IJAD INTERNATIONAL JOURNAL OF ART AND DESIGN

Fashion in Transition: From Industrial Growth to Circular Futures

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DOI: https://doi.org//10.69648/GRMT6262

International Journal of Art and Design (IJAD), 2026 3(1): 1-19

ijad.ibupress.com

Online ISSN: 2955-2400

Application: 16.04.2026

Revision: 21.05.2026

Acceptance: 23.06.2026

Publication: 26.06.2026

Gjureska, M. (2026). Fashion in transition: From industrial growth to circular futures. International Journal of Art and Design, 3(1), 1-19. https://doi.org//10.69648/GRMT6262

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Abstract

From the Industrial Revolution to the present day, the fashion industry has undergone profound transformation driven by industrialization, globalization, and the widespread adoption of synthetic materials. While these developments have increased accessibility and production efficiency, they have also contributed to significant environmental challenges, including pollution, resource depletion, textile waste, and greenhouse gas emissions. The purpose of this paper is to examine the factors that have shaped the contemporary fashion system and to explore current pathways toward sustainability.

The study employs a literature-based review and analytical approach, drawing upon academic sources, policy documents, and industry reports to examine the historical development of the fashion industry, the environmental consequences of textile production, the psychological drivers of consumer behavior, and the role of legislative and design-based interventions. The findings indicate that sustainability challenges are rooted not only in production processes and material choices but also in consumption patterns, branding strategies, and broader cultural perceptions of value.

The paper highlights the growing importance of circular economy principles, innovative materials, technological developments, and responsible design practices in supporting the industry's transition toward sustainability. It concludes that meaningful change cannot be achieved through technological innovation or material substitution alone, but requires a broader transformation of the systems, values, and consumption patterns that continue to drive production and demand.

Keywords: Fashion sustainability, consumer behavior, circular economy, textile industry, sustainable design.

BALKAN JOURNALS

Methodology

This paper is based on a narrative literature review methodology. It synthesizes academic literature, policy documents, industry reports, and institutional publications to examine the historical development of the fashion industry, the factors contributing to contemporary sustainability challenges, and emerging pathways toward circular futures.

The analysis is structured around four interconnected thematic areas. The first examines the environmental consequences of industrialization, mass production, and the widespread adoption of synthetic fibers within the textile industry. The second explores the relationship between consumer behavior, market demand, branding, and over-consumption through perspectives drawn from consumer psychology and marketing studies. The third investigates legislative and systemic responses to sustainability challenges, with particular attention to international sustainability agendas and European Union policy frameworks. The final section reviews contemporary design-oriented solutions, including circular economy strategies, zero-waste design, innovative materials, technological developments, and ethical approaches to fashion production.

Through an interdisciplinary synthesis of existing knowledge, the paper aims to provide a comprehensive overview of the factors that have shaped the contemporary fashion system, identify the drivers of its sustainability challenges, and evaluate emerging pathways toward more sustainable and circular futures.

Literature Review

The transition toward sustainable and circular fashion has attracted increasing scholarly attention as researchers seek to address the environmental, social, and economic consequences of industrial textile production. Existing literature spans multiple disciplines, including textile engineering, fashion design, consumer psychology, environmental policy, and circular economy research, reflecting the complexity of sustainability challenges facing the contemporary fashion industry.

Historical studies have documented how the Industrial Revolution fundamentally transformed textile production through mechanization, factory-based manufacturing, and later the introduction of synthetic fibres. These technological developments significantly increased production capacity and reduced manufacturing costs, laying the foundation for the modern global fashion industry while

simultaneously intensifying resource consumption and environmental pressures (McIntyre, 2005; Yorke, 2015). More recent research has further demonstrated that the environmental impacts of textile production extend beyond manufacturing to include intensive water consumption, chemical pollution, greenhouse gas emissions, and microfibre release throughout the product lifecycle (Malik & Bharti, 2021; Rathinamoorthy & Raja Balasaraswathi, 2024).

Alongside the environmental consequences of industrialization, scholars have increasingly examined the behavioural and psychological dimensions of fashion consumption. Research has shown that clothing purchasing decisions are influenced not only by functional needs but also by identity construction, social status, symbolic value, and emotional attachment. Luxury branding, consumer perception, and marketing strategies continue to shape purchasing behaviour, often reinforcing patterns of overconsumption that conflict with sustainability objectives (Lindstrom, 2008; Kapferer & Bastien, 2012). Recent work has further highlighted the persistent attitude–behaviour gap, demonstrating that environmental awareness alone does not necessarily translate into more sustainable purchasing decisions, particularly when factors such as price, convenience, habit, and trust influence consumer choice (Sario, 2025).

A third body of literature focuses on the transition from a linear to a circular economy within the fashion sector. Circular economy research emphasizes strategies that extend product lifecycles, minimize waste generation, and improve resource efficiency through reuse, repair, remanufacturing, and recycling (Kirchherr et al., 2017; Ellen MacArthur Foundation, 2013). These principles have increasingly influenced international and European policy frameworks, including the European Union Strategy for Sustainable and Circular Textiles, the Ecodesign for Sustainable Products Regulation, Extended Producer Responsibility schemes, and the Digital Product Passport, which collectively seek to improve product durability, transparency, and accountability throughout the textile value chain (European Commission, 2022, 2024; Organisation for Economic Co-operation and Development [OECD], 2016; United Nations, 2015; United Nations Environment Programme [UNEP], 2023).

Within fashion design research, increasing attention has been devoted to methodologies capable of embedding sustainability directly into the design process. Zero-waste fashion design proposes that environmental impacts should be addressed during product conception by eliminating material waste through innovative pattern-cutting approaches rather than managing waste after production (Rissanen

& McQuillan, 2016). More recently, digital technologies—including three-dimensional design software, artificial intelligence, digital prototyping, virtual fitting, and supply chain traceability—have emerged as important enablers of sustainable fashion by improving production planning, reducing material waste, and supporting more transparent and data-driven decision-making (Sario, 2025).

Despite the breadth of existing research, much of the literature examines these themes independently. Historical analyses frequently focus on technological development, consumer studies emphasize purchasing behaviour, policy research concentrates on regulatory frameworks, while design scholarship often explores sustainable methodologies in isolation. This paper contributes by integrating these perspectives into a single interdisciplinary narrative, tracing the evolution of fashion from industrialization to contemporary circular strategies while highlighting the interconnected roles of technology, legislation, consumer behaviour, and design innovation in shaping more sustainable futures.

Discussion

The literature reviewed in this paper suggests that the sustainability challenges facing the fashion industry are the result of interconnected environmental, economic, and social factors. While industrialization and synthetic materials have contributed significantly to pollution and resource depletion, consumer culture and market-driven production systems have equally accelerated patterns of over-consumption and waste.

The findings indicate that technological innovation and material substitution alone are insufficient to achieve meaningful sustainability. Legislative frameworks, circular economy principles, and design-led strategies represent important steps forward; however, their effectiveness depends on broader changes in consumption patterns and perceptions of value.

Ultimately, the transition toward circular futures requires a systemic approach that integrates policy, industry practice, design innovation, and consumer responsibility. Sustainability in fashion therefore represents not only a technological challenge, but also a cultural transformation in the way products are produced, valued, and consumed.

The Legacy of Waste: Industrialization, Synthetic Materials, and Environmental Consequences

The sustainability challenges facing the contemporary fashion industry cannot be understood without examining the historical developments that transformed textile production over the past two centuries. The origins of many environmental and social issues associated with fashion can be traced to the Industrial Revolution, which fundamentally altered the scale, speed, and organization of textile manufacturing. This transformation was driven by a succession of technological innovations that mechanized nearly every stage of textile production. The introduction of the Spinning Jenny, water frame, spinning mule, Flying Shuttle, and power loom, together with the transition from waterwheel to steam-powered factories, dramatically increased production speed, output, and manufacturing efficiency. At the same time, innovations such as Eli Whitney's cotton gin accelerated raw material processing, supporting the rapid expansion of the global textile industry (Yorke, 2015). Prior to industrialization, textile production was largely localized and labor-intensive, relying on natural fibers such as wool, linen, cotton, and silk. Garments were often produced in limited quantities and were valued as durable possessions intended for long-term use.

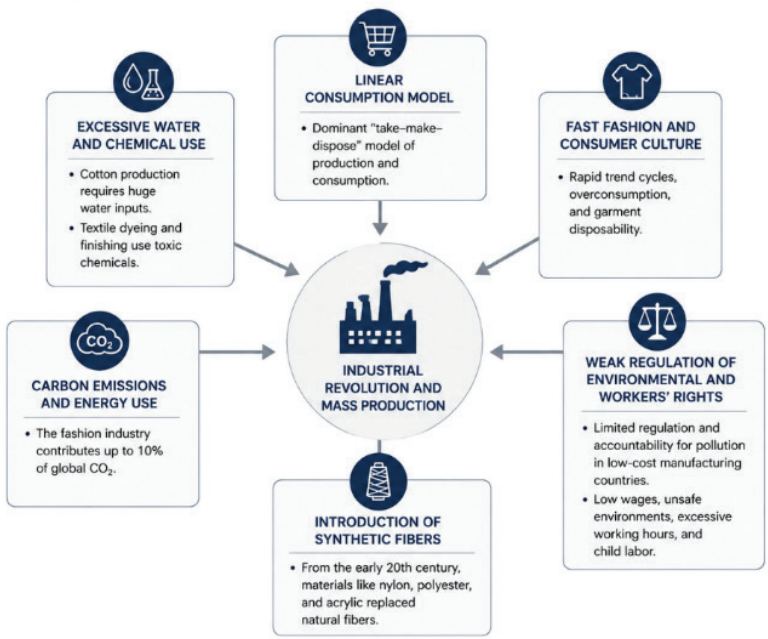
The Industrial Revolution introduced mechanized spinning, weaving, and manufacturing technologies that dramatically increased production capacity while reducing costs. Textile production became one of the earliest sectors to adopt industrial methods, laying the foundation for modern mass manufacturing systems. As production expanded throughout the nineteenth and twentieth centuries, clothing became increasingly accessible to broader populations, contributing to rising consumption levels and the emergence of fashion as a global industry.

The transformation initiated by the Industrial Revolution extended far beyond increased production capacity. As textile manufacturing expanded throughout the nineteenth and twentieth centuries, a complex network of environmental and social challenges emerged alongside industrial growth. Increased demand for raw materials encouraged intensive agricultural practices, while textile dyeing and finishing processes introduced large quantities of chemicals into production systems. The development of synthetic fibers further increased dependence on fossil-fuel-based resources, and the globalization of manufacturing often shifted production to regions with weaker environmental oversight and lower labor costs. Combined with the emergence of linear production models and fast fashion consumption patterns,

these developments created the foundations of the contemporary sustainability crisis in the textile industry, as summarized in Figure 1.

Figure 1.

Causes Leading to the Environmental Crisis in the Textile Industry.



Note. Author's conceptual synthesis illustrating the principal factors contributing to the environmental crisis in the textile industry, based on the literature reviewed in this chapter.

The growth of industrial textile production also intensified the demand for raw materials. Cotton cultivation expanded significantly, becoming one of the most widely used textile fibers worldwide. While cotton is a natural material, its large-scale production often requires substantial quantities of water, fertilizers, and pesticides. Intensive agricultural practices have contributed to soil degradation, water scarcity, and chemical contamination in many producing regions. Beyond fiber production, textile dyeing, printing, and finishing processes represent some of the most environmentally damaging stages of the textile lifecycle. These processes often require large volumes of water and involve the use of synthetic dyes, bleaching agents, fixing chemicals, salts, and various auxiliary substances. In many manufacturing regions, inadequately treated wastewater may contain heavy metals such as chromium, copper, zinc, lead, and cadmium, as well as toxic organic compounds

that can contaminate rivers, groundwater, and aquatic ecosystems. As a result, textile production has become one of the major industrial sources of water pollution in many parts of the world, highlighting the interconnected relationship between fashion, resource consumption, and environmental degradation.

Alongside environmental concerns, industrial textile production has long been associated with social and ethical challenges. The pursuit of lower production costs has historically encouraged the relocation of manufacturing to regions with inexpensive labor and less stringent regulations. As a result, concerns regarding worker exploitation, unsafe working conditions, excessive working hours, and inadequate wages continue to affect parts of the global textile supply chain. These issues demonstrate that sustainability within fashion extends beyond environmental protection and also encompasses social responsibility and ethical production practices.

The twentieth century marked another major transformation in textile manufacturing with the development and widespread adoption of synthetic fibres such as nylon, polyester, acrylic, and polypropylene. Unlike natural fibres, these materials are manufactured from petrochemical feedstocks through energy-intensive industrial processes, enabling large-scale production, improved durability, and lower manufacturing costs. Their versatility and affordability rapidly established synthetic fibres as the dominant raw materials within the global textile industry, fundamentally reshaping textile manufacturing and accelerating global consumption (McIntyre, 2005). However, these advantages have also introduced significant environmental challenges. Synthetic fibre production depends heavily on non-renewable fossil resources and contributes to greenhouse gas emissions throughout the product lifecycle, while the widespread use and laundering of synthetic textiles have emerged as major sources of microfibre pollution in aquatic and terrestrial environments (Malik & Bharti, 2021; Rathinamoorthy & Raja Balasaraswathi, 2024). These environmental consequences have become central drivers behind contemporary efforts to develop circular materials, improve textile recycling, and reduce the ecological footprint of the fashion industry. Figure 2 presents a chronological overview of the major synthetic fibres, tracing their progression from initial invention and laboratory development to commercial production. The timeline highlights the rapid emergence of synthetic fibre technologies during the twentieth century, particularly the commercialization of polyamide, polyester, acrylic, and polypropylene, which became the dominant synthetic fibres in the global textile industry. Their widespread adoption fundamentally transformed textile manufacturing by

enabling large-scale production, expanding material applications, improving performance characteristics, and increasing the affordability and accessibility of textile products.

Figure 2.

Chronological Development and Commercialization of Major Synthetic Fibres.

Widely used today (major global textile fibres)
Limited, niche, or historical importance

Synthetic fibre	First synthesis / laboratory production	First patent / invention	First commercial production	Present-day importance
PVC (Polyvinyl chloride) fibres	—	**1913** – Klatte (Germany) patented spinning fibres from PVC solution	**1934** – Pe-Ce (Germany)	Limited use today; mainly industrial and specialty applications.
Poly(vinyl alcohol) (PVA)	—	**1931–1933** – Herrmann & Haehnel	Early 1930s	Primarily technical textiles, medical sutures, water-soluble products.
Nylon 9	**May 1934**	—	Not commercialised	Historical research milestone only.
Nylon 6,6 (Polyamide)	**January 1935**	Developed by Carothers' team (DuPont)	**December 1939**	**One of the world's most important synthetic fibres** (apparel, hosiery, carpets, technical textiles, sportswear).
Nylon 6 (Perlon)	**January 1938** (Paul Schlack)	Caprolactam polymerisation	**January 1943**	**Major commercial fibre** used extensively in apparel, carpets, industrial textiles and engineering applications.
Acrylic fibres	Development during the **1940s**	Solvent technology developed during the 1940s	**1950** – DuPont; **1952** – Chemstrand	**Widely used**, especially for knitwear, blankets, upholstery and faux wool products.
Polyester (PET)	Development during the **1940s**	Whinfield (UK) invented PET	Early **1950s** (ICI; later DuPont)	**The dominant synthetic fibre worldwide**, accounting for over half of global fibre production.
Polypropylene (PP)	**1954**	Ziegler & Natta	Mid–late **1950s**	**Major fibre** for nonwovens, geotextiles, carpets, hygiene products and technical textiles.

Note. Adapted by the author from information presented in McIntyre (2005, Chapter 1, "Historical Background", pp. 14–15).

The rapid expansion of textile dyeing and finishing introduced additional environmental challenges associated with the extensive use of synthetic dyes and chemical processing agents. Many textile dyes are synthesized from aromatic compounds, some of which have been associated with toxic, mutagenic, and carcinogenic properties. When dye-contaminated wastewater is discharged without adequate treatment, these substances may pose significant risks to aquatic ecosystems, wildlife, domestic animals, and human health. The treatment of textile effluents has therefore become a critical environmental priority, prompting the development of physical, chemical, and biological wastewater treatment technologies, including adsorption methods using activated carbon and alternative low-cost agricultural waste adsorbents (Malik & Bharti, 2021).

The environmental consequences of this production model have become increasingly evident over time. Intensive cotton cultivation requires substantial quantities of water, pesticides, and fertilizers, contributing to water depletion, soil

degradation, and chemical pollution. The widespread adoption of synthetic fibres, derived primarily from petrochemical resources, has further increased the industry's environmental footprint through energy-intensive manufacturing processes and the continuous release of microplastic fibres during production, laundering, and disposal, contaminating freshwater and marine ecosystems (McIntyre, 2005; Rathinamoorthy & Raja Balasaraswathi, 2024). In addition, textile dyeing and finishing generate large volumes of chemically contaminated wastewater, while dyes, auxiliaries, and heavy metals used during textile processing may pose significant risks to aquatic ecosystems and human health if inadequately treated (Malik & Bharti, 2021). Combined with significant greenhouse gas emissions, high energy consumption, and the growing accumulation of textile waste in landfills and incineration facilities, these impacts have established the textile industry as one of the world's most resource-intensive and environmentally challenging manufacturing sectors..

The sustainability crisis facing fashion today is therefore not the result of a single material, technology, or business model. Rather, it reflects the cumulative effects of two centuries of industrial expansion, resource-intensive production, synthetic material innovation, and increasing consumption. Understanding this historical trajectory is essential for identifying pathways toward more sustainable systems capable of balancing economic development, environmental responsibility, and social well-being.

Consumer Psychology, Branding, and the Fashion Market

The rapid expansion of the fashion industry during the twentieth and twenty-first centuries cannot be explained solely through technological innovation or production efficiency. Equally important has been the evolution of consumer culture and the increasing ability of brands to shape desire, influence behavior, and generate demand. While clothing serves practical functions related to protection and comfort, fashion consumption extends far beyond necessity. It operates within a complex system of symbolic meanings through which consumers communicate identity, status, belonging, and aspiration. Consequently, understanding the sustainability challenges facing the fashion industry requires examining not only how garments are produced but also why they are consumed.

Contemporary fashion markets are largely driven by demand generated through branding, advertising, and emotional engagement. Brands no longer function

merely as identifiers of products but as cultural symbols capable of communicating lifestyles, values, and social positions. Consumers frequently develop emotional relationships with brands, associating them with personal aspirations, self-expression, and social recognition. As a result, purchasing decisions are often influenced by psychological motivations that extend beyond objective considerations such as quality, functionality, or necessity.

The influence of branding on identity has also been explored through contemporary art. Dietrich Wegner's *Cumulous Brand* series depicts hyper-realistic infants covered with recognizable corporate logos, presenting a visual critique of the pervasive role of branding in shaping identity from the earliest stages of life (Wegner, n.d.). The work suggests that consumer culture extends beyond the promotion of products, influencing aspirations, values, and social identity long before individuals become conscious consumers. This perspective reinforces the view that fashion consumption is driven not only by functional needs but also by deeply embedded psychological and cultural processes, highlighting the complexity of encouraging more conscious and sustainable patterns of consumption.

Research in consumer psychology supports this interpretation. In *Buyology*, Lindstrom (2008) argues that purchasing decisions are often driven by subconscious emotional processes rather than rational evaluation. Using functional magnetic resonance imaging (fMRI), his research demonstrated that strong brands can activate areas of the brain associated with reward, anticipation, emotion, and positive reinforcement.

These findings challenge traditional assumptions regarding consumer decision-making by suggesting that purchasing behavior is frequently rooted in emotional responses rather than objective assessments of need. Consumers often experience excitement, satisfaction, and anticipation when interacting with desirable brands, reinforcing purchasing behaviors and encouraging repeated consumption.

Within the fashion industry, these psychological mechanisms contribute directly to the growth of consumer demand. Fashion products are frequently marketed not as garments but as experiences, aspirations, and symbols of personal identity. Kapferer and Bastien (2012) argue that luxury consumption reflects aspirations deeply rooted in human history. From early civilizations, material possessions have served as symbols of identity, prestige, and social distinction, while contemporary luxury markets continue to evolve through democratization, rising purchasing power, globalization, and advances in communication. Together, these forces have

significantly expanded access to luxury consumption and increased consumers' exposure to aspirational lifestyles.

These same drivers have also contributed to the expansion of fashion consumption beyond functional requirements. Global communication, digital marketing, celebrity culture, and social media continuously reinforce aspirational consumption, encouraging consumers to seek novelty, exclusivity, and symbolic value.

The ability of brands to stimulate desire has contributed significantly to the emergence of hyper-consumption within contemporary fashion markets. As companies compete for consumer attention, marketing strategies increasingly emphasize novelty, exclusivity, and continuous product replacement. This demand for constant newness encourages higher levels of production, shorter product lifecycles, and increasing volumes of waste. Consequently, overproduction and overconsumption are not isolated phenomena but interconnected outcomes of a system in which consumer desire and market supply continuously reinforce one another.

A further obstacle to sustainable fashion consumption is the persistent gap between consumers' stated environmental values and their actual purchasing behaviour. Sario (2025) argues that this attitude–behaviour gap is shaped by a combination of psychological, social, and practical barriers. Although many consumers express concern about environmental issues, established habits, social pressures, the appeal of novelty, and the convenience of fast fashion often override sustainable intentions. Price remains particularly influential, as sustainably produced garments are frequently perceived as less affordable than mass-produced alternatives. Limited accessibility, the additional effort required to verify sustainability claims, and widespread greenwashing may further create confusion and distrust. Consequently, the transition toward more sustainable consumption depends not only on increasing environmental awareness but also on making responsible fashion choices more affordable, accessible, credible, and compatible with consumers' everyday routines (Sario, 2025).

This raises a critical question for the future of sustainable fashion: can consumption patterns rooted in deeply embedded psychological motivations be transformed? If desires for novelty, status, and social recognition continue to drive purchasing behavior, the transition toward slower and more sustainable forms of fashion consumption may prove challenging. Nevertheless, growing awareness of environmental issues, alternative business models, and changing consumer values suggest that opportunities for transformation do exist. The challenge facing the

fashion industry is not simply to produce differently, but to reconsider the cultural and psychological foundations upon which contemporary consumption is built.

Consequently, the transition toward sustainable and circular fashion is not solely a technological or manufacturing challenge but also a behavioral and cultural one. Circular fashion encourages consumers to extend product lifecycles, reduce unnecessary purchases, repair, reuse, and value garments beyond rapidly changing trends. These principles directly challenge economic models and branding strategies that have historically relied on accelerating consumption, frequent product replacement, and the continual creation of new desire.

From Awareness to Action: Legislative and Systemic Responses

As the environmental and social consequences of the fashion industry have become increasingly visible, sustainability has evolved from a voluntary initiative into a strategic priority for governments, international organizations, and industry stakeholders. The growing volume of textile waste, dependence on non-renewable resources, and rising concerns regarding climate change have highlighted the limitations of existing production and consumption models. Consequently, policymakers have begun to develop regulatory frameworks aimed at reducing environmental impacts and accelerating the transition toward more sustainable and circular systems.

Recent research demonstrates the scale of the challenge facing the global fashion industry. The sector is among the world's largest consumers of raw materials and is responsible for significant greenhouse gas emissions, water consumption, and waste generation. Despite increasing awareness of sustainability issues, global clothing production continues to rise, while only a small percentage of textile materials are effectively recycled into new garments. The majority of textile products ultimately end their lifecycle in landfills or incineration facilities, illustrating the continued dominance of linear production systems.

These findings have encouraged governments and international institutions to adopt a more proactive approach toward sustainability. Rather than relying solely on voluntary commitments from companies, contemporary policies increasingly focus on accountability, transparency, and the development of circular economic models. Such initiatives seek to address environmental impacts throughout the entire product lifecycle, from material sourcing and manufacturing to consumption, reuse, repair, and end-of-life management.

Among the most influential policy developments is the European Green Deal, introduced by the European Union as a comprehensive strategy for achieving climate neutrality and promoting sustainable economic growth. Recognizing the environmental impact of the textile sector, the European Commission has identified textiles as a priority value chain for the transition toward a circular economy. This commitment resulted in the adoption of the EU Strategy for Sustainable and Circular Textiles, which aims to ensure that textile products placed on the European market are more durable, repairable, recyclable, and resource-efficient (European Commission, 2022).

A central objective of the strategy is the transition from a linear economy toward a circular model in which materials remain in use for as long as possible. Within this framework, products are expected to be designed with longevity, reuse, repair, and recycling in mind. Such an approach challenges the traditional fast-fashion model by encouraging manufacturers to consider the entire lifecycle of a product rather than focusing exclusively on production and sales (European Commission, 2022).

To support these goals, the European Union has introduced the Ecodesign for Sustainable Products Regulation (ESPR), which extends sustainability requirements to a wide range of consumer goods, including textiles. The regulation seeks to improve product durability, reparability, recyclability, and overall environmental performance. By integrating sustainability criteria into product development, eco-design policies acknowledge the critical role that design decisions play in determining environmental outcomes (European Commission, 2024).

Another significant initiative is the introduction of the Digital Product Passport (DPP), a tool designed to improve transparency throughout the textile value chain. The Digital Product Passport provides information regarding a product's composition, origin, manufacturing processes, environmental impact, and end-of-life options. By making such information accessible to consumers, businesses, and regulatory bodies, the DPP aims to facilitate informed decision-making while supporting repair, reuse, and recycling practices. Furthermore, increased transparency may help reduce instances of greenwashing by requiring companies to substantiate sustainability claims with verifiable data (European Commission, 2024).

In addition to product-focused regulations, the European Union has promoted the implementation of Extended Producer Responsibility (EPR) schemes. Under this approach, producers are held accountable for the environmental impacts of their products beyond the point of sale, including collection, recycling, and waste management. By shifting responsibility from consumers and municipalities to

manufacturers, EPR policies encourage companies to design products that are more durable, recyclable, and resource-efficient. The principle reflects a broader shift toward lifecycle thinking, where environmental responsibility extends across all stages of a product's existence (European Commission, 2022; OECD, 2016).

The transition toward sustainable fashion is not limited to Europe. International organizations and governments worldwide have increasingly recognized the need for coordinated action in response to environmental challenges. The United Nations Sustainable Development Goals (SDGs), particularly those related to responsible consumption and production (SDG 12), climate action (SDG 13), clean water and sanitation (SDG 6), and decent work and economic growth (SDG 8), have provided a global framework for addressing sustainability issues within the textile and fashion sectors (United Nations, 2015). Similarly, circular economy strategies have gained international recognition as viable alternatives to traditional linear models of production and consumption, promoting resource efficiency, waste reduction, and regenerative systems (Ellen MacArthur Foundation, 2013; Kirchherr et al., 2017).

Despite the progress represented by these initiatives, significant challenges remain. The complexity of global supply chains, differences in national regulations, and the economic pressures associated with fast fashion continue to hinder large-scale transformation. Furthermore, concerns regarding greenwashing remain prevalent, as some sustainability claims are not always supported by meaningful changes in production practices. While regulatory frameworks provide important foundations for change, their effectiveness ultimately depends on implementation, monitoring, and collaboration among governments, industry stakeholders, designers, and consumers.

Nevertheless, contemporary legislative and policy developments demonstrate a growing recognition that sustainability cannot be achieved through individual actions alone. Addressing the environmental impact of fashion requires systemic interventions capable of reshaping production processes, consumption patterns, and material flows. By establishing clearer standards, increasing transparency, and promoting circular principles, these initiatives create the conditions necessary for a more sustainable fashion industry. However, legislation alone is insufficient. Lasting transformation also depends on the ability of designers, manufacturers, and innovators to develop practical solutions capable of redefining how fashion products are conceived, produced, and valued.

Pathways Towards Sustainable Fashion

The sustainability challenges facing the fashion industry have encouraged designers, manufacturers, policymakers, and consumers to reconsider established models of production and consumption. While no single solution can fully address the environmental and social impacts of fashion, a growing number of strategies, technologies, and design methodologies are contributing to the transition toward more sustainable systems. These approaches seek not only to reduce environmental harm but also to redefine the relationship between materials, products, consumers, and value.

Among the most influential frameworks guiding contemporary sustainable design are the R-strategies, which aim to extend product lifecycles and minimize waste generation. These principles are widely adopted by fashion designers and small and medium-sized enterprises (SMEs) seeking to implement circular design practices. These strategies include reducing resource consumption, reusing products, repairing damaged items, refurbishing existing garments, remanufacturing components, repurposing materials, and recycling textile fibers. Rather than viewing products as disposable commodities, circular approaches seek to maintain materials within productive use for as long as possible. Such principles have become increasingly important within both industry practice and sustainability policy, particularly within the European Union's transition toward a circular economy.

Design methodologies have also evolved in response to concerns regarding material waste. Zero-waste fashion design, advanced by researchers such as Timo Rissanen and Holly McQuillan, rethinks conventional pattern-cutting by designing garments that minimize or eliminate pre-consumer fabric waste at the pattern-development stage. Rather than treating waste as a by-product of production, this approach integrates sustainability into the creative design process through innovative and contemporary pattern-cutting solutions (Rissanen & McQuillan, 2016). Similarly, slow fashion approaches emphasize durability, quality, repairability, and emotional attachment, encouraging consumers to value garments beyond short-term trends. Together, these methodologies demonstrate how sustainability can be embedded directly into fashion design from the earliest stages of product development rather than addressed only after production.

Technological innovation is playing an increasingly important role in reducing the environmental footprint of fashion. Three-dimensional design software, digital prototyping, and virtual sampling enable designers to develop and evaluate

garments without producing multiple physical samples, thereby reducing material consumption and production waste. Virtual fitting rooms and smart mirrors allow consumers to visualize garments digitally before purchase, helping to reduce product returns and associated transportation impacts. At the same time, artificial intelligence and digital product management systems are improving supply chain transparency, inventory management, and demand forecasting, reducing the risk of overproduction. Contemporary practice increasingly demonstrates that artificial intelligence can support sustainability throughout the fashion value chain. The Japanese fashion industry, in particular, has emerged as a leading example of integrating AI into trend forecasting, virtual styling, demand prediction, traceability, and supply chain management, enabling brands to optimize production, minimize waste, improve transparency, and develop more data-driven circular business models. These developments illustrate how digital technologies are transforming not only product design but also consumer engagement, inventory planning, and the overall governance of sustainable fashion systems (Sario, 2025).

Material innovation has emerged as one of the most dynamic areas of contemporary sustainable fashion research. Researchers and manufacturers are exploring alternatives to conventional synthetic and resource-intensive materials through the development of bio-based and regenerated fibers. Examples include mycelium-based leather alternatives, Piñatex derived from pineapple leaf fibers, Orange Fiber produced from citrus industry waste, algae-based textiles, and textile-to-textile recycling technologies. These innovations seek to reduce dependence on virgin resources while creating new opportunities for circular material flows within the fashion industry.

Transparency and accountability have also become increasingly important within sustainability initiatives. Eco-labels and certification systems such as the EU Ecolabel, OEKO-TEX®, GOTS (Global Organic Textile Standard), Bluesign®, and Cradle to Cradle provide consumers and industry stakeholders with information regarding environmental and social performance. While certification alone does not guarantee sustainability, these systems contribute to greater transparency and encourage more responsible production practices throughout the supply chain.

In addition to technological and material innovations, sustainability is increasingly influencing ethical decision-making within the fashion industry. Growing public concern regarding animal welfare, environmental responsibility, and social justice has encouraged many brands and institutions to reconsider established practices. A notable example is the decision by several major fashion organizations and

luxury brands to eliminate the use of fur from their collections and fashion events. Such decisions reflect a broader shift toward ethical responsibility, demonstrating how changing social values can influence industry standards and reshape consumer expectations.

Despite these promising developments, significant disparities remain in the capacity of different countries and regions to implement sustainable fashion practices. While many of the innovations discussed—including certified sustainable materials, digital product passports, AI-supported supply chain management, and advanced traceability systems—are increasingly accessible within developed economies, their adoption remains considerably more challenging in many developing and non-EU countries. Limited access to certified raw materials, insufficient technological infrastructure, financial constraints, and fragmented supply chains often restrict the implementation of circular business models and digital sustainability solutions. These disparities raise important questions regarding the global inclusiveness of the sustainability transition: Can circular fashion become a truly global paradigm if the technologies, materials, and regulatory frameworks required for its implementation remain unevenly distributed? Addressing this challenge will require not only technological innovation but also greater international cooperation, knowledge transfer, capacity building, and investment to ensure that sustainability transitions are accessible across diverse economic and industrial contexts.

Collectively, these developments indicate that the future of fashion is moving toward more circular, transparent, and responsible systems. While significant challenges remain, the growing integration of sustainable design methodologies, technological innovation, material research, certification frameworks, and ethical practices demonstrates that meaningful progress is being made. The future of fashion will likely depend not on a single solution but on the ability of multiple strategies to work together in reducing waste, extending product lifecycles, and redefining value within the industry.

Conclusion

The transition toward sustainable fashion represents one of the most significant transformations in the history of the textile industry. While industrialization, synthetic material innovation, and globalization have increased production efficiency and democratized access to fashion, they have also established production and consumption systems that exceed environmental limits and challenge long-term sustainability.

This review demonstrates that the sustainability crisis cannot be understood solely through materials or manufacturing processes. Rather, it emerges from the interaction of industrial development, consumer behaviour, branding strategies, policy frameworks, and design practices. Although circular economy principles, legislative initiatives, technological innovation, and sustainable design methodologies provide important pathways toward change, lasting transformation depends on coordinated action involving designers, manufacturers, policymakers, and consumers.

Ultimately, the transition toward circular futures represents an opportunity to redefine fashion as a system that balances creativity, economic development, and environmental responsibility. It requires moving beyond consumption behaviours rooted in status signalling and the accumulation of resources as markers of individual success toward a broader understanding of value that prioritizes collective well-being, environmental protection, and human health. In this sense, sustainability represents not only a technological or economic transition but also a transformation of cultural values and social priorities.

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