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CircularMAT: Materials Advisor Tool to promote circular material selection in fashion design

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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).

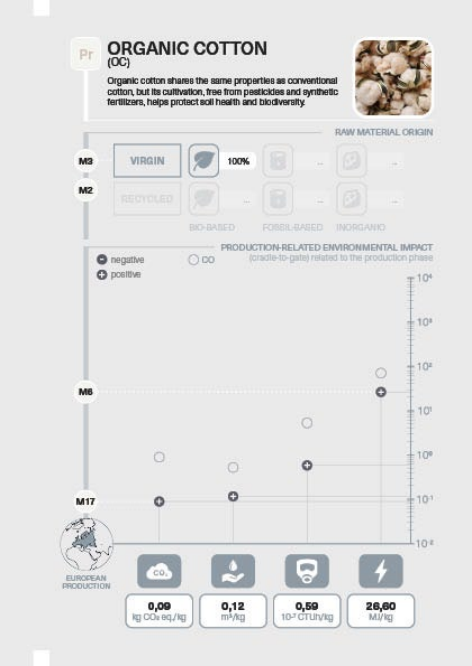

Fig. 1: Example Material Card [Front]. Author's Elaboration.

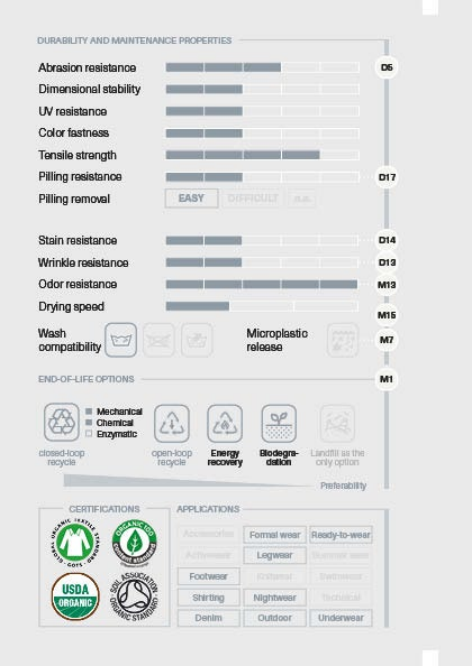

Fig. 2: Example Material Card [Back]. Author's Elaboration.

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.

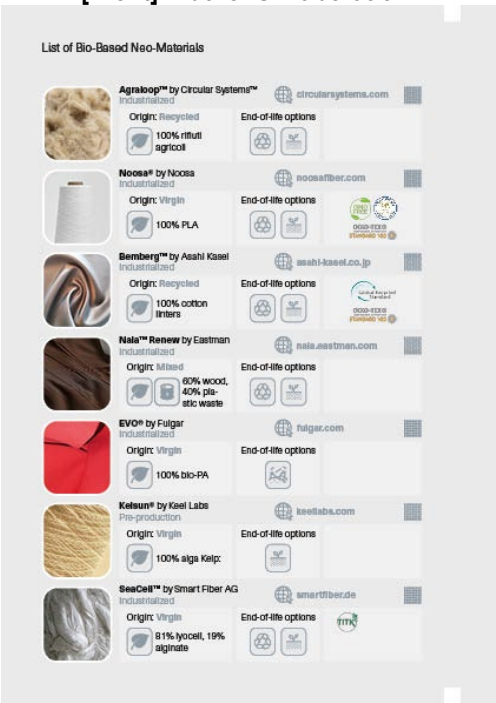

Fig. 4: Example Neo-Material Family Card [Back]. Author's Elaboration.

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?.

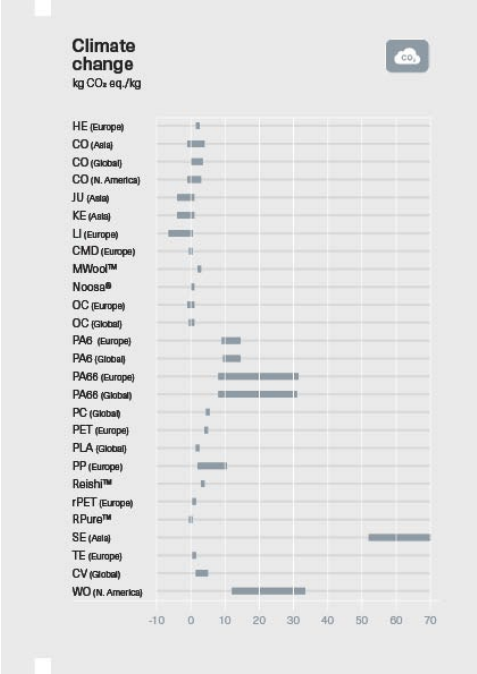

Fig. 5: Example Material Comparison Card [Front]. Author's Elaboration.

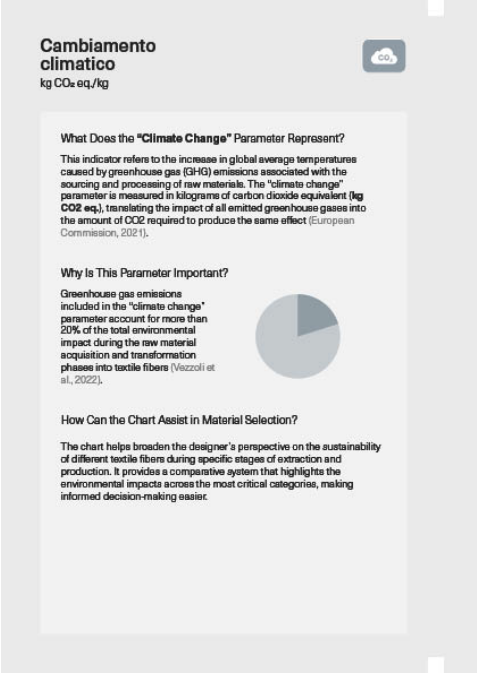

Fig. 6: Example Material Comparison Card [Back]. Author's Elaboration.

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**.

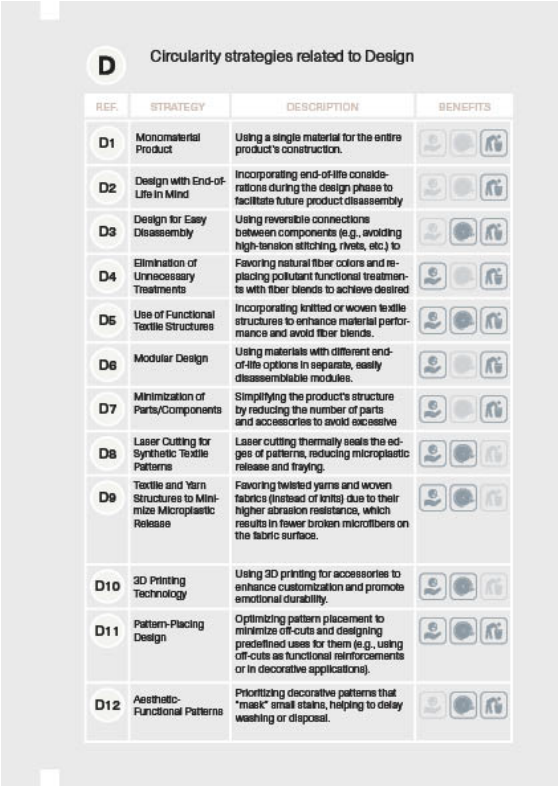

Fig. 7: Example Circularity Strategies Card [Front]. Author's Elaboration.

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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