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Circular Economy Approaches in Fashion Textiles: Fibre Innovation, Recycling, And Trends

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Abstract- Fashion is becoming a dominant force that applies the principles of the circular economy and makes goods sustainable, reduce the scale of waste, and protect the viability of resources. This review clarifies the main trends in the area of circular fashion such as the development of systems of textile recycling, the production of new types of fibers and the transformation of the following markets. The analysis also notes how artificial intelligence is the key to transformative technology that simplifies the process of automation of processes, enhances transparency, and drives the creation of new business models, e.g., shared-use and collaborative-consumption models. However, these innovations are faced with significant obstacles, especially difficulties with managing mixed-material compositions, absent infrastructure and lack of consumer-behaviour limitations that hinder its mass adoption. The review highlights that technological progression, enabling regulatory initiatives, and multi- stakeholder partnerships represent essential conditions that have to be applied to the creation of a fully-circular fashion ecosystem.

Keywords- Circular economy, sustainable fashion, textile recycling, Fiber innovation, artificial intelligence, fashion supply chain.

I. Introduction

The fashion industry is an extremely powerful economic instrument in the world economy at a very high price to the environment. The industry tends to revolve around a TAKE, MAKE, DISPOSE model (Fig-1) hence resulting into a rapidly depleting model of resources. The consequences of this linear mode of production are high amounts of waste in the form of textiles, excessive use of water, and excessive greenhouse gas emissions. The situation has been worsened by the introduction of cheap fast fashion, in which individuals wear clothes and get rid of them after a few months. Most of the abandoned clothes are found in garbage heaps, which is an over consumption and waste.

To reverse this, the industry must also adopt a more sustainable manufacturing process, as well as educate the general population on the environmental impact of high textile usage. Circular economy offers a different approach where clothing can be reused, repaired and recycled (Fig- 2). Such a transformation can minimize waste, increase the life of resources, and ecological footprint of fashion industry. Fashion is among the most polluting industries, and one of the greatest contributors to pollution is water use, greenhouse gases, and textile waste (Niinimaki et al., 2020; Bick et al., 2018). The culture of overconsumption in the industry is facilitated by the accelerated patterns of production in the TAKE-MAKE-DISPOSE model which detes natural resources and damages the environment (Brydges, 2021; Joy et al., 2012).

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The circular economy (CE) can assist to decrease wastes, extend the lifespan of a product, and permit closed-loop systems that can assist in reuse, repair, and recycling (Kohler and Finkbeiner, 2021; Bocken et al., 2016). The textile industry should redefine the product life cycle, including the source of raw materials up to the disposal, in order to reduce its environmental footprint (Li et al., 2020).

Nevertheless, there are difficulties with the implementation of CE in the fashion industry because of the lack of collection systems of used clothes, recycling facilities of blended fabrics, and people in general lack understanding of the sustainable options (Maiti and Singh, 2022; Roos et al., 2020). Also, the business model of fast-fashion makes transition efforts harder because it facilitates short-term buying behavior (Moon and Youn, 2022; Pal and Gander, 2018).

Circular fashion requires innovations to facilitate it. Circular ecosystems can be achieved with the help of new fiber-regeneration systems, chemical recycling technologies, and digital tools like AI and blockchain that would allow achieving improved traceability and smarter product use (Wang and Li, 2020; Zhang et al., 2021; Roos et al., 2020).

The present review is devoted to the application of the practice of a circular economy to the fashion and textile industry based on three major pillars:

- Material circularity and sustainable design.
- Policies that promote the reduction and recovery of recycling.
- Trends in the market and the business model that facilitate circular consumption.

The fashion industry has traditionally been based on a linear TAKE-MAKE-DISPOSE system, where a significant number of resources is squandered and the environment harmed. The circular economy presents a new option of transforming the system with reusing, repairing, and recycling in order to create a closed-loop system, which is sustainable.

Figure 1
Linear Economy (Author-2025)

Figure 2
Circular Economy Cycle (Author-2025)

Fiber Innovation

The first stage in circular fashion is the selection of materials. The majority of conventional fabrics are not recyclable, biodegradable, or durable, which constrain the possibility of their placement into closed-loops (Köhler & Finkbeiner, 2021). As a

result, innovation in fibers that will support sustainable design, reuse, and recycling is increasingly rising.

The recycling of blended fabrics like cotton-polyester that are cheap and comfortable but incredibly hard to separate and recycle is one of the major issues in circular fashion (Roos et al., 2020; Zamani et al., 2017). Researchers consider mono-material garment construction, where a single type of fiber is used to create a product, this approach means it is much easier to recycle (Zhang et al., 2021; Li et al., 2020). Other methods of sustainable design, including pattern cutting based on zero-waste principles and buildings of products in modular forms, are also attracting interest (Moorhouse & Moorhouse, 2020).

Future alternatives that could replace traditional materials are regenerated and bio-based fibers. As an example, TENCEL™ and REFIBRA technologies use wood pulp and cotton waste to make biodegradable and recyclable fibers (Moorhouse and Moorhouse, 2020). Also, chemical recycling technologies allow breaking down used fabrics into a set of reusable raw materials, diverting the reliance on virgin materials and promoting material circularity (Maiti & Singh, 2022; Wang and Li, 2020).

CIRCULAR FIBER-TO-FIBER RECYCLING PATHWAY FOR TENCEL™ / REGENERATED FIBERS

Wood Pulp → TENCEL™ Production → Use Phase → Post-Consumer Textile Waste
↓
Recycling Process
↓ ↓
Chemical Recycling Mechanical Recycling

Artificial intelligence (AI) and textile data analysis are opening new opportunities to the development of circular fashion. Computer vision and machine learning have enabled companies to the quality of fabrics, identify signs of wear, and even determine the recycling potential of fabrics. These features aid in reuse and material recovery decision-making (Sandin & Peters, 2018). Nevertheless, a number of difficulties persist such as the scarcity of data and the absence of standardized fiber classification systems, limiting the large-scale use of technologies (Sandin & Peters, 2018).

The introduction of fibers is a key aspect of the development of circular fashion. Recycling in which waste products are used to create other products is experiencing challenges in balancing aesthetics, durability, and sustainability. The current upcycling models are based on the small scale but show that the idea of the circularity can be initiated by conscious sourcing of materials and design choices at the stage of the product development (Sung, 2017).

CIRCULAR ECONOMY RECYCLING STRATEGIES

Circular fashion relies on recycling extensively: used clothing and manufacturing waste can be re-introduced to the supply chain, consequently minimizing waste and decreasing the need in virgin materials (Sandin and Peters, 2018; Shirvanimoghaddam

et al., 2020). Nevertheless, Recent estimates indicate that in 2024, world textile waste has attained approximately 120 million metric tons, of which an approximate of 80 percent of used clothing goes to landfills or is burnt, and only less than 1 percent is recycled into new fiber (Boston Consulting Group [BCG], 2025).

The absence of textile waste collection and sorting infrastructure is one of the fundamental issues hindering the circular fashion. In most areas, particularly in low- and middle-income states, there are no systematic systems to sort by the type of material, quality, or recyclability of waste (Maiti and Singh, 2022; Roos et al., 2020). Manual sorting of used clothes is often done, which is time-consuming and likely to have errors, especially in cases of blends or dyed fabrics.

The recycling of textiles generally takes two general forms:

- **Mechanical recycling:** cutting or shredding fabrics in order to recover fibers. Although the process is cheap and relatively easy, it tends to compromise the quality of the fiber.
- **Chemical recycling:** de-polymerizing fabrics into simple polymer or fibrous components, which can subsequently be re-spun into new yarns or fibers. This process is more efficient in maintaining quality of materials and yet is more difficult to manage technologically and economically particularly in blended fabrics.

The other pathway is upcycling where the waste textiles are reused to produce alternative products without breaking down the fibers. Upcycling is providing value added products and also funding localized and community driven sustainability programs. However, its scalability is limited to demand of consumers, its acceptance by the market, and the economic feasibility (Pedersen et al., 2018; Diddi and Yan, 2019).

In order to enhance the rate and efficiency of recycling, the new innovations are targeting automated textile sorting systems. Near-infrared (NIR) scanning, machine learning, and computer vision are technologies in progress to sort fabrics by type and determine their recyclability (Zhang, Hu and Liu, 2021; Roos et al., 2020). Initial experiments have shown a high level of accuracy (more than 90%), in sorting pure fabrics such as cotton or polyester, but mixed fabrics or composite fabrics are challenging to sort with reliable accuracy.

Nevertheless, technological improvement is not enough. Recycling is also impossible without strong reverse logistics, producer responsibility and cross-stakeholder (manufacturers, retailers, consumers, waste management firms) collaboration. It is also improbable that scale- up can take place without the support of favourable policy frameworks, including extended producer responsibility (EPR), take-back requirements, and recycling infrastructure incentives (Kohler and Finkbeiner, 2021; Maiti and Singh, 2022).

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TRENDS AND CIRCULAR BUSINESS MODELS

Over the past years, the fashion industry has movingly adopted new ways of doing business and changing consumer behavior trends as a way of accommodating the concept of a circular economy. One of these trends is the increase in collaborative consumption, such as second- hand shopping, clothing rentals, and resale websites, which will extend how long a garment can be used and minimize the necessity of creating a fresh piece (Pedersen and Netter, 2015; Pal and Gander, 2018).

Table I. Common Circular Business Models

BUSINESS MODEL	DESCRIPTION	KEY BENEFITS	CHALLENGES
Second-hand resale	Selling pre-owned clothes via resale platforms or thrift stores	Reduces waste, offers affordability and access	Consumer reluctance, quality concerns, hygiene perceptions
Clothing rental	Renting clothes for short-term or rotational use (subscription or pay-per-use)	Access to variety, reduces overproduction	Logistics, cleaning costs, wear-and-tear management
Clothing repair & upcycling	Repairing damaged garments or creatively reusing materials	Extends garment life, supports local/micro business	Consumer awareness, demand, design limitations

Source: Author (2025), Compiled from literature.

Such models are usually dependent on consumer trust, convenience, and perceived quality to be successful (Pedersen et al., 2018; Diddi and Yan, 2019). A large number of consumers, particularly the younger generations, are less concerned with sustainability during their garment purchases, are more price-sensitive, and focus on beauty and novelty.

There is also an increase in the service-based models: rather than owning clothes, the consumers can obtain garments as a service through subscription, rental, or clothing-as-a- service services. They are often facilitated by digital solutions (real-time inventory, data analytics, IoT) that facilitate tracking of product utilization, maintenance, and returns - thus facilitating circularity (Zhang, Hu and Liu, 2021; Li et al., 2020).

Simultaneously, the contribution of technology is on the rise, especially the systems based on AI. Second-hand markets and clothing-as-service can be made more efficient and reliable with the help of automated quality inspection, resale sorting, reverse logistics, and dynamic pricing.

However, with all these innovations and opportunities, the universal implementation of circular business models is still underutilized. The main obstacles are logistical complexity (reverse supply chains, returns), the high operational or maintenance cost, a fast-fashion culture among consumers, and the prevalence of low-cost, disposable clothing (Pedersen and Netter, 2015; Diddi and Yan, 2019).

It is also influenced by regulatory and policy challenges. Circular economy practices are voluntary in most countries. Scalability is limited without compulsory interventions (e.g. EPR, compulsory collection systems, mission to recycle and reuse) (Kohler and Finkbeiner, 2021; Shirvanimoghaddam et al., 2020).

FUTURE DEVELOPMENTS AND OPPORTUNITIES

The future of circular fashion depends on the progress in various spheres.

- **Material and fiber innovation:** Materials and fibers Biodegradable, regenerable, and easily recyclable fibers (such as bio-based, lab-grown, and regenerated materials) are necessary to decrease the use of virgin resources and restore the possibility of having a closed-loop fashion system. Fiber technology not only enhances the level of recyclability but also increases the product life and its level of environmental performance, contributing to the overall sustainability of the industry (Maiti & Singh, 2022; Wang and Li, 2020).
- **Smart technologies and artificial intelligence (AI):** Automated sorting, quality assessment tools, digital product passports and blockchain-enabled traceability are all advanced AI-driven systems that are changing the supply chain management. They can ensure the accurate tracking of material flows, optimizing the recycling processes, and enhanced transparency which, in the end, enables the operationalization of circular practices within a complex global textile network (Zhang, Hu and Liu, 2021; Li et al., 2020).
- **Circular business models:** Circular business models like clothing rental, resale platforms, repair service, and subscriptions play a vital role in the lengthening of the product life cycle and decreasing overproduction. These models enhance resource efficiency by encouraging more people to adopt sustainable consumption practices since they switch their consumption patterns to a service-based one (Pedersen and Netter, 2015).
- **Policy reform and regulatory frameworks**: Compulsory policies and regulation, such as extended producer responsibility (EPR), ecodesign regulation, and financial assistance of recycling infrastructure is important to scale circular initiatives. Regulation efforts do not only force businesses to go green but also can support innovation and collaboration throughout the whole value chain, meaning that the circular strategies will be provided at a systemic level (Köhler and Finkbeiner, 2021; Shirvanimoghaddam et al., 2020).
- **Education, awareness and consumer involvement:** There should be an overall success of circular fashion which relies on the development of consumer knowledge and sustainable consumption patterns. Programs that inform consumers on environmental impacts, proper clothing maintenance, reuse, and recycling should be initiated to initiate a behavioral change. Educated and active consumers become drivers of circular practices, thus becoming an addition to technological and policy interventions (Diddi and Yan, 2019).

CONCLUSION

The shift towards a circular economic paradigm of the traditional fashion industry is the key to minimizing environmental decay, minimizing resource wastage, and encouraging more sustainable consumption trends. Circularity is not a simple task to reach, and it will require the development of recyclable, biodegradable, and regenerative materials; AI-based sorting, tracing, and recycling systems, as well as the introduction of new business models, including resale, rental, repair, and subscription services.

Nevertheless, since there is substantial progress, there are still serious barriers such as technology limitation in processing mixed-fabric, the lack of collection and recycling facilities, ingrained fast-fashion consumption, and the lack of regulations. Addressing these issues requires joint efforts throughout the value chain, including policymakers, manufacturers, retailers, and consumers, with the help of facilitating policies, specific incentives and prevalence of education.

Finally, the future of a fully material innovation, digitalization, business innovations, and multi- stakeholder innovation seems a valid direction towards an even more resilient and full-circular fashion industry. Through a long-term dedication, the sector will be in a position to balance between economic development and the environment and social sustainability.

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