock, such as time. This approach could help utilise these unused garments, extending their useful life.

Tools for enhancing garment longevity have seen limited development and primarily depend on adaptations of existing technology (Wetherell et al, 2023). 3D fashion design tools, such as CLO3D, are being quickly adopted by university fashion programmes and brands alike to enhance traditional design processes. These tools are now frequently used for production purposes, such as sampling, as well as for commercial applications, including e-commerce and social media (Bain 2022). It is crucial to explore innovative approaches in fashion technology to facilitate garment longevity, with a focus on how current software, such as CLO3D could enable increased lifespans, rather than helping speed up the process of producing and selling new items (Kozlowski et al, 2019). Due to large quantities of resources going into the production of clothing, from the raw materials and manufacturing to the shipping and care (Tonti 2024), exploring ways to enabling garment longevity; extending the time a garment is in use, is crucial to the circular system (Ellen MacArthur Foundation 2021).

Methodology

This research adopted an ethnographic approach to understand how technology can be used to enable garment longevity. Practice-based research was undertaken using two case study examples, the first was looking at the past with garments that are placed in archives that hold information about former design and pattern cutting methods. The second was looking at a present-day challenge, deadstock garments that are produced and remain unused. To understand how technology influenced longevity in these two cases the researchers were emersed in the process, exploring how technology, such as CLO3D could be used to address the longevity of these past and present garments. Both case studies explored the interplay between physical and digital worlds, using traditional physical pattern cutting and manufacturing techniques to inform the digital development. This process is demonstrated in figure 1.

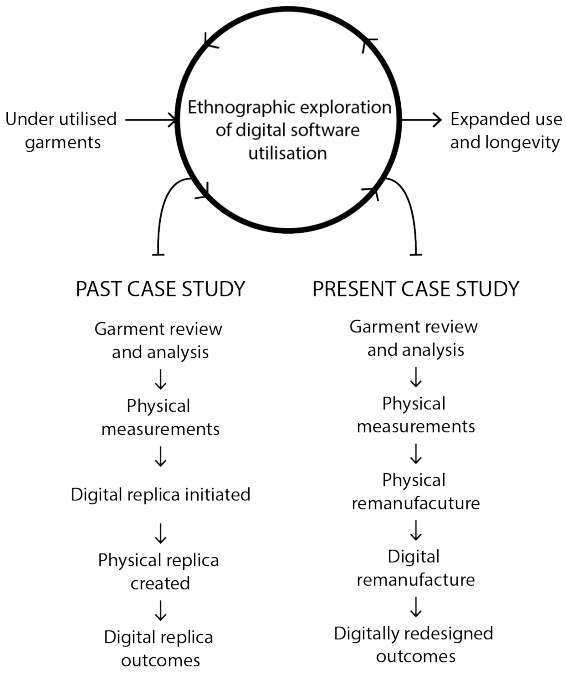


Figure 1. Methodological Diagram

Past

Two garments from UK-based archives were selected for investigation, chosen due to their limited prior research and restricted

accessibility. Object-based analysis methods were implemented to examine and learn from these historical artefacts. Complying with archival handling protocols, a detailed inspection of physical garments, guided by a 'Checklist for observation' (Mida & Kim, 2015, pp. 216–219) to record fundamental data on the garments' key features and construction methods. Additionally, a comprehensive set of measurements were acquired to inform a reinterpretation of the garment patterns.

A combination of manual and digital pattern cutting methods were blended to achieve an accurate pattern replication. Physical prototypes were produced and fitted on a live model, offering the potential to test functionality, crosscheck alongside the original artefacts and refine in response to analysis. Pattern pieces were digitally assembled in CLO3D to create an initial 3D model, with digital textiles carefully selected to replicate the original garment materials. Throughout this phase, software functions were manipulated to refine the digital representation of the original artefacts, with outcomes assessed through an evaluative framework.

Present

A selection of garments donated by a sportswear brand were used, some of which represent best sellers, and others that are no longer in production for reasons such as poor fit, and sizing issues. The aim was to understand how digital technology can be used to redesign these garments, exploring how popular styles could be redesigned and remade from out-of-production garments that represent unsold deadstock bringing longevity to unused and unvalued stock. To gain a better understanding of the garment construction and the challenges associated with unsold items, a physical assessment was conducted. This involved noting the fabric type, construction details, fit (including measurements), and reasons for the garment being out of circulation. Following this, a physical and digital plan was developed to help the researchers comprehend the differences between exploring longevity in a physical context versus a digital one. This plan outlined various remanufacturing ideas aimed at converting unsold stock into popular styles.

The physical space was explored first, enabling a thorough understanding of the construction challenges and opportunities. Some garments only required a light remanufacture, turning trousers into shorts, and others required an overhaul of design, converting t-shirts into shorts for example. The digital space was then explored, using the digitised copy of the garments in CLO3D, mimicking tools used in industry presently. New styles were then rendered through a trail-and-error approach, overlaying patterns and digitally constructing a range of new outcomes based on best selling styles and accessories.

Findings

This research aimed to enhance the designers understanding and accessibility of both archival (past) and contemporary (present) sustainable practices by exploring ways to expand the use of a garment through existing digital tools.

Past

The study of archival dress artefacts presented multiple challenges throughout the research process. For instance, handling protocols significantly restricted direct interaction with the garments; standard archival practices required that garments be handled only with gloved hands and any movement or examination was carefully guided by an archivist. These limitations minimised the researcher's ability to physically touch the materials and was therefore restricted to visual observation and imagination to understand the tactile qualities.

Reverse engineering patterns from archival garments posed additional challenges. Instead of pinning and tracing the pattern directly, the researcher was required to take multiple measurements in order to replot the pattern, an approach that introduced inaccuracies which were presented in the reinterpretation process. This approach was however the most appropriate method in this circumstance and highlighted the importance of accurate measurement records.



Figure 2. Image demonstrating freezing and pinning digital garment panels in CLO3D

The digital reconstruction of the archival garment in CLO3D involved extensive trial and error to accurately replicate and manage the fullness of the skirt. Through experimentation with the software function, a successful outcome was achieved by adjusting the mesh and strategically freezing and pinning parts of the fabric to achieve the desired drape and resolve common collision issues, seen in figure 2. This aspect of the work took significant time to problem solve. However, the process was remarkably quicker when applied to replication of the second archival simulation.



Figure 3. Image illustrates the archival garment in its component parts

During a project evaluation where the digital replicas, such as figure 3, were presented to museum archivists, the research team was encouraged by the positive response to the digital outcomes which communicated the relationship between the archival garment and its component two-dimensional parts. This suggested the work's potential to deepen understanding of historical pattern-cutting techniques and to enrich museum collections.

Present

Working through the physical plan, it became clear that redesigning and remanufacturing the deadstock garments without digital input was time consuming and had the high possibility of errors, such as inaccurate lay plans. When exploring how to redesign a selection of t-shirts into shorts, it was challenging to picture the outcome in advance. As the garments were already constructed, it was difficult to work accurately with the fabric on both the front and backside of the garment in tandem.

Conversely, working with physical samples enhanced the understanding of garment construction factors that may arise during the remanufacturing stages. For instance, while modifying the elasticated waistband on a pair of hiking trousers, simply removing the elastic was not possible. It became evident that additional reinforcement would be necessary to ensure stability in the fabrics, requiring extra fusing and topstitching. The opportunity to physically test and examine samples facilitated more precise digital redesign options, ultimately resulting in more feasible solutions for remanufacturing.

When working with the digital plan, the process was smooth and redesigned ideas were quickly rendered. The deadstock items selected for this experiment had various issues, including poor fit such as a misshapen hood. The deadstock garment fabrics closely matched those of the best-selling garment that served as a template for redesign. Having a digital plan gave focus to the process, enabling multiple ideas to be tested and the outcomes visualised, enhancing the creative impact of the designer.

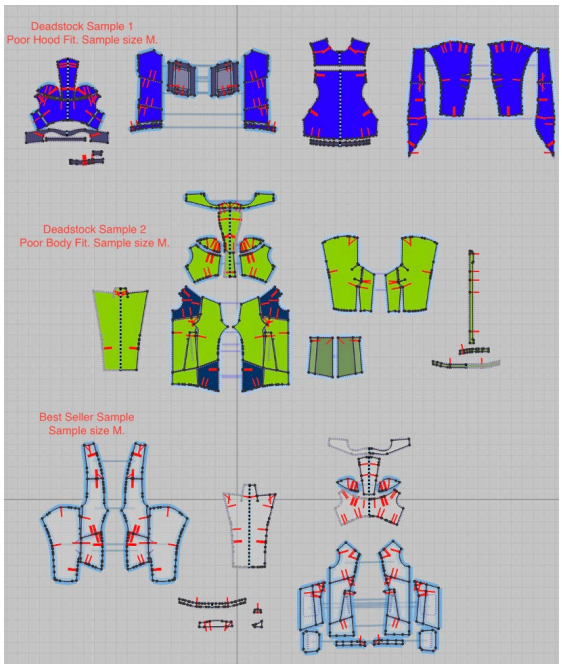


Figure 4. Image showing a digital pattern comparison of a best-selling (white) garment versus two deadstock garments (green and blue).

The digital lay plans were much easier to experiment with, reducing the barrier for designers to reengage with deadstock products and cutting down the time burden when exploring redesign options.

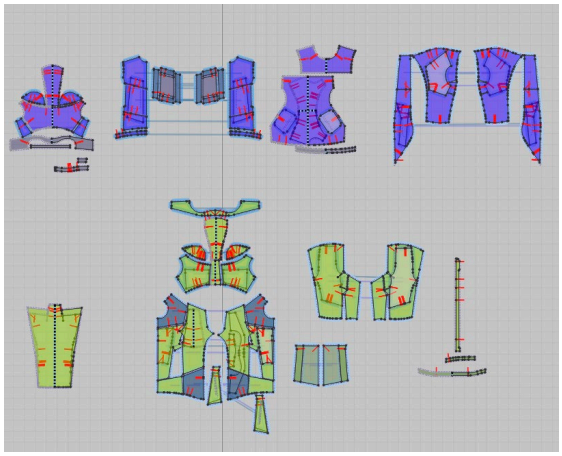


Figure 5. Image showing a digital pattern lay plan ready to digitally recut the deadstock garments into new pattern pieces.

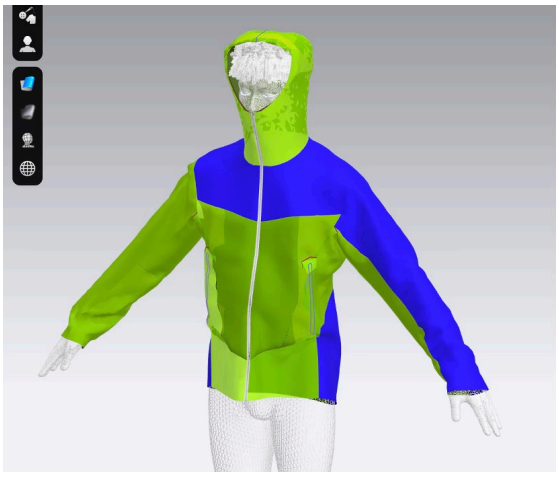


Figure 6. Image showing the final digital outcome of a redesigned jacket made from two deadstock jackets.

Figure 4 and 5 demonstrates how the digital patterns can be easily compared and overlaid, enabling the designers to find new viable solutions for unsold stock. The final redesigned results can be visualised, edited and tested as shown in figure 6. Once the designer is satisfied, the new pattern can then be exported, allowing edits to be applied directly to physical garments for remanufacturing, creating new outcomes. This method could be used for both small edits to garments from rebuilding a waistband, through to a full garment redesign.

In both case studies, it became evident that a solid understanding of garment pattern cutting, and design is essential for effectively engaging in the digitisation process. The feedback loop between digital and physical helps to ground the digital work in realistic and achievable outcomes.

Longevity and Accessibility

Figures 7 and 8 demonstrate how digital technology could be hypothetically utilised to enable longevity in both past and present garments, extending the reach of archival pieces, and diverting garments from deadstock. They explore how both archival and contemporary garments could have their use prolonged.

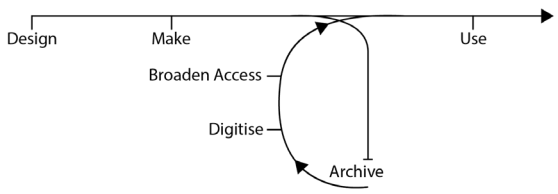


Figure 7. Diagram of Longevity, Past Case Study.

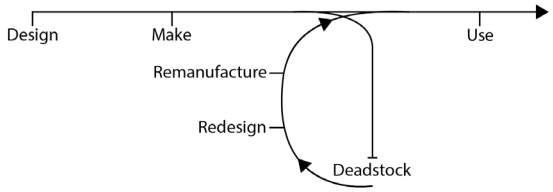


Figure 8. Diagram of Longevity, Present Case Study.

By expanding the use of digital technology, designers can engage with both historical and contemporary garments, offering innovative solutions through familiar tools. Enhancing accessibility to past garments contributes to creating a more circular fashion system. By learning essential skills from history, we can fortify our design foundations. Additionally, developing a process to revisit and redesign garments in ways that align with today's design practices may encourage designers to reconsider items that have not sold.

Conclusion

Re-engaging designers with historical collections and deadstock garments presents valuable opportunities to combine historical insights with contemporary remanufacturing and sustainable practices. By repurposing 3D design technology, we can reverse-engineer both historical and contemporary garments, digitally preserving this knowledge to extend their lifecycle. This approach not only unlocks new educational opportunities but also influences future industry practices.

CLO3D helps to enable access to explore new design options for deadstock items. It could create an environment where redesigns have greater potential for scale and adoption, helping brands transition from micro offerings to more impactful solutions. CLO3D enables the digitisation of archival garments, enriching knowledge of past collections while showcasing historical techniques that inspire new perspectives for future fashion production.

There are areas that warrant further exploration, particularly regarding the long-term storage and accessibility of digital assets such as CLO3D files. Additionally, researching and tracking the usage of both past and present garments would offer valuable insights into how these items have been utilised over time. One limitation is the resource-intensive nature of digitising garment patterns, particularly when there is no original CLO3D file available. However, if the garments did not have an existing digital footprint, the digitisation process is possible but time consuming. Further investigation could help to support garment longevity and promote a more sustainable application of technology in the fashion industry.

References

Gungor, A., & Gupta, S. M. (1999). Issues in environmentally conscious manufacturing and product recovery: a survey. *Computers & Industrial Engineering*, *36* (4), 811-853. https://doi.org/10.1016/S0360-8352(99)00167-9

Bain, M. (2022). *The new technologies fashion schools are teaching students.* The Business of Fashion (BOF). Retrieved October 2024, from https://www.businessoffashion.com/articles/technology/the-new-technologies-fashion-schools-are-teaching-students/

Business of Fashion. (2022). *The state of fashion: technology*. https://cdn.businessoffashion.com/reports/The_State_of_Fashion_Special_Edition_Technology_2022.pdf?int_campaign=sof22_040522&int_content=v1&int_medium=articlezembed_asset&int_source=onsite_marketing

Chan, E. (2024) Why Aren't More Brands Upcycling Their Excess Stock? British Vogue. Retrieved February 2025, from https://www.vogue.co.uk/article/brands-deadstock

Ellen MacArthur Foundation. (2017). A New T*extiles Economy: Redesigning fashion's future.* https://www.ellenmacarthurfoundation.org/a-new-textiles-economy

Ellen MacArthur Foundation. (2021). *Circular business models: redefining growth for a thriving fashion industry.*https://www.ellenmacarthurfoundation.org/fashion-business-models/overview

Kent, S. (2024) *Fashion's Plastic Addiction in Four Charts*. Business of Fashion. Retrieved October 2024, from https://www.businessoffashion.com/articles/sustainability/fashion-polyester-addiction-textile-exchange-recycled-plastic/

Kozlowski, A., Bardecki, M. & Searcy, C. (2019). Tools for sustainable fashion design: An analysis of their fitness for purpose. *Sustainability, 11* (13), 3581. https://doi.org/10.3390/su11133581

Kupresanin, A., & Chen, B. (2019). Fashion beyond physicality. Medium. https://medium.com/@superbureau/fashion-beyond-physicality-486d71b05dae

McNulty, R. (2019). *Future Applications of Digital Clothing for Historical Costume: The past, present and future of fashion.* Proceedings of EVA London 2019. https://doi.org/10.14236/ewic/EVA2019.45

Mida, I., & Kim, A. (2015). *The dress detective: A practical guide to object-based research in fashion*. Society of Antiquaries of London, Bloomsbury Academic, an imprint of Bloomsbury Publishing Plc.

Niinimäki, K., Peters, G., Dahlbo H., Perry P., Rissanen T., & Gwilt A. (2020). The environmental price of fast fashion. *Nature Reviews Earth &* Environment, 1 (4), 189–200. doi: 10.1038/s43017-020-0039-9. DOI: 10.1038/s43017-020-0039-9

Nike (2025). Introducing the Nike Re-Creation Program. Retrieved March 2025, from https://about.nike.com/en/newsroom/releases/nike-re-creation-program

Patagonia (2025) Worn Wear Recrafted. Retrieved March 2025, from https://wornwear.patagonia.com/collections/recrafted

Pecorari, M. (2019). Fashion archives, museums and collections in the age of the digital. *Critical Studies in Fashion & Beauty, 10 (*1), pp.3-29. DOI: 10.1386/csfb.10.1.3_7

Pucker, K. (2024). *Beware the 'Sheinification' of Fashion.* Business of Fashion. Retrieved March 2024, from https://www.businessoffashion.com/opinions/sustainability/shein-fast-fashion-hm-sustainability/

Stahel, W. R. (2019). *The circular economy : a user's guide*.

The North Face (2025) Renewed. Retrieved March 2025, from https://thenorthfacerenewed.co.uk/collections/remade

Tonti, L. (2024). *'It's the industry's dirty secret': why fashion's oversupply problem is an environmental disaster'*. The Guardian. Retrieved January 18, from https://www.theguardian.com/fashion/2024/jan/18/its-the-industrys-dirty-secret-why-fashions-oversupply-problem-is-an-environmental-disaster (Accessed: March 2024).

Wetherell, S., Nicholson, T., & James, A. (2023). 3D Fashion Design Software as a Critical Tool for the Remanufacture of Sportswear. *5th PLATE Conference Espoo, Finland, 31 May - 2 June 2023*.

WRAP (2022). *Nation's wardrobes hold 1.6 billion items of unworn clothes* People open to new ways of shopping* [Press Release].
https://www.wrap.ngo/media-centre/press-releases/nations-wardrobes-hold-16-billion-items-unworn-clothes-people-open-new

Extended Abstract
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Building a Digital Circular Economy for Electrical and Electronic Equipment

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Keywords: Circular economy; Waste electrical and electronic equipment; Digital technologies; Industry 4.0.

Introduction

The rapid development of digitalisation has brought disruptive changes to the economy and life, as well as a growth in the consumption of Electrical and Electronic Equipment (EEE). Waste Electrical and Electronic Equipment (WEEE) is now the fastest growing waste stream in the world (Balde et al., 2024). Despite this, less than a quarter of EEE is recovered globally. This means that the vast majority of WEEE is sent to landfill (Singh et al., 2020).

In the face of rising pollution, resource scarcity and supply chain volatility, there are growing calls for a Circular Economy in which product lifetimes are maximised and resources are kept in use for as long as possible (Kirchherr et al., 2017). This means that EEE is effectively reduced, reused, repaired, remanufactured, recycled and recovered (Potting et al., 2017) at the end of its lifecycle. Circular Economy has gained significant attention in the last decade from industry and policy makers (Geissdoerfer et al., 2017). Within this rapidly growing field, a body of research is growing on how digital technologies can enable a more circular economy (Pagoropoulos et al., 2017). For example, Despeisse et al. (2017) examine how 3D printing could unlock a Circular Economy by enabling localised remanufacturing; Voulgaridis et al. (2022) study applications of Internet of Things (IoT) in the Circular Economy to improve traceability; and Bressanelli et al. (2022) consider the role of digital twins in the Circular Economy as a way of improving inventory and demand information across the supply chain. At a policy level, there has also been increasing interest in how digitalisation can enable the Circular Economy. In 2022, the European Commission announced its Circular Economy Package, which identified for Digital Product Passports (DPP) as a key framework for improving material, component and product traceability as part of a Circular Economy (European Commission, 2022).

Despite their promise, there is limited knowledge as to how new digital technologies and capabilities such as IoT, Big Data and Digital Fabrication could be leveraged to support the transition to Circular Economy. Furthermore, it cannot be assumed that digitalisation will necessarily lead to sustainability gains and several circular economy rebound effects may take place (Zink and Geyer, 2017). Digitalisation may in fact lead to a proliferation of WEEE, if systems are not properly managed and implemented. This research aims to further explore the linkages between digitalisation and the circular economy, specifically in the EEE sector. It addresses the following research questions: (1) what are the current and future potential applications of digital (Industry 4.0) technologies in the EEE sector? (2) What are the main strengths, weaknesses, opportunities and threats related to the integration of digital technologies in the EEE sector?

Methods

To address these research questions, this study undertakes a state-of-the-art technology horizon scan of digital (Industry 4.0) technologies (including AI, Big Data, Digital Fabrication, Digital Twins, Internet of Things, Robotics and Automation, Virtual Reality/Augmented Reality) and their potential application in a CE for EEE. Empirical and academic case studies are systematically collected and analysed in order to identify the potential threats, opportunities, and likely future developments related to a digitally-enabled CE in the EEE sector. Ongoing evidence is collected from two ongoing CE and EEE research projects, led by the authors.

Results

The results of this study are presented as a typology of case studies (see example Table 1). Potential threats, opportunities, and likely future developments related to the development of a digital CE for EEE are presented, including discussion of a range of digital (Industry 4.0) technologies (see Table 2). These findings emphasize potential for these technologies to extend product lifetimes, optimize resource use, and support circular practices but also demonstrate critical challenges that must be addressed to realize these benefits fully.

Several strengths of Industry 4.0 technologies in enabling CE practices for EEE were identified. Among these, IoT technology stands out for its ability to enhance traceability and transparency through real-time product monitoring across the EEE lifecycle (Fernandes et al., 2023). This capability supports improved product repairability and facilitates quality control. Similarly, AI has a potential to improve the repair and maintenance processes. For example, AI-driven repair optimization (Liao et al., 2024), improves product designs by identifying recurring failure points.

Despite these strengths, several weaknesses were identified. For example, AI tools often rely on high-quality datasets, and any inaccuracies can undermine user trust. Additionally, the energy-intensive nature of AI development poses environmental concerns, potentially offsetting its benefits (Ligozat et al., 2021). Digital technologies such as blockchain and IoT are increasingly used to improve traceability and responsible sourcing of critical raw materials like cobalt and tungsten, addressing transparency gaps in resource extraction and mining (Sherpa and Sinha, 2021) The results highlight several opportunities for leveraging digital technologies to enable CE in the EEE sector. One such opportunity is AI-driven predictive maintenance, which can transform operational efficiency by proactively addressing issues (Shin et al., 2021).

	AI	**Robotics and auto-mation**	**IoT**
10 Refuse			
9 Reduce	Motivo (n.d)		Hp printing as a service (n.d)
8 Rethink			
7 Reuse	Teleplan (Barteková & Börkey, 2022)		
6 Repair			
5 Refurbish	Lenovo (n.d) Circular Brain (n.d.)		
4 Remanufacture	eit manufacturing (n.d)	eit manufacturing (n.d)	
3 Repurpose			
2 Recycle	Sweeep (n.d)	Recycleye (n.d)	Velos (n.d)
1 Recover		AMP (n.d)	

Table 1. Examples applications of Industry 4.0 Digital Technologies in the Circular Economy for EEE

	SWOT
AM	S: Customisation, Small scale production, Production of spares, Weight saving W: Not suitable for mass production, Build quality O: Customisation and decentralised manufacturing
AI	S: Supply chain transparency, Predictive analytics and decision-making e.g. enhancing repairability W: Limited Accuracy O: Predictive Maintenance T: High energy consumption
Big Data	S: Predictive maintenance and reliability W: Data integration, complexity O: Improved design and innovation
IoT	S: Enhanced traceability and transparency O: Improved efficiency in recycling and maintenance
Robotics & automation	S: Efficiency in recycling W: Complex maintenance O: Scalable solutions T: Causing more E-waste
VR/AR	S: Enhanced training and maintenance efficiency W: High implementation costs O: Improved product design and customization T: Resistance to adoption

Table 2. Strengths, weaknesses, opportunities and threats related to Industry 4.0 Digital Technologies in the Circular Economy for EEE

Another is digital fabrication, which facilitates customization and decentralized manufacturing, reducing dependency on global supply chains and enhancing adaptability to local demands (Rao et al., 2022).

Finally, the study identifies threats that could hinder the effective integration of these technologies. AI's high energy consumption poses an environmental challenge, potentially offsetting its sustainability benefits. Similarly, robotics, if not planned for end-of-life, could inadvertently increase e-waste, undermining CE goals. Resistance to AR/VR adoption, driven by steep learning curves and job displacement fears, presents another critical challenge to widespread implementation (Jalo & Pirkkalainen, 2024). While Industry 4.0 technologies offer transformative potential for a digital CE in the EEE sector, their adoption must be carefully managed to mitigate associated risks and maximize benefits. Future research should explore strategies for mitigating these challenges while maximizing the benefits of digitalisation in enabling a circular economy for EEE.

References

AMP Robotics. (n.d.). AMP Robotics: AI-powered sortation solutions. Retrieved from https://ampsortation.com/

Balde et al. (2024) The Global E-waste Monitor 2024. United Nations Institute for Training and Research (unitar).

Barteková, E., & Börkey, P. (2022). Digitalisation for the transition to a resource efficient and circular economy.

Circular Brain. (n.d.). Retrieved from https://circularbrain.io/

Daily, J., & Peterson, J. (2017). Predictive maintenance: How big data analysis can improve maintenance. Supply chain integration challenges in commercial aerospace: A comprehensive perspective on the aviation value chain, 267-278. http://dx.doi.org/10.1007/978-3-319-46155-7_18

EIT Manufacturing. (n.d.). Activities: RENEE. Retrieved from https://www.eitmanufacturing.eu/news-events/activities/renee/

Eswaran, M., & Bahubalendruni, M. R. (2022). Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: A state of the art review. Journal of Manufacturing Systems, 65, 260-278. https://doi.org/10.1016/j.jmsy.2022.09.016

Fernandes, L., Rosado da Cruz, A. M., Cruz, E. F., & Lopes, S. I. (2023). A review on adopting blockchain and IoT technologies for fostering the circular economy in the electrical and electronic equipment value chain. Sustainability, 15(5), 4574. http://dx.doi.org/10.3390/su15054574

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. Journal of cleaner production, 143, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048

HP. (n.d.). Instant Ink. Retrieved from https://instantink.hpconnected.com/uk/en/l/

Jalo, H., & Pirkkalainen, H. (2024). Effect of user resistance on the organizational adoption of extended reality technologies: A mixed methods study. International Journal of Information Management, 75, 102731. https://doi.org/10.1016/j.ijinfomgt.2023.102731

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, conservation and recycling, 127, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005

Laskurain-Iturbe, I., Arana-Landín, G., Landeta-Manzano, B., & Uriarte-Gallastegi, N. (2021). Exploring the influence of industry 4.0 technologies on the circular economy. Journal of Cleaner Production, 321, 128944. https://doi.org/10.1016/j.jclepro.2021.128944

Lenovo. (n.d.). Down electronic waste with AI-powered device refurbishment. Retrieved from https://news.lenovo.com/down-electronic-waste-with-ai-powered-device-refurbishment/

Liao, H. Y., Esmaeilian, B., & Behdad, S. (2024). Automated evaluation and rating of product repairability using artificial intelligence-based approaches. Journal of Manufacturing Science and Engineering, 146(2). http://dx.doi.org/10.1115/1.4063561

Ligozat, A. L., Lefèvre, J., Bugeau, A., & Combaz, J. (2021). Unraveling the hidden environmental impacts of AI solutions for the environment. arXiv preprint arXiv:2110.11822. http://dx.doi.org/10.3390/su14095172

Motivo. (n.d.). Motivo: AI-powered solutions. Retrieved from https://motivo.ai/

Pagoropoulos, A., Pigosso, D. C., & McAloone, T. C. (2017). The emergent role of digital technologies in the Circular Economy: A review. Procedia cirp, 64, 19-24. https://doi.org/10.1016/j.procir.2017.02.047

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular economy:

measuring innovation in the product chain. Planbureau voor de Leefomgeving, (2544).

Rao, C. H., Avinash, K., Varaprasad, B. K. S. V. L., & Goel, S. (2022). A review on printed electronics with digital 3D printing: fabrication techniques, materials, challenges and future opportunities. Journal of Electronic Materials, 51(6), 2747-2765. http://dx.doi.org/10.1007/s11664-022-09579-7

Recycleye. (n.d.). Recycleye: AI waste management solutions. Retrieved from https://recycleye.com/

Sherpa, Y., & Sinha, D. (2021). Digital solutions for a circular electronics value chain: A thought paper for International E-Waste Day 2021. International Telecommunication Union (ITU), WEEE Forum, GSMA, & Sofies Group. https://weee-forum.org/wp-content/uploads/2021/10/Thought-Paper-2021.pdf

Shin, W., Han, J., & Rhee, W. (2021). AI-assistance for predictive maintenance of renewable energy systems. Energy, 221, 119775. https://doi.org/10.1016/j.energy.2021.119775

Singh, N., Duan, H., & Tang, Y. (2020). Toxicity evaluation of E-waste plastics and potential repercussions for human health. Environment international, 137, 105559. https://doi.org/10.1016/j.envint.2020.105559

Sivarajah, U., Kamal, M. M., Irani, Z., & Weerakkody, V. (2017). Critical analysis of Big Data challenges and analytical methods. Journal of business research, 70, 263-286. https://doi.org/10.1016/j.jbusres.2016.08.001

Sweep. (n.d.). SWEEEP Kuusakoski: AI WEEE sorting. Retrieved from https://recycleye.com/sweeep-kuusakoski-ai-weee-sorting/

Velos IoT. (n.d.). Improving waste management with smart bins. Retrieved from https://blog.velosiot.com/improving-waste-management-with-smart-bins

Zhang, T., & Kraisintu, K. (2011). The role of traceability in sustainable supply chain management.

Extended Abstract
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Accelerating Circularity in High-Tech Manufacturing: Towards a Roadmap for Implementing Digital Product Passports (DPPs) at SMEs

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Keywords: Digital Product Passports; Circular Economy; High-Tech Manufacturing; SMEs, Digital Longevity.

Introduction

Transitioning to a Circular Economy (CE) requires innovative lifecycle management (Bastein et al., 2021). In high-tech manufacturing, SMEs face unique challenges in achieving circularity and resource efficiency. A durable digital infrastructure is needed. Digital Product Passports (DPPs) enhance transparency, traceability, and sustainability throughout multiple product lifecycles (Transitie team Advies Circulaire Economie, 2022) using detailed documentation of materials, production processes, and multiple product lifespans, enabling informed decision-making for reuse, recycling and remanufacturing (Langley et al., 2023). While larger organisations have begun adopting DPPs, SMEs struggle with financial, regulatory, and technical barriers (European Commission, 2020; TNO, 2022), including differing requirements for data access (Jensen et al., 2023). Research on DPPs remains in its early stages (Lopes & Barata, 2024).

This study explores DPP implementation challenges and opportunities in SMEs, particularly those producing and assembling electronic equipment for industry. The study is conducted in collaboration with TechValley— a consortium of high-tech SME suppliers and Original Equipment Manufacturers (OEMs) in the Netherlands —It aims to provide a roadmap for effective adoption of DPPs, addressing key barriers and leveraging digital technologies for sustainable value creation (Kollenburg, 2023).

Through a structured analysis, this research aims to address the following central question:

How can digital technologies be used to achieve practical, feasible and circular value creation through DPP implementation at SMEs in the high-tech manufacturing industry?

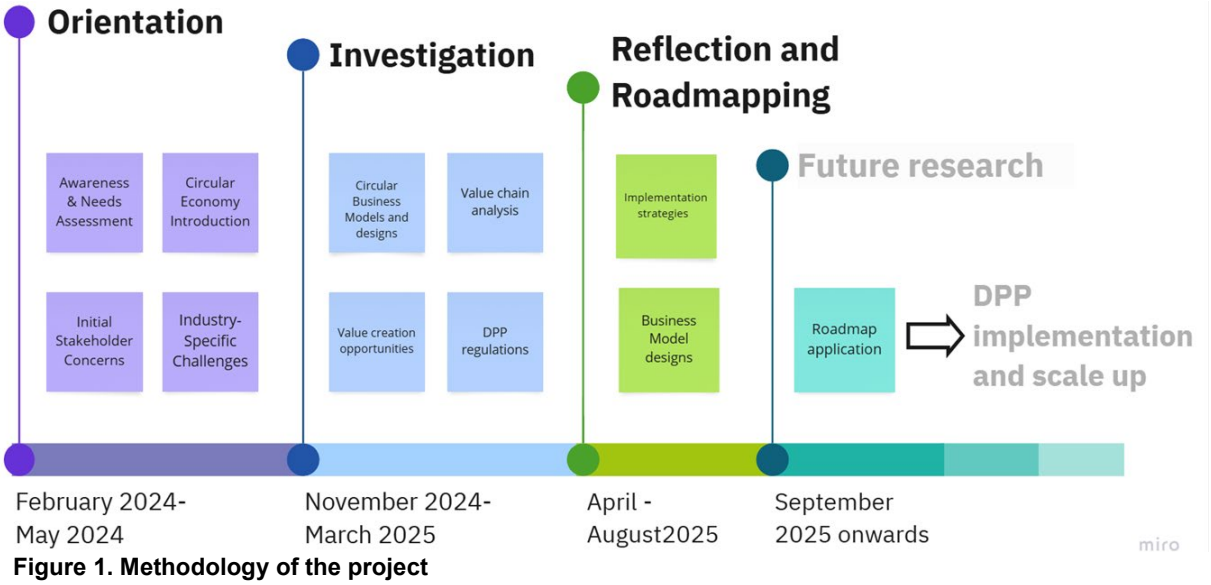


Figure 1. Methodology of the project

Methods

The research employs a multi-phased approach (figure 1), including literature reviews, stakeholder interviews, and four collaborative workshops with engineers, service engineers, business developers and managers from six companies (table 1) and two branch organisations.

Table 1. Companies from North Holland participating in the project

Role of the company	Product or service	No. of employees
Solution provider	Machine vision, robotics, data analytics and motion control	200 in 5 locations in the Netherlands
Manufacturer	High-quality coffee machines	450+ in 10 subsidiaries and two factories in Europe
Manufacturer	Blending, bagging, and transport equipment	50, one location in the Netherlands
Manufacturer	Equipment for seed processing.	75, one location in the Netherlands
Solution provider	Production automation	190, three locations in the Netherlands
Manufacturer	Specialists in 3D profiling technology within the heavy steel industry	120 in the Netherlands, 45 in Asia and 50 in the USA.

In the *Orientation Phase* (fig. 1), we gathered initial insights from stakeholders in workshops. These sessions helped create awareness of CE and DPP developments. Additionally, they helped identify key challenges, strategic priorities, and knowledge gaps regarding DPPs, laying the foundation for the subsequent workshops.

Participants were introduced to circular design and business strategies in the next two workshops (*Investigation Phase*, fig. 1) (Bakker et al. 2014). Together, we analysed the value chain, identified opportunities for value creation, and analysed how circular business models and designs can be used in circular production and product lifecycles to achieve competitive advantage. The workshops covered DPP-related regulations, such as Extended Producer Responsibility, Corporate Sustainability Reporting, and Eco-design (European Commission, 2023, 2024; Rijkswaterstaat, 2024).

During subsequent workshops in the *Reflection and Roadmapping* Phase (fig. 1), participants reflected on DPP barriers and opportunities of DPPs and the created business model designs from earlier workshops. Based on the reflections, we created a roadmap for conception, piloting, adoption and upscaling of DPPs.

The resulting roadmap aims to provide the basis for future research involving DPP implementation and scale-up.

Results

Circular design and Business Opportunities.

Participants identified key opportunities for DPPs to enhance circularity and business models at SMEs:

- **Cost Reduction**: Optimised material use, predictive maintenance, improved spare parts management, and standardised modular designs help manufacturers reduce production and service costs.
- **Improved Customer Relations**: Detailed lifecycle data supports after-sales services and take-back schemes.
- **New Business Models**: Leasing, refurbishment, resale, and "Product as a Service" models become viable.
- **Predictive Maintenance**: Traceability prevents failures, optimising downtime and workforce planning.
- **Sustainability Improvements**: Standardised records facilitate recyclability and secondary material use.
- **Transparency**: Consumers access sustainability metrics, regulatory compliance, and recycling potential.

Digital technologies Enabling DPP implementation and Product Longevity.

DPP implementation in high-tech manufacturing SMEs relies on digital technologies that enhance data traceability, resource optimisation, and predictive maintenance. Key enabling technologies include:

- **IoT & AI:** Enable automated DPP generation, real-time tracking for predictive maintenance and repair, and lifecycle analytics for reuse, remanufacturing and refurbishing.
- **Distributed Ledger Technologies (DLT):** Secures product data, ensuring transparency and regulatory compliance.
- **Digital Twins:** Simulate wear for optimising designs to improve maintenance, repair, reuse, remanufacturing and refurbishing.
- **Big Data & Additive Manufacturing:** Improve production of material recovery and on-demand spare parts.

These technologies contribute to longer product lifetimes through:

- **Predictive Maintenance:** Providing access to manuals, and performance data for reducing machine down-time.
- ***Enhanced repairability:*** Enabling efficient disassembly and supporting material recovery and circular sourcing.
- **Transparency & User Awareness**: Empowering users with lifecycle data to encourage responsible use and sustainable purchasing decisions.

While SMEs face cost and integration challenges, scalable solutions such as cloud-based AI, collaborative blockchain networks, and modular digital twins can mitigate barriers. Successful adoption requires sector-specific customisation and regulatory alignment.

Barriers to DPP implementation.
Despite benefits, SMEs face significant obstacles:

- **High Costs:** Digital infrastructure investments remain prohibitive.
- **Regulatory Uncertainty**: Evolving requirements create hesitancy in investment.
- **Data Integration Complexities**: Gaps in supply chain data and ERP system alignment hinder implementation.
- **Business Value Uncertainty:** SMEs struggle to quantify DPPs' operational and financial benefits.
- **Governance & Accountability**: Challenges in managing QR codes, traceability, and data accuracy persist.
- **Data Security Concerns**: Protecting intellectual property is a major challenge.
- **Recycling Limitations**: Some industries face material-specific recycling constraints.

Preliminary Roadmap for DPP implementation at SMEs.
A structured, SME-focused roadmap emerged from the workshops, comprising five stages:

1. **Technology Assessment:** Identify feasible digital tools, e.g. IoT, AI, and digital twinning.
2. **Business Opportunities**: Conduct SWOT analyses and stakeholder mapping for viability exploration.
3. **Piloting**: Develop a Proof-of-Concept, prototyping and testing case-specific solutions, including automated DPP generation and user tests at case studies with TechValley partners.
4. **Implementation**: Co-create implementation strategies with SMEs, researchers, and other stakeholders in the supply chain. The strategies include implementing standardised Distributed Ledger Technologies, secure data infrastructures, and collaboration agreements.
5. **Scaling Up**: Developing an innovation agenda and network for broader adoption amongst partners within and across the supply chain.

Conclusions and recommendations

Despite the clear potential of DPPs to enhance circularity, SMEs in high-tech manufacturing face significant adoption challenges, including high costs, complex regulations, and limited expertise in digital technologies. Addressing these barriers requires tailored strategies that align with SMEs' operational realities. This research identifies business opportunities through a structured methodology combining a literature review, stakeholder interviews, and participatory co-creation workshops. The proposed roadmap is designed to provide insights into business opportunities, guiding them in integrating DPPs into existing

production and business models. Key findings highlight that DPPs:

- Focus on business opportunities:
  - Improve maintenance, repairability, and traceability, extending product lifecycles.
  - Enable efficient recycling and reuse by enhancing material visibility.
- Increase transparency towards suppliers and users, improving communication across the supply chain, resulting in improved value propositions and sustainable business models.
- Facilitate learning-by-doing by actively co-creating a Proof-of-Concept and prototype. Moreover, stimulate participatory testing and validation.

This study contributes to the broader discourse on the digital longevity of DPPs and hardware in high-tech manufacturing by designing and iteratively adapting durable digital infrastructures to SMEs' CE needs. Cross-industry collaboration and knowledge exchange will be essential for long-term scalability.

Future research will focus on executing the roadmap at SMEs by developing proofs-of-concept and prototypes. Additionally, we will evaluate the adoption of the designs in real-world cases by assessing contributions to circular value creation, economic viability and technical feasibility.

By bridging policy, technology, and business viability, this research supports the development of circular high-tech value chains.

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References

Bakker, C., Hollander, M. den, Hinte, E. van, & Zijlstra, Y. (n.d.). Products that last 2.0 : product design for circular business models. 128.

Bastein, Ton; Van Harmelen, Toon; Hauck, Mara; Godoi Bizarro, D. W. S. (2021). TNO-rapport De impact van slim èn circulair: hoe innovaties in de maakindustrie bijdragen aan een lagere footprint | FME. https://www.fme.nl/tno-rapport-de-impact-van-slim-en-circulair-hoe-innovaties-de-maakindustrie-bijdragen-aan-een on 26-03-2025.

European Commission. (2020). Circular economy action plan - Publications Office of the EU. https://op.europa.eu/en/publication-detail/-/publication/45cc30f6-cd57-11ea-adf7-01aa75ed71a1/language-en/format-PDF/source-170854112 on 26-03-2025.

European Commission. (2023). Corporate sustainability reporting - European Commission. 2023. https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en on 26-03-2025.

European Commission. (2024). Ecodesign for Sustainable Products Regulation - European Commission. https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products-regulation_en on 26-03-2025.

Jensen, Steffen Foldager, Jesper Hemdrup Kristensen, Sofie Adamsen, Andreas Christensen, and Brian Vejrum Waehrens. 2023. 'Digital Product Passports for a Circular Economy: Data Needs for Product Life Cycle Decision-Making'. Sustainable Production and Consumption 37:242–55. doi: 10.1016/j.spc.2023.02.021.

Kollenburg van, T. (2023) 'In stapjes radicaal digitaal circulair worden'. Hogeschool Rotterdam Uitgeverij, ISBN: 9789493012462.

Langley, David J., Eugenia Rosco, Marios Angelopoulos, Oscar Kamminga, and Christa Hooijer. 2023. 'Orchestrating a Smart Circular Economy: Guiding Principles for Digital Product Passports'. Journal of Business Research 169. doi: 10.1016/j.jbusres.2023.114259.

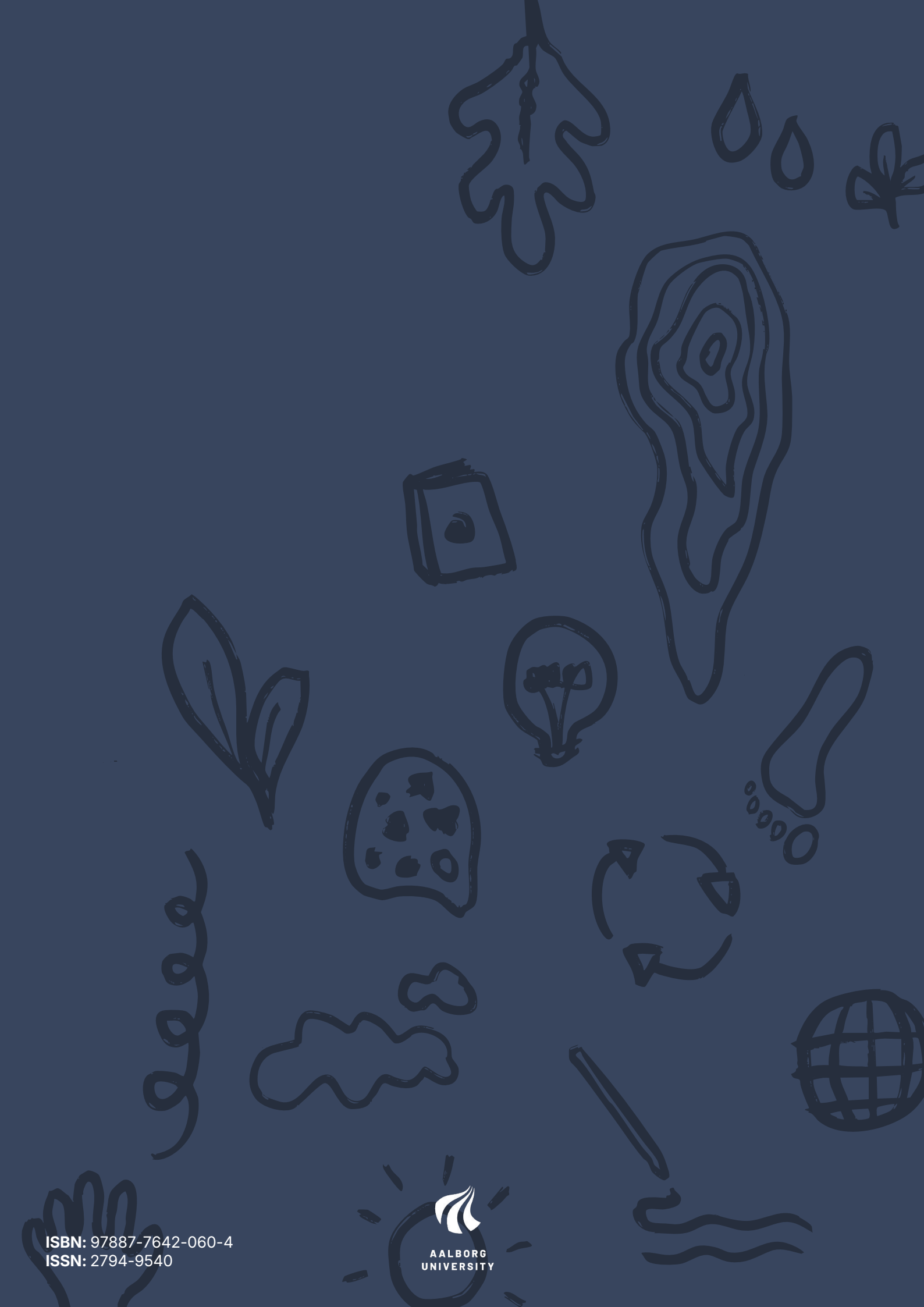
Rijkswaterstaat. (2024). Uitgebreide producentenverantwoordelijkheid. From: https://www.afvalcirculair.nl/producentenverantwoordelijkheid/. on 26-03-2025.

TNO. (2022). Productpaspoort: Basisvoorwaarde voor een duurzame economie. TNO Nieuws. https://www.tno.nl/nl/newsroom/insights/2022/03/productpaspoort-basisvoorwaarde-duurzame/ on 26-03-2025.

Transitieteam advies circulaire Economie. (2022). Adviesroute naar een circulaire economie voor de maakindustrie. https://circulairemaakindustrie.nl/document en/adviesroutekaart-transitieagenda-maakindustrie on 26-03-2025.

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