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RESEARCH ARTICLE

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Circular fashion: evolving practices in a changing industry

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ABSTRACT

Today we are witnessing a change in the production paradigm of the fashion industry. The negative impacts of different processes along the supply chain are evident and consumers have begun to shift to brands seeking effective organizational strategies and supply chain-management models that consider the safeguarding of the planet's resources and demonstrate respect for people. Impelled by these developments, fashion brands are moving from market-driven to purpose-driven strategies. The fashion industry is now recognizing the circular economy (CE) as the leading entrepreneurial model for addressing supply-chain issues related to sustainability. However, there are still gaps in the levels of environmental, economic, social, and cultural sustainability being achieved. Implementation of this model on a large scale is still in the early stages and recent experience indicates a need to rethink the current linear system to enable different actors along the fashion-supply chain to adapt. Further, the fashion system lacks a holistic vision that can support and guide this sustainable transformation toward CE. This article describes how several companies are currently implementing circularity and presents evidence that an emphasis on this concept is relevant for the global fashion industry. It aims to show how emergent design practices are supporting fashion companies to better focus their sustainability agendas, to approach them in a holistic manner, and to consider all business processes with the goal of implementing sustainable development strategies. Analyzing contemporary design-driven best practices, the article introduces a taxonomy highlighting effective ongoing strategies (mini-loops) leading to incremental changes toward CE. Furthermore, it synthesizes possible future trajectories that could lead the fashion system to finally close the loop of circularity.

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Circularity; fashion-industry transformation; sustainable innovation development; sustainable value creation

Introduction

Sustainability has emerged as a "megatrend" in recent years (Mittelstaedt et al. 2014) and in the international fashion landscape the shift toward a more responsible system has given rise to the prominence of sustainable fashion (Hultberg and Pal 2021; Pal, Shen, and Sandberg 2019). The public's engagement in sustainability is also increasing as consumers, especially in European countries, are calling on fashion companies to act responsibly and to consider the social and environmental effects of their businesses (Riesgo, Lavanga, and Codina 2020; Granskog et al. 2021). The shift in consumer behavior highlights the need to address the issues of fashion sustainability as they are becoming significant determinants in final purchasing decisions (Gazzola et al. 2020).

As Granskog et al. (2021) has reported, despite the deep uncertainty that the fashion industry has experienced during the COVID-19 pandemic, there may be a silver lining for more sustainable performance. Several scholars have also speculated on whether the crisis might trigger a sustainability transition (Cohen 2020; Bodenheimer and Leidenberger 2020; Goffman 2020; Taylor et al. 2020). Further, as Uddin (2020) has remarked, the situation has been a "perfect storm" that has had extensive impacts on the global fashion system and its constituent networks. Fashion weeks were canceled, retailers closed, workers were laid off, and volumes of unsold stock increased. The direct result was that an expanding share of the fashion industry fell into financial difficulties (Granskog et al. 2021). Additionally, the pandemic further eroded the already precarious social dimensions of the fashion industry. Several global brands were forced to cancel orders and payments for garments that had already been produced and these outcomes had a devastating impact on

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manufacturers who faced losses in the billions (Anner 2020).

From the perspective of today, the current stage of the pandemic could be an opportunity for the fashion industry to strengthen its sustainability commitment and to accelerate industrywide changes to business strategies that displace the currently unsustainable linear system and begin to move toward a circular model (Casey 2021). This positive momentum has increased the visibility of the industry's sustainability agenda that has developed over the past four decades and emphasized the need for collaboration among industry, governments, and organizations to implement strategies focused on sustainability-related issues (Thorisdottir and Johannsdottir 2019). The signing of the Fashion Pact, a document presented to world leaders in 2019 at the 45th G7 Summit held in Biarritz, France, was initial evidence of this shift.[1] The pact's signatories—companies in the fashion and textile industries including their suppliers and distributors—pledged that their businesses would follow science-based objectives and operational changes to meet the Paris Agreement. The objectives of the accord center on three major issues: climate, biodiversity, and oceans (Mohr, Fuxman, and Mahmoud 2022; Pastran, Colli, and Nor 2021).

As an industry, fashion has followed the general evolutionary pattern of the world economy which in recent years has been characterized by emergence of competitive and unsustainable linear business models dominated by the globalization of markets and a subsequent overabundance of supply. This situation has led to the rise of new financial scenarios. Over the course of the past ten years, more responsible and market-driven companies have emerged with the goals of ensuring more effective coordination between supply and demand, developing new products, and organizing the physical flows of exchange and communication between companies and their customers (Voola et al. 2022; Beverland, Cankurtaran, and Loussaïef 2022; Wong and Ngaiy 2021; Crittenden et al. 2011). A primary factor motivating these initiatives has been the need to react to market trends (sustainability and transparency) and/or to respond to the evolving behavior of customers (e.g., prosumers, so-called LOHAS consumers).[2]

More recently, these approaches have given way to purpose-driven companies in which every business decision is consistent with a set of core values. These firms strive to demonstrate strategies that meet their business objectives and to create a suitable environment for their customers and employees. Purpose-driven companies set their objectives beyond mere profit as an end in itself and innovate continuously to increase their positive effects on people, the territories in which they operate, the environment, and the full range of their stakeholders (Gartenberg 2022). Notable examples of this commitment are brands such as Patagonia, Stella McCartney, and Ecoalf.[3] What distinguishes these companies is their voluntary choice to produce in a way that achieves their profit objectives and, at the same time, provides social and environmental benefits. These purpose-driven businesses are motivating others in the fashion industry to begin to formulate reliable strategies to reduce their adverse influences. This new attitude provides incentives for circular behavior—for instance designing and performing according to the 9Rs framework for progressively increasing the circular economy (CE) (Potting et al. 2017)—and calls for a clear focus throughout the entire organization on circularity as well as throughout the whole production process (Enquist and Sebhatu 2021).

This article addresses the role of design in reshaping the fashion supply-chain to enhance circularity. A purpose-driven model is inherently design-driven, as it has a design goal. The process of design is applied to develop strategy, to solve problems, and to create values. In the emergent sustainability transition, the role of design becomes strategic in its technical function in planning the fashion-system circle(s), reinforced by evidence that most sustainability benefits are obtained from procedures and processes implemented at the design stage (Bocken et al. 2016).

In the current context, design-driven strategies refer to those "design thinking practices" that leverage the different internal systems governing a company such as policies combined with procedures created by management (Verganti 2009). These interventions go beyond customers and consider "intermediaries" who understand and profoundly shape the markets in which they work (Rainville 2021; Verganti 2009). A design-driven perspective also enables a comprehensive and purpose-driven approach to circularity that can contribute to the establishment of feasible and common strategies among businesses, stakeholders, and communities (Battistella et al. 2012).

Grounded in this perspective, this article presents the results of an investigation of how fashion companies, particularly firms based in Europe, are addressing the circular transition with the support of design knowledge. The work presented here refers to the circular fashion field which is defined as a regenerative system that utilizes waste and transforms it into new products and useful resources. This system seeks to achieve a supply chain in which disused textiles

are collected, recycled, and remanufactured into new products (Bocken et al. 2016; EMF 2017; Geissdoerfer et al. 2018; Niinimäki 2018; Rathinamoorthy 2019).

We address specifically how circularity has been applied by small- and medium-sized enterprises (SMEs) that represent a majority of businesses in the European fashion sector and are considered key actors in leading change toward a circular fashion system. As reported by Black (2019), the size of these companies and their relative newness compared to the rest of the industry are strategic assets. Of special importance is their flexibility with respect to responses to evolving market conditions and demands (Cernat et al. 2014). As a result, many SMEs in the European fashion sector maintain a dynamic approach that allows them to guide systemic circular transitions. According to the CE framework, this is happening by keeping products in circulation at their highest value, designing and manufacturing them to be used again, and making garments from safe and recycled or renewable inputs (EMF 2020; Black et al. 2019).

The objective of the article is to report on how several firms are performing circularity—all along their supply chains—by focusing separately on two main aspects: (1) raw materials sourcing/production and (2) manufacturing. We discuss how these firms are able to strategically manage a single dimension of sustainability but continue to struggle to combine all facets in ways that will lead to the co-creation of renewed sustainable value to be re-input into the fashion cycle.

The second section presents our framework for defining the meaning of circularity and explaining how it applies to the fashion system. The third section then illustrates the methodology. We describe how design is strategically guiding development of a circular model for the fashion industry. This section also discusses how current circular strategies need to be supported by design to improve productive processes and to enhance associated practices for fashion. The fourth section introduces the results of the investigation and centers on final formulation of a taxonomy to visualize current circular behaviors in the fashion field. What emerges from this section is the identification of current working trajectories to determine the design directions that are driving the fashion industry toward circularity. The taxonomy identifies two main mini-loops related to two macro design-driven approaches to circularity: (1) raw materials and (2) manufacturing practices. The fifth section highlights exemplary best practices of companies that are operating along the two micro-loops by practicing circularity. We then conclude by describing how our model creates opportunities for further research. This section outlines how design could support the creation of an industrial ecosystem based on sustainable synergies and proposes practical examples of interventions for enabling the fashion industry to close the loop of circularity.

Addressing circular innovation in the fashion system

The current fashion-production model does not consider all stages of a product's life cycle, but only those useful for capitalist purposes (Stahel 2016). It is an approach that produces an enormous amount of waste and has various adverse effects on the environment. Further, viewing such processes through the lens of economics, this mechanism results in a loss of value immediately after its creation, which represents a missed business opportunity. This article reports on changes in the production paradigm of the fashion industry that show a transition toward circularity. According to this shift, designing for circularity is becoming a common goal of a growing number of firms. Therefore, the challenge of creating truly circular products within the fashion- and textile-supply chain appears to be one of the relevant steps to use materials more effectively and to preserve the planet's finite resources.

Yet, what does circularity mean? The concept of circularity derives directly from the domain of economics in which scholars first began to develop theories about the so-called "circular economy" as a response to the impacts of a linear production model based on the triad of "source-make-dispose." Such a definition highlighted the limits of the prevailing approach based on ecological and social requirements (Stahel and EMF 2019; Stahel 2010, 2016; EMF 2017; Raworth 2022; European Commission 1976).

This linear approach also corresponds to a specific design strategy that focuses exclusively on the product itself (Aho 2016), only considering the resources available, driven by the need that a consumerist market imposes to produce and sell ever-larger volumes of products without considering what happens to them after they break or become obsolete. In contrast, the CE model emphasizes rethinking the concept of growth and introducing a different perspective on the benefits necessary for a society to flourish. Such a approach implies gradually separating economic activity from the consumption of finite resources by reconsidering the design process in ways that avoid the production of waste (EMF 2017). Therefore, the circular model is intended to simultaneously grow economic, natural,

and social capital, and, as stated by the Ellen MacArthur Foundation (EMF) (2017), is based upon three objectives: designing out waste (DoW) and pollution, developing strategies to keep products and materials in use, and regenerating natural systems.[4]

To reach these circularity goals, it is crucial to limit the loss of value embedded in products and materials by keeping them circulating in closed cycles. These cycles aim to extend the life of products and to improve resource use. Once a product has reached the last stage in its cycle, its components, or a given set of materials, are put back into the cycle. This reuse could entail recycling resources, recovering different parts of the product, or reclaiming materials to continue their life through other forms.

In fashion, a circular design structure serves as a sustainable alternative in comparison to the previous generation of products and materials, being able to minimize resource inputs into the system and waste, emissions, and energy leakage out of it (Ostermann et al. 2021). This approach aims to mitigate adverse effects without compromising growth and prosperity (Geissdoerfer et al. 2018) and can be embraced by the fashion industry through specific supply chain-management strategies. These interventions can be implemented to offer opportunities for effective pathways toward a circular change in the system. They are primarily based on companies optimizing resources within their supply chains and working on solutions to solve unsustainability issues and excessive consumption patterns by focusing on decreasing the use of primary raw materials, avoiding waste production, and regenerating the systems involved.

Moreover, as Pal (2017) argues, the circular strategies of fashion companies tend to be structured according to Bocken's eight key sustainable business-model archetypes: maximizing material and energy efficiency, creating value from "waste," substituting with renewables and natural processes, delivering functionality rather than ownership, adopting a stewardship role, encouraging sufficiency, repurposing the business for society/environment, and developing scale-up solutions.

These business-model archetypes are now being tested in the market and can be found in new production and consumption paradigms. For example, they are evinced by the trend of developing efficient and effective solutions to extend the life of clothing: garments are now being rented and leased or, alternatively, brands themselves are increasingly offering free repair services to extend the life of products. These solutions have a dual effect: they satisfy customers emotionally and reinforce business value (Niinimäki 2018). A pivotal example is offered by Patagonia with its service "Worn Wear" that provides free repair to consumers who bring to one of the company's shops a used (and worn) garment, regardless of its brand.[5] Anyone can take advantage of free repairs of Gore-Tex garments, zippers, zipper flaps, buttons, punctured or torn fabrics, and more. The "Worn Wear" campaign is designed to encourage people to take care of their garments and to fix them if necessary to ensure that they last as long as possible as well as to educate people on how to care for their clothing to extend its functional performance. This "Worn Wear" initiative is consistent with the goal of the circular economy to adopt a new, more strategic, and future-oriented perspective in all aspects of a company's activities and to highlight how "repair is one of the strategic operations to keep products in use and could be coupled with business models such as rental and re-commerce" (EMF 2020, 6).

Hence, the business-model archetypes that have to date been introduced are inspiring the transformation of industrial systems in the textile and fashion industry and they are instrumental in leading to circular development through timely interventions that companies are incorporating into their approaches. At the same time, these archetypical interventions show the tendency of companies to operate through compartmentalized processes and systems: they still lack an overall vision of the fashion-supply chain and the intrinsic characteristic of holism required for circularity. Both knowledge and circular industrial practices are fragmented and thus require guidelines to make the ongoing and future initiatives more streamlined and effective. Furthermore, the fashion industry is facing severe constraints in implementing a circular system and its inherent strategies.

Considering this scenario, the following section illustrates the current state of circularity implementation in the fashion industry through field studies, aiming to better clarify the key role of design in driving toward a circular transformation. Drawing on the findings of the field studies, we highlight how design is embedded in thinking strategically about the circular model's development and show how current circularity strategies need to be guided by design to improve production processes and to enhance circular visions for fashion.

Methods

The insights for this article are drawn from three field studies that we conducted between 2019 and 2022 (Williams et al. 2019; Black et al. 2019). The

aim of these projects was to collect and incorporate knowledge into an interpretive model of how circular practices are embedded in the current fashion system. The first phase of the research consisted of mapping the sustainability-related practices of nearly 200 fashion companies in 24 European countries. These businesses have distinguished themselves by having reached a mature stage in their sustainability performances which has resulted in operating according to innovative approaches that progressively move away from greenwashing and become effectively viable and strategic (see Figure 1). The companies that we identified are heterogeneous and included fashion and textiles companies that have implemented sustainability not only in design but also in their management and technological practices. Further, consistent with the typical scale of actors in the European industry, most of the firms that we analyzed were SMEs, which means that they keep their revenues, assets, and number of employees below a certain threshold—generally less than 250 employees and €50 million in revenues per year (Black et al. 2019).

Among the 200 companies that we mapped, 45 were selected as case studies due to the advanced level of their sustainability transformation—applying in their practice a reformative approach that fosters how their key personnel think and work with sustainability (Sterling 2010)—and their specific method in implementing circular practices, often adopting a design-thinking approach as a driver. A design-thinking approach means fostering a positive impact of design on competitive advantage through an iterative process that creates sustainable values through the product and includes utilitarian, emotional, psychological, and sociocultural considerations (Verganti 2009) (Figure 2, Table 1).

The case-study database that we built included numerous sources from desk research involving company reports, scientific papers, specialized press accounts, and government publications. The case studies aimed to narrow down a vast field of research into easily researchable topics and they were chosen according to several criteria: (1) the commitment these companies place on proactively meeting the new sustainability demands of their stakeholders, (2) how they pursue strategic implementation of sustainable practices within their system by adopting a design-driven approach that means generating ideas that are humanly desirable, technologically feasible, and financially viable, (3) their dimension, since the study was intended to be as representative as possible we wanted to have cases from a range of companies (from micro- to medium-sized), and (4) the scalability of their practices which involved selecting companies that were representative of the different methods and technologies for textile-waste recycling so as to enable us to understand the state of the art.

The processing of these resources was based on content analysis (Duriau, Reger, and Pfarrer 2007) to identify recurring patterns and to allow us to find associations between how different circular practices are carried out. We defined the units of meaning—the frequency of individual words and phrases according to the set categories for coding: circular practices, sustainable materials, fashion design sustainable practices, product recovery, and waste collection. The analysis phase allowed us to start to draw the frame of our taxonomy of current circular practices in the fashion-supply chain. We identified

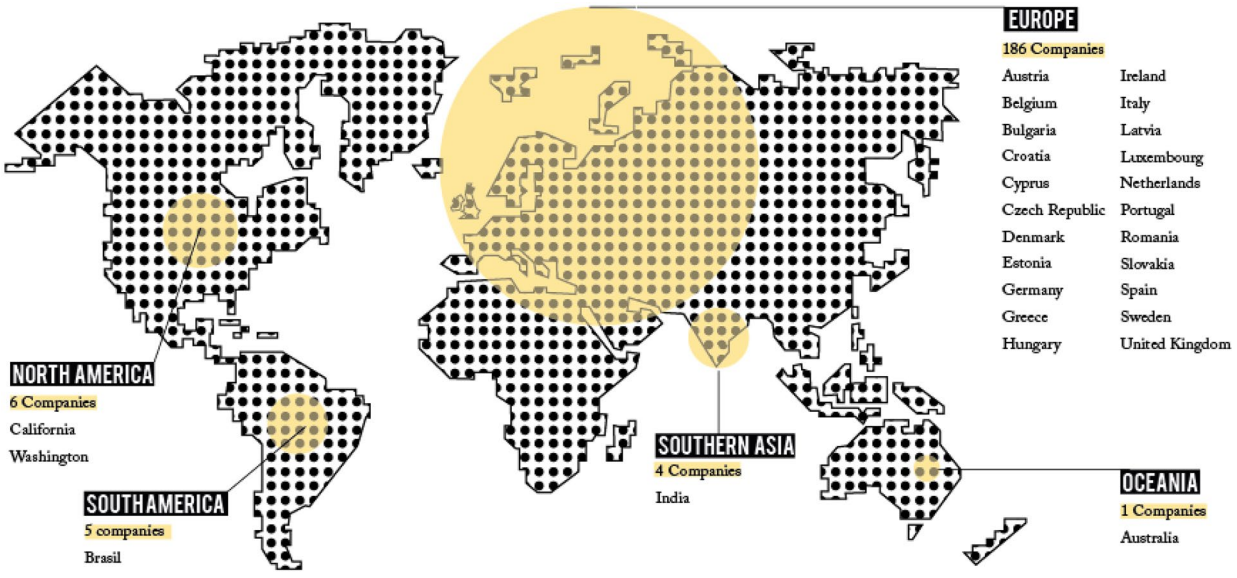

Figure 1. Map of the sustainability-related companies.

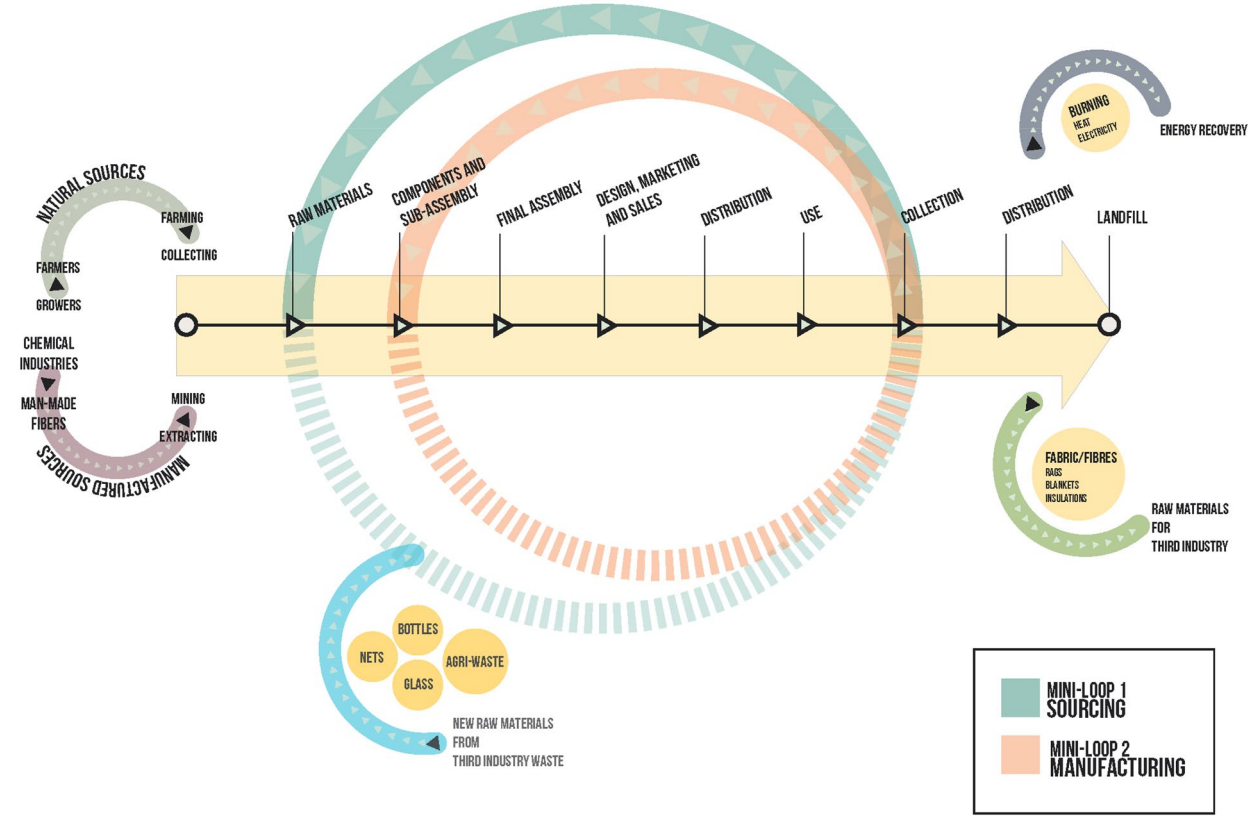

Figure 2. The mini-loops model.
Source: Adapted from D'Itria (2022).

the three steps of the supply chain where the circular practices were performed with the greatest frequency, namely raw materials supply, product manufacturing, and waste collection and management. This further research phase allowed us to better refine the model and to identify the specific design-driven circular fashion approaches that are currently being carried out within the fashion- and textile-supply chain.

We conducted a further qualitative phase after the case-study analysis based on interviews with the selected representatives of the previously identified 45 companies. The interview selection was based on an additional desk-research phase to better profile the companies and to identify the varying degrees to which firms have incorporated circular features into their operations (especially with respect to the optimization of materials and products). We then characterized each of the case studies according to the level of commitment of each company to satisfy the requirements of circularity. More specifically, we focused on how firms were actively seeking to practice sustainable design to reduce the life cycle impacts of their products and to keep the resultant materials in a closed loop. The evidence we collected enabled us to create a taxonomy of current circular production practices in the fashion field. The resultant typology is a first attempt to understand how specific design-driven approaches can support the transformation toward circular fashion.

Identifying design-driven circular fashion approaches

Based on the qualitative research findings, this section explores the role of design in leading to systemic circular changes in the fashion and textile industry. It is initially crucial to understand the main systemic barriers to implementing circular fashion practices. These obstacles have been discussed extensively in the literature and can be synthesized as follows:

- A lack of awareness on the part of companies and inadequate education of the workforce regarding circularity (Dissanayake and Weerasinghe 2022).
- Firms continue to consider recycled materials to be a new niche market and is thus more expensive, entails lower quality, and is less performative than virgin counterparts (Jia et al. 2020).
- Recycled textiles have no economic benefits and/or market opportunities (Leal Filho

Table 1. List of case studies.

Country	ID Code	Sector	Mini-loop 1 (raw materials)	Mini-loop 2 (components and subassemblies)
Austria	C1	Materials/fibers	x	
Austria	C2	Materials/fibers	x	
Belgium	C3	Materials/fibers	x	
Czech Republic	C4	Production		x
Denmark	C5	Materials/fibers	x	
Denmark	C6	Materials/fibers	x	
Estonia	C7	Clothing		x
Finland	C8	Materials/fibers	x	
Finland	C9	Materials/fibers	x	
Germany	C10	Materials/fibers	x	
Germany	C11	Recycling	x	
Germany	C12	Materials/fibers	x	
Germany	C13	Recycling	x	x
Greece	C14	Materials/fibers	x	
Ireland	C15	Clothing		x
Italy	C16	Materials/fibers	x	
Italy	C17	Materials/fibers	x	
Italy	C18	Materials/fibers	x	
Italy	C19	Clothing		x
Italy	C20	Clothing		x
Italy	C21	Recycling, upcycling		x
Italy	C22	Material innovation, research and development		x
Italy	C23	Material innovation		x
Latvia	C24	Clothing		x
Luxembourg	C25	Clothing		x
Netherlands	C26	Materials/fibers		
Netherlands	C27	Clothing	x	
Netherlands	C28	Materials/fibers		x
Netherlands	C29	Materials/fibers	x	
Netherlands	C30	Materials/fibers		x
Portugal	C31	Materials/fibers	x	
Portugal	C32	Materials/fibers	x	
Portugal	C33	Materials/fibers	x	
Romania	C34	Recycling		x
Slovakia	C35	Clothing		x
Spain	C36	Materials/fibers	x	
Sweden	C37	Materials/fibers	x	
Sweden	C38	Materials/fibers	x	
Sweden	C39	Technology	x	
Sweden	C40	Clothing		x
Sweden	C41	Clothing		x
UK	C42	Clothing		x
UK	C43	Materials	x	
UK	C44	Materials/fibers	x	
UK	C45	Materials/fibers	x	

et al. 2019). Technologies for material detection and sorting are still in the preliminary research and development stages and the industry is still forced to rely on manual sorting operations that require expansive and extensive labor involvement (Sandwick 2019).

- There is a lack of textile-to-textile recycling technology. Modern textiles are made with diverse materials, colors, and finishers and scaling up the recycling process—both chemical or mechanical—is challenging in terms of technical obstacles and economic feasibility (Pedersen, Earley, and Andersen 2019).
- There is a lack of consumer interest and awareness (Kirchherr et al. 2018).
- There is an absence of adequate collection and sorting schemes to guarantee circular processing at the end-of-life stage (Dissanayake and Weerasinghe 2022).

The fashion sector's circular solutions should be centered on building long-lasting products that embed as a feature the possibility of feeding cascading loops through regeneration or recycling to circulate materials and to create value across different supply chains. But, as Theeraworawit, Suriyankietkaew, and Hallinger report (2022), companies today tend to ignore the interconnected nature of supply chains and they resist adopting holistic approaches that acknowledge that actions taken at one stage are passed on to the next. The key goal of this study is to show how the transition to a circular system can be enabled and empowered by intervening at the design stage and highlighting how the most currently successful design strategies are being adopted by the fashion industry. These design strategies were codified from the processing of the data collected and the results of the mapping process, the analysis of case studies, and then validated by a qualitative survey through interviews to

identify and describe the most promising fashion-design practices.

The taxonomy visualizes current circular behaviors in the fashion and textile field and shows two main promising design approaches currently associated with a circular supply-chain model: (1) Design focused on materials with high sustainable performance characteristics and (2) Design focused on enhancing durability through manufacturing strategies such as recyclability, upcyclability, and refurbishment. These circular approaches need to be investigated in today's fashion and textile systems. With this in mind, the most ambitious aim of this article is to present a realistic picture of circular systems. The greatest challenge lies in the fact that to date the fashion and textile industry operates in accordance with a linear paradigm. The two emerging design directions that can promote circular perspectives result in cyclical inputs positioned along a supply chain based on a linear model. They are represented here as two mini-loops related to the two macro areas of intervention for circular practices from a design perspective:

- Sourcing that addresses all the aspects related to strategies that focus on design-driven solutions based on the production and use of materials with high sustainable performance characteristics. This loop starts in the raw materials step and re-enters the system in the collection phase.
- Manufacturing refers to design-driven practices that enhance circularity through production strategies based on reusing and transforming resources and materials. This loop starts in the production phase and re-enters in the collection step.

Figure 2 shows the current linear fashion-supply chain. On this line are positioned the external actors who supply raw materials at the beginning of the system, whether of natural or artificial origin. At the end of the line are actors who recover waste from the sector either to transform it into energy through thermal valorization practices or to reuse it as a secondary raw material in their supply chain through industrial synergies (e.g., the building-materials industry transforms textile waste into carpets or insulation panels). Regarding internal supply-chain phenomena, our research describes how mini-loops are inserted along the production chain to create circular phenomena. From this representation, it is also clear how industrial synergies can occur along these diagrams, on Mini-loop 1, by collecting waste from third industries as new raw materials (i.e., plastic-industry waste is recovered to produce recycled polyethers).

We discuss in the following sections the two mini-loops to elaborate on how their relative design direction influences the supply chain, generates values throughout, and facilitates circular experiences for the involved companies. A subsequent presentation of best practices further supports these design-driven paths.

Mini-loop 1: Sourcing

Mini-loop 1 represents all design practices which have been enabled by the introduction of several disruptive innovations related to materials such as production practices in recycled fibers and embryonic process technologies related to sorting and recycling (Sandvik and Stubbs 2019). The industries operating in Mini-loop 1 are striving to be more restorative and regenerative in the flow not only of products but also byproducts and waste by narrowing, slowing, and closing resource and energy flows (Bocken et al. 2016).

Companies that operate in this loop are differentiated by their ability to overcome sectoral barriers including technical constraints, institutional inertia, and the scalability of their technologies or circular business models. Generally, these are textile SMEs investing in hyper-sustainable technologies—machinery and equipment developed from the application of scientific knowledge to produce resource-efficient technology and to drive activity that increases investments and growth while substantially reducing sustainability impacts—to produce, recover, and transform raw materials from existing biological or technical cycles. Adapting the notion of upcycling as introduced by McDonough and Braungart (2002), on one hand, the biological cycle includes biologically-based biodegradable raw materials obtained from natural resources. On the other hand, the technical cycle comprises human-made materials, environmentally hazardous materials, and rare metals used, for example, in electronics.

These companies have refined traditional production practices or experimented with new radical processes gaining traction and reaching a higher level of sustainability compared to traditional ones. They have designed or redesigned their products in ways so that they usually require fewer resources and have a reduced impact on the environment, communities where they operate, and people. These firms have enabled important transformations by focusing their circular practices on redesigning materials or creating new ones by focusing on materials design and

related methods to empower the whole design process and to represent the initial step in creating sustainable items.

Mini-loop 2: Manufacturing

Mini-loop 2 represents all design practices in the fashion and textile industry that are aimed at reducing the dependence of firms on natural resources and enhancing manufacturing practices by reclaiming surplus, unexploited materials, or used products. These companies conduct research and develop innovative production practices to achieve performance that is equal or superior to the processing of virgin products and, in turn, minimizes the need for raw resources. These outcomes can be achieved by exploiting the reverse side of the fashion-value chain and specifically focusing on collection, sorting, and processing.

First, the collection phase consists of recovering the products that consumers discard (Paras, Curteza, and Varshneya 2019). Second, the sorting phase involves the selection of disused products according to their condition or type (Geissdoerfer et al. 2018). Finally, the processing phase involves different design-led actions intended to re-establish the function of the products and/or materials and to increase their value (Abraham 2011).

Companies that operate within Mini-loop 2 cope with industry issues such as dealing with inadequate infrastructure available for managing material waste generated by the fashion industry, facing the limitations of current regulations that were designed for a linear system and do not incentivize or enable circular practices, and reconciling consumer misconceptions about extended product life and secondhand materials or garments.

These companies, primarily SMEs, are investing in design-led practices to reduce dependence on natural resources and to enhance the reuse of items by increasing their value. As Murray (2002) stated, these practices are intended to preserve the planet's virgin and limited resources and to leverage the hidden value embedded in the recycled product by exploiting the potential of design knowledge to make this value explicit and to enable recirculation.

In this context, it becomes crucial to consider the waste hierarchy. To fully implement circularity in the textile and fashion industry, it is necessary to engage in upcycling and recycling on an industrial level (Khamisani 2021; Cassidy and Li-Chou Han 2017). Upcycling is a design method that offers the opportunity to circulate leftovers in production through new design processes. In turn, the waste left behind during upcycling is recycled and returned to the loop of the fashion industry or to third-party sectors.

Best practices for implementing new circular processes in the fashion system

Starting from the mini-loop model, we further explored its potential by conducting several field studies. We initially focus on two emblematic cases of the respective mini-loops: Vegea®[6] (Mini-loop 1) and UPMADE[7] (Mini-loop 2). In addition, we present a third "hybrid" case study involving a firm called Re:newcell which was selected for its ability to exploit the characteristics of the two cycles and to merge them to refine and implement circularity.[8]

The sourcing loop: Vegea®

Vegea is an Italian company that has developed a leather-like coated fabric. The company began by studying the physical and mechanical characteristics of various vegetable fibers and assessing their ability to be transformed into new leather-like materials. This first phase enabled the identification and production of new fibers obtained from grape skins and seeds. These raw materials, which are byproducts of the wine industry, have proven to be optimal for feeding an innovative production process that converts the waste and vegetable oils embedded in the pomace (the pulpy residue that remains after crushing) into a unique material. The technology does not require waiting for the seasonal rhythms associated with the grape harvest. After the pomace is pressed and separated, it is dried to avoid biodegradation. This process ensures that the materials maintain their properties unaltered for at least three years and hence remain readily available to be transformed.

The name Vegea comes from a combination of Veg (Vegan) and Gea (Mother Earth). It refers to the next generation of sustainable materials and capitalizes on renewable resources as an alternative to animal-based materials and nonrenewable fossil resources which are the source of almost all synthetic alternatives to animal skin. Vegea designed its process outside of common sectoral barriers by also embracing a collaborative model involving public and private contributors and allowing for the establishment of synergies and partnerships with local industry and research actors.

After the success of its first prototype, the company continuously invested in research and development to create innovative technologies and processes capable of minimizing the negative effects on the

environment. The aim has been to establish new production chains to valorize biomass and agro-industry residues. This waste is a valuable raw material that can be transformed into new fashionable products. For this reason, the company has established strategic collaborations with Italian wineries to set up a process to recover their production as raw material for the Vegea process.

Vegea is an emblematic example of a company that has promoted innovative industrial ecosystems starting from waste streams. The new production chain provides better valorization of ecosystems, creation of self-reliance, and development of greater circularity in production, distribution, consumption, and recycling methods. In this context, Vegea has responded to the challenge of overcoming barriers in its supply chain to enable systemic learning and to create and produce new fashion solutions with greater eco-efficiency that reduce and utilize food waste as a resource to explore material creation opportunities.

According to the Micro-loop 1 parameters, Vegea has differentiated itself by overcoming its own sectoral barriers such as technical constraints and environmental impacts and experimenting with a radical new process. The company's production practices are much more sustainable than traditional ones, as their products are based on 100% sustainable resources and have a positive impact on the environment and the people involved in their supply chain.

The manufacturing loop: UPMADE® system

The UPMADE system is designed to introduce the circular economy into the fashion and textile industry. It allows brands and manufacturers to apply the industrial upcycling method and to obtain certification by designing and producing new eco-friendly clothing made from surplus materials. UPMADE provides a solution that supports in a real and practical way the goal of circular economy to design and in turn produce zero waste. According to Aus et al (2021), between 24.7% and 39.2% of the textile material sourced for customary clothing production is wasted. The UPMADE method closes the loop by applying upcycling on an industrial scale and reducing textile waste, allowing the conversion of otherwise wasted materials into valuable and sellable products (Aus 2011).

Jointly created by the second author of this article in cooperation with the Stockholm Environmental Institute Tallinn, the UPMADE system aims to use textile upcycling on an industrial scale by creating garments made entirely from production residues that are 100% upcycled. This maximization of resources leads to energy, water, and other resource savings by avoiding the production of new materials.

The UPMADE system consists of software, design tools, and a certification process. Using production, fabric, and design information from the brand's original order, the UPMADE software conducts waste analysis (to determine what kinds of leftover materials are available) and environmental analysis (to determine what resources can be saved because of upcycling). This is a unique kind of gap analysis. Using specific production data, a new upcycled product is created, leading to a physical sample. Each sample is presented with the results of a life cycle assessment. At the end of the process, the UPMADE system issues a certification for the manufacturers and validates that recycled products are made from production residues, fabric waste does not contain harmful chemicals, and production operations are socially responsible, meet workplace-safety requirements, and do not use child labor. UPMADE certification gives brands and retail companies a choice between manufacturers that are proven to deliver custom-made upcycled products and consequently allows brands to increase transparency with their customers who are increasingly seeking this information.

In 2014, UPMADE certified its first garment producer in Bangladesh and saved nearly 175 million liters of water and more than 108,000 kilograms (kg) of carbon dioxide (CO_2) in its first five years. This means that textile waste has been reduced by nearly 13,000 kg and the materials have instead been converted into new clothes (Saarniit and Moora 2019). Such achievements are evidence that the system can help certified factories to reduce textile leftovers and to sell more production services while at the same time enabling the brand to produce more products from fabric that it has bought. UPMADE also helps create longer-term cooperation between the brand and the factory which can reinforce the transparency of the supply chain.

Consistent with the features highlighted in Micro-loop 2, UPMADE invests in design-led practices enabled by technologies to reduce dependence on natural resources and to enhance the reuse of items by increasing their value.

The crossbreeding loop: Re:newcell

Renewcell is a Swedish company founded in 2012 by a group of innovators from the KTH Royal Institute of Technology in Stockholm. The firm has developed an innovative process that allows for the chemical recycling of cellulosic materials. The process can transform used materials including cotton and rayon

(also known as viscose) into a biodegradable pulp to obtain new fibers and, therefore, new yarns, fabrics, and garments. The revolutionary innovation of its recycling process lies in the fact that the product does not suffer a decrease in fiber quality: when virgin-wood resources are compared to its cellulose fibers, the quality is the same.

In 2014, the company produced a dress made from blue jeans recycled using Re:newcell technology. The resulting yellow dress was the first garment ever made from previously used and chemically recycled textiles and the first fully recyclable garment. Re:newcell soon began producing other garments including tee-shirts, children's pajamas, and scarves. By 2017, Re:newcell had opened a production facility and this development marked the larger-scale viability of the technology, the optimization of its process, and the refinement of its process to increase efficiency, robustness, and quality. In addition, during the same year, the company received a major investment from the Swedish retailer H&M that provided important financial resources and gave the company visibility and credibility in the fashion industry.

Re:newcell is an emblematic case that represents how innovative textile companies can support the fashion industry's transition to a circular supply-chain model. Its key innovation is represented by the company's use of waste produced within the same supply chain as the raw material to create a final fiber that is equivalent to a virgin one. The company's sustainable business model is designed to minimize Re:newcell's impacts on the planet, particularly on water and land because if one kg of clothing is produced from recycled materials instead of from virgin cotton, oil, or wood thousands of liters of water are saved and there are decreased environmental impacts on land (Pensupa, 2020). These objectives are also embedded in other aspects of the company's production practices which entail using only renewable energy, safeguarding wildlife, and requiring no pesticides.

This company bridges the two mini-loops to refine traditional manufacturing techniques with design-led practices. It exploits and repurposes used materials to create new products through also implementing novel production processes and cycles, without affecting the resources available to the planet and restoring the intrinsic quality and value of the recycled material.

As a hybrid company that operates between the two mini-loops, Re:newcell has differentiated itself by overcoming sectoral barriers such as regulatory issues related to the very hybrid nature of the company, which is unique due to the fact that it cuts across both the wood products and fashion industries. First, the legislation represented an important obstacle because the company did not fall within the regulatory framework of the market system. Such a framework had not been updated at the time and is only now changing according to the new strategic actions promoted by the European Union (EU) to encourage circular business models (i.e., European Clothing Action Plan). Other barriers were related to technological aspects that the company has chosen not to make public for strategic and competitiveness reasons and the lack of investors able to foresee the potential of a disruptive process in the absence of tangible examples or competitors. Furthermore, Re:newcell did not comply with common business standards due to its hybrid and intersectoral commitments (Black et al. 2019).

Through a design-driven approach, Re:newcell developed a process that nurtures a regenerative supply-chain model using a resource that is both accessible and abundant as well as bridges cross-sector barriers and facilitates mutual exchange and collaboration across different industrial ecosystems.

Conclusion

This article addressed the potential role of design in changing the course of fashion-production processes by rethinking and innovating the traditional supply-chain processes to achieve circularity. The taxonomy presented profiles of the design-driven trajectories that are initiating circular change in the fashion and textile industries by introducing circularity into the linear materials and manufacturing dimensions.

The taxonomy presented in this article suggests that the emphasis on circularity is relevant to the global fashion industry and provides a roadmap for companies seeking a systemic approach to their sustainability strategies to reach a point of fully closing the circularity loop. Study of the mini-loops supports the stimulation of a perspective change in the sector guided by design. The effect on the supply chain can occur only through a change at the design stage that considers all of the system's variables and imagines possible new processes. These mini-loops highlight how transitioning to a circular model calls for new infrastructure systems. Such infrastructure should consider the product's entire lifecycle and the possibility of enabling materials to circulate for extended periods of time through an interplay of knowledge and practices in different steps of the supply chain. The overall objective should be to maximize product longevity together with the

optimal use of resources, as well as to avoid the production of waste and to minimize the impacts of industrial activities on the ecosystem (Ferguson 2009). Such synergies along different steps in the supply chain extend beyond organizational boundaries and include interorganizational collaboration and networks in which actors from other sectors (e.g., textile, food, agriculture, chemicals) play a more interactive and relational role (Bourlakis et al. 2014).

Companies that engage in the modes of circularity depicted by the mini-loops are now beginning to overcome one main obstacle: developing new materials and/or innovative production models that must be adopted in what is a still linear context. The linear practices can profoundly influence the circularity potential of the innovation, impairing its ability to effectively return materials to the production system. For example, today's theoretically circular fibers (biodegradable or compostable materials that can be reintegrated into biological cycles) are often blended with other unsustainable materials (synthetic fibers that cannot be repurposed). The result of such blending makes it impossible to recycle and return the original materials to their respective production cycles. Furthermore, the circular innovations are also constrained by limitations imposed by research and development and challenges associated with obtaining grants or other types of funding.

Stemming from the results of this article, research directions toward circular fashion should focus on establishing a clearer picture of how an industrial ecosystem based on positive synergies influences the sector experiences toward closed loops. Furthermore, while this article investigated circular fashion practices in terms of sourcing and manufacturing, additional studies are required to gain more insight into the final part of the supply chain into different patterns of consumption. There is a need to investigate, for instance, whether new green retailing and the phenomenon of digitization in customer interaction can be associated with enhanced beneficial effects on sustainability, connecting the upstream manufacturing green transition with downstream green distribution and behavioral change on the part of consumers.

Regarding the further development of mini-loops, future research should broaden our understanding by investigating the proposed pathways to strategically incorporate design-driven actions to become adoptable guidelines for the growing number of companies working in this field. Their work is promising, but as discussed in this article, these innovations in fashion are still adapting to the prevailing context. Most of the companies we find in today's market are SMEs born during the last two decades. This should not be taken as a constraint. These smaller but dynamic firms will be able to demonstrate, as they already have done to some extent, that they are best suited for survival. In fact, due to their dynamism, which allows them to adapt flexibly to different events as was the case with the COVID-19 emergency of the past years or the evolving climate crisis.

To conclude, innovation in the fashion-design path toward circularity is a rich field of research. The cases portrayed in this article speak to a process of rapidly unfolding change due in part to recent policy actions such as the EU's Green Deal and the European Clothing Action Plan that focus on supporting a circular transformation of European industry toward a sustainable paradigm. Such a dynamic environment will contribute to the quest to make fashion more sustainable and responsible.

Notes

1. See https://www.thefashionpact.org.
2. LOHAS is an acronym meaning Lifestyles of Health and Sustainability.
3. See https://eu.patagonia.com, https://www.stellamccartney.com/sustainability, and https://ecoalf.com.
4. See https://ellenmacarthurfoundation.org.
5. See https://wornwear.patagonia.com.
6. See https://www.vegeacompany.com.
7. See https://www.upmade.org.
8. See https://www.renewcell.com/en.

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