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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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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.

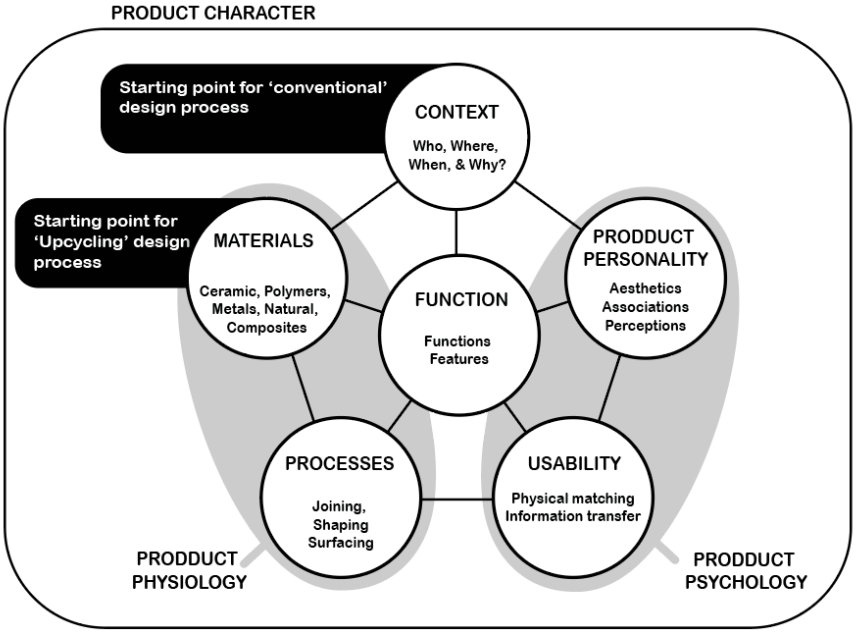

Figure 1. The dissection of Product Character, adapted from (Ashby & Johnson, 2002)

#	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.

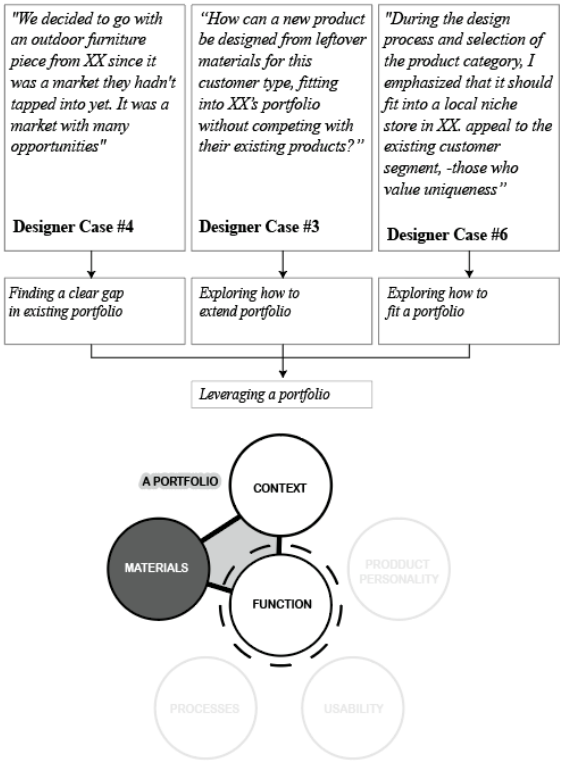

Figure 2. Example of analyzing quotes regarding exploration of functionality.

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.

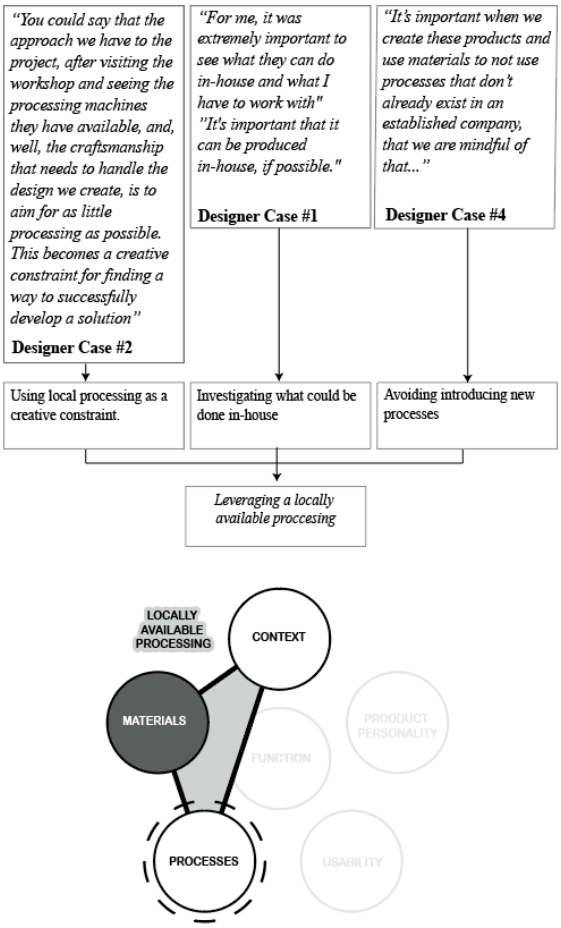

Figure 3. Example of analyzing quotes regarding Processes.

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.

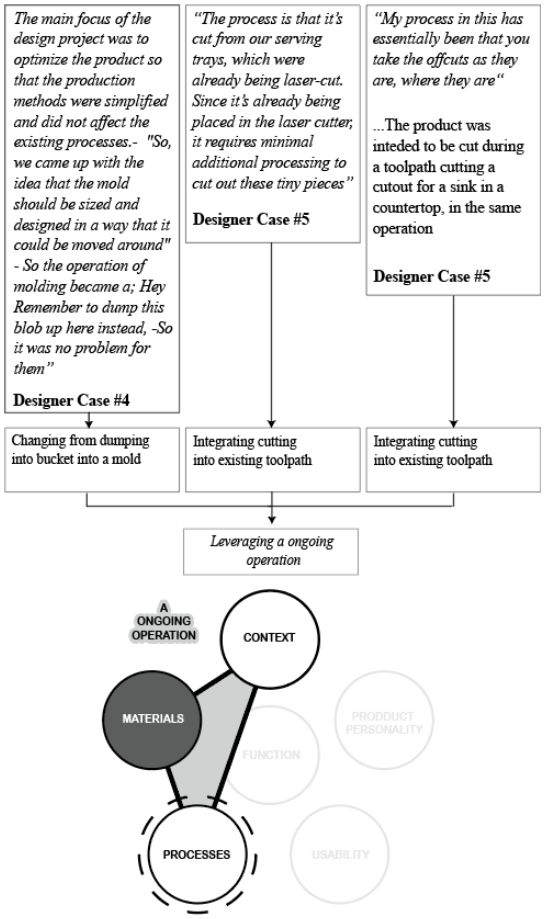

Figure 4. Example of analyzing quotes regarding Processes.

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.

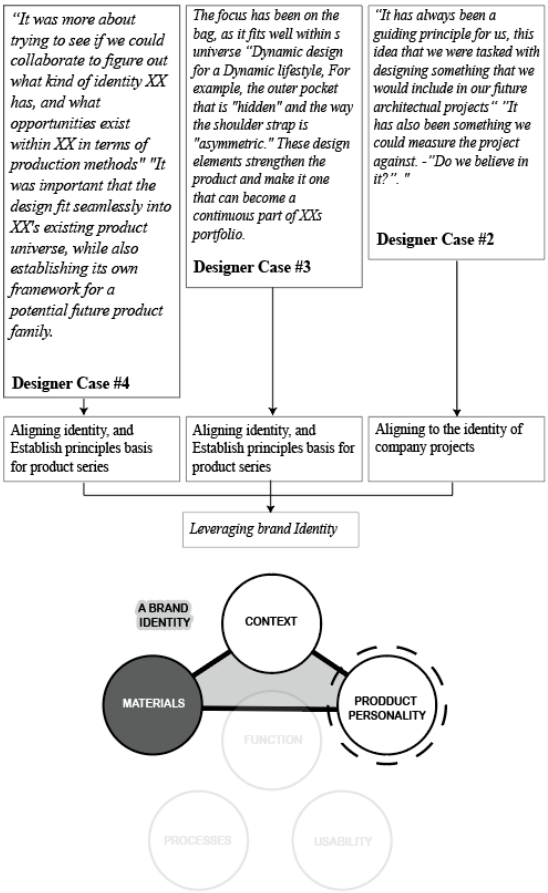

Figure 5. Example of analyzing quotes regarding exploration of product personality.

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.

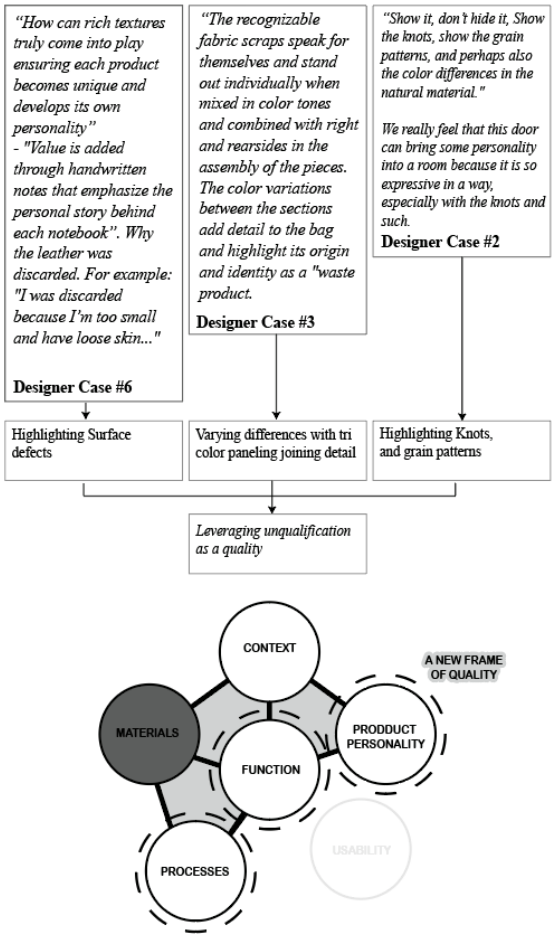

Figure 6. Example of analysing quotes with aligning Functionality, Product personality, and Processes.

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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