

TRANSFORMING THE FASHION INDUSTRY: INTERSECTIONS OF MARKET DYNAMICS, SUSTAINABILITY, AND EMERGING TECHNOLOGIES

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Abstract: *The fashion industry has undergone a profound transformation over the past two centuries, evolving from aristocratic guild-dominated craftsmanship to a globalized market driven by innovation, marketing, and sustainability. From the establishment of Haute Couture in the mid-19th century to the dominance of global fashion conglomerates, the industry has reflected shifts in consumer demand, market dynamics, and branding strategies. This study examines the evolution of the fashion sector, with a focus on the financial performance of major global brands from the luxury, premium, and fast fashion segments. The data reveal significant shifts in market dynamics, highlighting the increasing dominance of luxury fashion houses. While fast fashion brands previously thrived on affordability and accessibility, their reliance on overproduction and lower-quality materials has raised concerns about sustainability. Beyond financial trends, this study explores the role of emerging technologies in sustainability-driven business strategies. The adoption of artificial intelligence (AI), blockchain, and 3D printing is reshaping the fashion industry by enhancing transparency, improving the traceability of the supply chain, and reducing material waste. As sustainability becomes imperative for both environmental and economic reasons, these innovations offer pathways for fashion brands to align with global initiatives such as the UN 2030 Agenda and the EU Green Deal. By integrating historical analysis with insights into financial shifts and technological advancements, this research highlights how the fashion industry must adapt to remain competitive while embracing sustainability.*

Keywords: *Fashion evolution, sustainable fashion, technology in fashion, sustainable technologies.*

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1. Introduction

The years 1850-1890 represent the period in which modern fashion emerged, defined by the development of the “fashion designer” as a profession and the haute couture system (1). Haute couture is “at the heart of the fashion ecosystem” (2), and Charles Frederick Worth is called the “father of haute couture,” often regarded as the first to put his name on a label, establishing himself as an “arbiter of taste and style” (3). Since 19th-century technology allowed the creation of ready-to-wear pieces at affordable prices so that the French middle class could afford them, members of high society began seeking new ways to differentiate themselves, changing their clothing style more frequently. Thus, Haute Couture was born, with high craftsmanship and original design stimulating the progress of the luxury fashion industry (4). The Englishman Charles Frederick Worth arrived in Paris in the mid-19th century and, demonstrating mastery, began creating exceptional garments for the elite of Parisian society, including Eugénie, Empress of France, and Elisabeth, Empress of Austria (1). Thus, Haute Couture transformed France into the center of modern Western fashion until the mid-20th century. From the 1900s to the 1940s, designers in this sector experimented with structure, silhouette, materials, and

techniques used (4). Before the emergence of couture fashion, the fashion segment was dominated by numerous strict laws and craft guilds with basic skills, and fashion was primarily the domain of aristocrats, who determined styles and purchased couture “made-to-measure” clothing from salons (5). Charles Frederick Worth succeeded in transferring this industry from guilds to couturier status, highlighting the idea that a couturier is an artist and that the only difference between his creations and art is defined solely by technique (5). Indeed, through imagination and talent, the couturier sets the tone in fashion, offering those who wear his creations, images characterized by refinement and splendor.

Designers of the early 20th century, such as Paul Poiret, Coco Chanel, Cristóbal Balenciaga, Madame Grès, Madeleine Vionnet, and Mariano Fortuny, were pioneers of innovative directions in fashion development, driven by creativity, research, and development (4). A new chapter in fashion began at the end of the 1910s, dominated by simplicity, which was much more suited to post-war society (1). Thus, Jean Patou focused on creations that included shorter skirts and developed sporty styles, while the graphic-accented illustrations of George Lepape, the bold designs of Wimmer-Wisgrill, and the relaxed designs of Coco Chanel outline the existence of a new sensibility (1).

2. Marketing Instruments Used to Improve Fashion Presence Between 1850-1950

Since the 1850s, fashion trends and styles of the time were presented through publications, with French ones influencing the entire fashion world. French fashion journals such as *La Mode Illustrée*, *L'Art et la Mode*, *Le Moniteur de la Mode*, and *La Mode Pratique* showcased images of new clothing styles, accessories, and hairstyles, thereby setting beauty standards (1). These publications appeared periodically, with some still existing today, such as *Harper's Bazaar* in America, an important fashion magazine. Additionally, in 1900, the Exposition Universelle in Paris displayed pieces reflecting the Belle Époque period, with French designer Jeanne Paquin designing the “clothes” for the *La Parisienne* sculpture placed at the main entrance-another marketing technique used. Paquin was among the first fashion houses to renew this segment by introducing more modest designs, reducing excessive amounts of fabric and ornamentation, and liberating women from the constraints of the corset (6). Paquin also drew inspiration from the Empire style, which was responsible for modernizing women's clothing after the French Revolution. Thus, in 1907, when she launched the “*Empire*” dress, Jeanne Paquin published a two-page advertisement in *Les Modes* magazine, featuring a painting by Henri Gervex depicting an afternoon in the House of Paquin's salon (6). Another communication and marketing tool used since the early 20th century has been fashion shows. Authors Cole and Deihl (1) highlight that designers such as Paquin, Paul Poiret, and Lady Duff Gordon (Lucile) staged dramatic fashion presentations. From the early 20th century to the present, a series of fashion designers have revolutionized this industry, shaping it as we see it today. Among the pioneers of that era, names such as Lanvin, Chanel, Schiaparelli, Dior, Balmain, Hermès, Yves Saint Laurent, Balenciaga, and Givenchy remain key pillars of the fashion world, as they are the most renowned and significant fashion houses globally, a fact reflected in the frequency of purchases by customers worldwide.

In the mid-20th century, another fashion promotion tool emerged - television. By 1950, over a million households in the United States owned televisions (1). This represented an important tool for promoting consumer goods, and together with the print

media, it transmitted marketing messages to women, who played a crucial role in purchasing decisions.

In the book *Fashion Theory* edited by Malcolm Barnard, Adam Geczy and Vicki Karaminas (5) state that fashion emerged with modernity, manifesting as an expression of capitalism's desire for change, as the key link between modernity and time, and as an intertwining with representation - an aspect that is increasingly present today with the rise of digital fashion. While early marketing tools like fashion journals and couture salons set the groundwork for fashion's cultural power, today's industry is increasingly shaped by data, technology, and evolving consumer expectations. These shifts are especially visible in the financial performance and market positioning of fashion brands across different segments.

Having provided the historical evolution and early strategic approaches shaping modern fashion, the following section briefly outlines the methodological framework adopted for analyzing current market dynamics and technological developments.

3. Research Method

This study employs a narrative literature review methodology, synthesizing secondary data from scholarly literature and authoritative industry reports to analyze contemporary market dynamics and technological innovations influencing sustainability in fashion. Following the foundational historical context provided earlier, the article analyzes current market trends within luxury and premium fashion segments using industry reports (McKinsey & Company, Bain & Company, Brand Finance). Subsequently, it evaluates emerging technologies - blockchain, artificial intelligence, and 3D printing, highlighting their role in advancing industry sustainability and operational efficiency.

This narrative literature review thus synthesizes insights across historical, economic, and technological domains, providing a coherent analytical perspective on the contemporary challenges and opportunities facing the global fashion industry regarding sustainability and innovation.

4. Financial Performance and Market Shifts in Fashion

As established by the methodological framework, this section begins the detailed analysis by exploring contemporary market dynamics within the fashion industry. Even though there are several brands with historical significance, defined by know-how and cultural identity, financial indicators remain an extremely important dimension that determines the survival capacity of these companies. Therefore, it is necessary to analyze the most profitable brands in the fashion industry. Financial data provided by Brand Finance outlines the ranking of apparel companies with the highest brand value. Thus, as of 2023 (7), the first position is held by Nike, with a brand value of \$31,307 million, followed by Louis Vuitton with \$26,290 million, and Chanel in third place with \$19,386 million. Compared to 2017 (8), the first place was held by the same company with \$31,762 million, followed by two fast-fashion companies: H&M with \$19,177 million and Zara with \$14,399 million. In 2017, Louis Vuitton ranked sixth, after being in third place in 2016, emphasizing the fact that consumers were placing greater importance on fast-fashion brands (H&M, Zara, Uniqlo) as they were widely available at affordable prices. Although Nike remains in first place, its brand value decreased by -6% in 2023 compared to 2022, while Zara recorded a -15% decline, reaching \$11,049 million. H&M and Uniqlo, which were in the top rankings in 2017, dropped to positions 11 and 12, respectively, in 2023, while Zara fell from third place in 2017 to ninth in 2023. Positive fluctuations in brand

value were recorded by luxury brands: Dior +46%, Chanel +27%, Rolex +28%, Louis Vuitton +12%, Hermès +5%, and Cartier +1%. This trend is due to the increasing purchasing power of consumers in Asia. A report by BDA Partners (9) indicates that since 2020, the luxury goods segment in Asian countries has grown steadily, with China accounting for the largest share of sales. The main factors driving the increased appetite for luxury products include China's economic growth, the millennial generation segment, and shifting consumer preferences. The previously mentioned report (9) also highlights that the target segment consists of millennials, whose interest in luxury products has grown considerably. They consume high-end streetwear items and are willing to spend increasing amounts on products from brands that align with their values, paying attention to aspects such as sustainability and social responsibility. Another key factor contributing to the growth of the luxury fashion segment is the rising popularity of the K-Pop industry. As a result of this trend, luxury brands have started collaborating with Asian celebrities, particularly K-Pop idols, who are predominantly followed by Generation Z. This strategy has brought luxury goods closer to this demographic, boosting sales.

According to Statista (10), the luxury fashion market in Asia is expected to grow at a CAGR of 4.18% between 2024 and 2028. Bain & Company (11) estimates that by 2030, in the global personal luxury goods market, customers from different regions will account for the following shares: China will represent 30-40%, while America and Europe together will hold 40%. The large share of Chinese consumers in luxury goods is primarily due to economic indicators that exhibit a positive growth trend and an increasing appetite for luxury. A ranking reflecting luxury goods consumption projections until 2028 by Statista (10) estimates that the United States will rank first, with a total consumption of \$83,312.79 million, followed by China with \$65,415.67 million, and Japan with \$38,806.58 million. France follows with \$21,759.45 million, and Germany with \$18,509.65 million. Asian markets, especially China and Japan, show the highest projected growth rates through 2028, reinforcing the global pivot toward luxury. Compared to Western consumers, Chinese consumers are relatively new entrants to the luxury fashion segment, which is one of the factors contributing to the rapid growth of this segment in the Asian retail market. Additionally, online commerce, the high availability of fashion items, social media, and influencer marketing are other factors driving luxury goods consumption in these relatively new markets. Fashion, as both art and a symbol of the West, remains a significant determinant of consumer desire.

Bain & Company (11) states that in the coming years, online and monobrand channels will account for two-thirds of the entire luxury goods market by 2030. Consequently, companies will need to provide customers with unique and differentiated experiences throughout the purchasing process, with sustainability and technology also being essential focal points.

According to Brand Finance's "Global 500 2024" ranking (12), which assesses the most valuable and powerful brands worldwide across all industries, Louis Vuitton ranked 52nd globally in 2024 with a brand value of \$32.235 million, up from 70th in 2023. In contrast, Nike, which previously held the top spot in the apparel category, ranked 62nd in 2024 with a brand value of \$29.873 million, down from 54th in the previous year. Chanel also saw significant growth, moving from 98th in 2023 to 73rd in 2024, with a brand value of \$26.028 million, recording a growth of +34.47%. Another brand from the LVMH portfolio, Dior, has also seen an increase in value, rising from 147th place in 2023 to 136th place in 2024. A spectacular increase also recorded the fast-fashion brand Zara, which

jumped from 181st place in 2023 to 120th place in 2024. Looking ahead, Brand Finance's 2025 projections (13) highlight the continued rise of luxury fashion brands. Chanel is projected to climb further to 46th place, with its brand value growing to \$37.913 million, while Louis Vuitton and Nike are estimated to fall slightly to 55th place in case of the first brand (brand value \$32.917 million) and the 66th place for the second one (brand value of \$29.428 million).

These shifts underscore the growing dominance of luxury fashion brands in the global market and reflect changing consumer preferences toward quality, exclusivity, and brand values such as sustainability and ethical practices. The position occupied by each fashion company in the coming years will be determined by several factors, one of the most significant being sustainability. The increasing demand for conscious production and consumption aligned with sustainable development principles, as well as shifting consumption trends, will dictate the direction each manufacturer must take. Companies that fail to adapt may risk being pushed out of the market. Although in recent years, many companies have initiated sustainability efforts - from responsible sourcing of raw materials and design to improvements in sales and distribution processes - challenges persist, particularly for fast-fashion companies. These brands often lack full transparency and continue to rely on overproduction models, which are fundamentally misaligned with sustainable development goals. Despite its own environmental footprint, the luxury fashion sector is often perceived as more sustainable by comparison. While luxury brands are not without issues - such as labor practices or resource intensity - their use of higher-quality materials and production of fewer collections annually can contribute to a lower overall environmental impact. For instance, according to Britannica (14), certain fast fashion brands release up to 36 collections per year, while luxury houses typically launch only four: spring/summer, autumn/winter, resort/cruise, and pre-fall (15).

Economic data further illustrates the resilience of the luxury segment. According to The State of Fashion 2024 report (16), the luxury fashion segment had the highest economic growth in 2022, increasing by +36% in a single year from 2021. In an unstable economic context, with rising inflation rates and various emerging challenges, the luxury segment managed to grow its economic profit due to its ability to set higher prices without reducing demand. The same report (16) shows that among the five analyzed fashion segments - luxury, affordable luxury, premium, mid-market, and discount - only luxury and affordable luxury recorded positive performance, with affordable luxury growing by +10%, while the others experienced declines: -20% for premium and discount, and -34% for mid-market (including Inditex), or -64% if Inditex is excluded. While affordable luxury saw growth, the economic profit (EP) index recorded the same average value as in 2010-2018. However, the luxury segment had an average EP four times higher than the same indicator recorded in 2010-2018, reaching 90 in 2022.

In this volatile economic and social landscape, sustainability has become not only a moral imperative but a strategic necessity. The European Parliament (17) reports that the textile sector was the third-largest contributor to water pollution and land degradation in Europe, in 2020. It is responsible for approximately 20% of global clean water pollution, primarily due to dyeing and finishing processes. Moreover, textile consumption in the EU generated an average of 270 kg of CO₂ emissions per person in 2020, totaling 121 million tonnes. To address these challenges, global frameworks such as the UN 2030 Agenda for Sustainable Development (18) and the European Green Deal (19) advocate for a systemic transformation of the economy. These initiatives aim to balance the social, economic, and

environmental dimensions of development. The European Green Deal, in particular, envisions a resource-efficient, zero-emission economy by 2050, with economic growth decoupled from resource use and inclusive of all communities and regions. For fashion companies, this means shifting from a linear model of production and consumption to a circular, sustainability-driven business model - redefining growth as a continuous, responsible journey rather than a resource-intensive race.

5. Emerging Technologies and Their Role for a Greener Future

To support the shift from linear to circular business models, fashion companies are increasingly turning to emerging technologies such as blockchain, artificial intelligence (AI), and 3D printing. Among these, blockchain holds particular promise in addressing long-standing challenges related to transparency and traceability across global fashion supply chains.

5.1. Blockchain: Enhancing Transparency and Traceability

Blockchain is a large distributed digital database (ledger) that stores records of transactions and consists of a growing list of data structures and records, named 'blocks', which are linked and secured cryptographically (20). In the fashion industry, its core function is to provide an immutable, transparent record of every stage in a product's lifecycle - from the sourcing of raw materials to retail distribution. Transparency and traceability are key factors when it comes to sustainable fashion, and they can be both guaranteed by the blockchain technology. According to an online article named Europe's Future in Blockchain Technology (21), the benefits of blockchain include enhanced data security, real time traceability, greater transparency, operational efficiency and process automation.

These capabilities are particularly relevant in a sector where lack of supply chain transparency remains a persistent issue. As Fashion Revolution (22) reported, in 2022, 50% of major global fashion brands disclosed little or no information about their supply chains. Although this figure improved slightly in 2023 - with 52% of companies publishing first-tier supplier lists - deeper layers of the supply chain remain largely opaque (23). Blockchain offers a promising solution to these ongoing issues, enabling the traceability of raw materials, verification of product authenticity, and monitoring of labor conditions. The fashion industry is also vulnerable to unauthorized manufacturing practices (24). Blockchain technology can help reduce the risk of counterfeits, protect brand integrity, and prevent the circulation of potentially unsafe products. In this context, blockchain acts as a security layer that protects product authenticity and facilitates quality assurance. Blockchain offers a structural solution to these gaps by recording and verifying every transaction and stakeholder involved, thereby reducing the risk of counterfeiting, unethical labor practices, and material fraud (24). Furthermore, blockchain enhances product provenance and custody chain allowing stakeholders to access accurate information about a garment's origin, production flow and the related social and environmental conditions (25). This capability supports global sustainability efforts such as the United Nations Sustainable Development Goals (SDGs), particularly those related to responsible production, climate action, and labor rights. It also helps address critical vulnerabilities, such as unauthorized subcontracting - a widespread practice that increases the risk of labor exploitation (26). By digitizing and verifying each point in the supply chain, the blockchain helps mitigate this risk. It creates digital records that track every step of the supply chain, including the suppliers and contractors, enabling all are able to monitor

supplier credentials and enforce compliance, supporting fair working conditions and transparency at every level.

In doing so, blockchain aligns with the triple bottom line framework, having a positive impact on all of the three components: environmental - minimizes material waste through traceable, responsible sourcing; social - ensures ethical labor practices, fair wages, and safe working environments; economic - improves product quality and trust, reducing loss from counterfeits and increasing long-term profitability.

Despite its advantages, blockchain implementation is not without challenges (25):

Technological barriers:

- Scalability and Speed - blockchain systems are limited in transaction throughput, which can slow down large-scale operations in the fashion supply chain;
- Security Risks and Platform Selection – even though blockchain platforms such as Ethereum are widely used, they can still carry security vulnerabilities such as previous hack incidents or platform forks, which can undermine trust;
- Interoperability and Platform Suitability - the existence of numerous blockchain types (public vs private, proof-of-work vs proof-of-stake) complicates integrations, because not all are suitable for all business models;
- Data Immutability - although seen as a benefit, it can be problematic in dynamic industries like fashion, where production characteristics may evolve;
- User Acceptance – the effectiveness of this technology in fashion depends on the consumer understanding and acceptance and currently, the awareness is limited and will take time to develop, which can delay the adoption of blockchain.

Organizational barriers:

- Lack of Internal Knowledge and Skills - many fashion companies lack the technical expertise to understand and manage blockchain systems;
- Limited Middle-Management Engagement – in some cases, blockchain initiatives are driven more by the upper management and the lack of involvement of the operational teams can negatively influence the implementations and scalability of this technology;
- Absence of Universal Standards - the industry lacks standardized blockchain protocols for traceability, making implementations inconsistent.

Environmental Challenges:

- Internal Environmental factors - companies need to have powerful sustainable practices set up before adopting blockchain. Without this pre-existing commitment to transparency and sustainability, blockchain cannot fulfill its purpose of traceability and trust-building.
- External Environmental Factors: government regulations - legal and regulatory environment for blockchain is still emerging and uncertain in many regions, making it hard for companies to implement it easily; lack of government incentives - the absence or reduced financial incentives which support blockchain adoption lead to a lower motivation to experiment with this technology; market uncertainty - consumers still prioritize price and design over sustainability and traceability and as a result, market demand for blockchain verified products is reduced.

While blockchain is not a stand-alone solution for sustainability, it can serve as a powerful tool that can improve transparency and verification when included within a

broader system of responsible business practices. Its success, however, depends on overcoming these technological, organizational, and environmental hurdles through strategic investment, cross-sector collaboration, and consumer education.

While blockchain provides the infrastructure for transparent and accountable supply chains, it is only one part of the technological toolkit required to transform fashion into a sustainable industry. The integration of additional technologies such as artificial intelligence (AI) allows for further optimization, enabling companies to enhance efficiency, predict demand more accurately, and make environmentally informed decisions throughout the product lifecycle. As the fashion industry struggles with overproduction, resource waste, and shifting consumer preferences, AI offers the potential to address these challenges through data-driven solutions that support both environmental and economic sustainability.

5.2. Artificial Intelligence: Driving Efficiency and Innovation

On the other hand, artificial intelligence (AI) represents a critical technological tool that, when strategically applied, can support fashion companies in adopting more sustainable business models. AI is an important factor which enables sustainability within the fashion sector, offering a transformative capability across production, supply chain, retail and consumption. AI supports the Sustainable Development Goals (SDGs) by optimizing resource use, reducing waste and improving decision-making throughout the product lifecycle – from the raw materials sourcing to final consumer interaction (27). One of AI's most significant contributions is in supply chain optimization. It can be used in garment classification, as well in identifying fabric defects and selecting appropriate materials, all of which help reduce waste and long-term production costs. Techniques such as machine learning (ML), conventional neural networks (CNNs) and Artificial Neural Networks (ANNs) are used to predict demand, detect fabric flaws and automate sorting tasks and monitor waste flow, reducing waste and energy usage. For example, H&M uses AI-based forecasting tools to predict trends and avoid overproduction, thereby preventing garments from ending up in landfills (28).

Additionally, AI facilitates eco-conscious design by enabling data-informed decisions related to fabrics, fit, and functionality. Tools such as 3D scanning and AI-powered morphotype mannequins help optimize sizing, reduce product returns, and improve resource efficiency during manufacturing (27). AI also enhances sustainability by promoting consumer engagement and transparency. Platforms like Farfetch utilize AI to provide users with detailed information on the environmental footprint of garments, empowering shoppers to make more ethical and informed purchasing decisions (28). Through predictive analytics and demand forecasting, AI helps reduce overproduction - one of fashion's most pressing environmental issues. By forecasting customer preferences, purchase patterns and market trends, brands can align supply chain with actual demand, thus lowering overstock and minimizing textile waste (27)(28).

Overall, AI technology contributes positively across all three dimensions of sustainability: environmental - through waste reduction, optimized resource use, and minimized carbon emissions; economic - by lowering operational costs through automation and process efficiencies; social - by improving working conditions, reducing errors, and increasing transparency in labor practices. Despite its potential, the integration of AI into fashion operations presents several challenges. The AI systems require vast amounts of high-quality, annotated data to function effectively. However, in the fashion domain, such data is not only limited in availability but also expensive to produce, often requiring skilled

human annotators. This lack of well-structured datasets restricts the efficacy of AI applications in areas such as design automation, personalized marketing, and product recommendation (29). Also, AI may involve high costs and the need for organizational change and consumer education.

In conclusion, AI plays a crucial role in advancing sustainability across the fashion value chain by enabling data-driven decision-making, minimizing resource use, optimizing production, and empowering conscious consumption. While promising, its full potential will be realized through targeted investment, industry collaboration, and a commitment to integrating AI with ethical, environmental, and social sustainability goals.

While AI enhances decision-making, demand forecasting, and supply chain efficiency, another transformative technology is 3D printing, which is redefining the physical creation of fashion products. Unlike AI, which optimizes processes, 3D printing transforms the production methods themselves. It enables material efficiency, design customization, and local manufacturing - core principles of sustainable fashion. As the industry moves toward circularity and reduced environmental impact, 3D printing presents promising opportunities to reshape not only what we wear, but how and where it is made.

5.3. 3D Printing: Sustainable Innovation in Fashion Manufacturing

3D printing is a transformative technology with significant potential to advance sustainability in fashion manufacturing. It is a process by which objects are created layer by layer from a digital model, often developed in computer-aided design (CAD) software (30). Within the fashion sector, this technology facilitates the creation of complex, highly customizable designs while enabling more material-efficient production methods (31). 3D printing offers several sustainability benefits for fashion manufacturing:

- a. Reduced material waste - Unlike traditional cutting and sewing methods, 3D printing uses only the required amount of material, thereby significantly minimizing waste (31);
- b. Support for localized and on-demand production - this technology supports localized, on-demand production, helping brands avoid overproduction and lowers the environmental cost of global supply chains;
- c. Lower carbon footprint and energy usage - due to its localized nature, 3D printing reduces emissions associated with transport and warehousing. Additionally, because 3D printing requires fewer production processes, it uses less energy (31);
- d. Use of biodegradable and recyclable materials - Bio-based filaments such as PLA and lignin, derived from renewable resources, can be used in the fashion industry. These materials often biodegradable, promote eco-conscious innovation (32)(30). Biopolymers such as PLA, PHA, and PBS offer sustainable alternatives to conventional petroleum-based plastics, with good biodegradability and lower carbon footprints (33);
- e. Extended lifecycle product - the ability to produce, replace and fix broken or missing parts of the products enhances repairability. Moreover, the capacity to customize garments according to individual preferences supports longevity of the garments due to a perfect fit and emotional satisfaction (32).

Despite these advantages, the integration of 3D printing into mainstream fashion manufacturing faces several challenges. Material rigidity and limited flexibility can affect garment comfort and wearability (32). There are also usability barriers linked to complex software tools and steep learning curves, which may slow down adoption among non-

specialist users. Furthermore, current 3D printing technologies struggle to match the speed and scalability of the traditional mass production methods (31). Initial implementation costs are relatively high and companies must invest in training workforce with the technical skills required for effective use of this technology.

In conclusion, while 3D printing offers meaningful opportunities for enhancing sustainability in the fashion industry - particularly through waste reduction, localized production, and material innovation - its long-term success will depend on overcoming technical, operational, and infrastructural challenges.

6. Conclusions

The fashion industry has undergone a significant evolution, shifting from guild-based craftsmanship and elite couture to a globalized system driven by branding, marketing, and mass production. This transformation, while generating economic growth and creative expression, has also created complex challenges related to overproduction, environmental degradation, and ethical labor concerns. Fast fashion's rise, marked by affordability and rapid turnover, has intensified these issues, while luxury brands are increasingly positioned as potential leaders in sustainable innovation due to their ability to invest in quality, longevity and consumer trust.

The fashion industry is widely recognized among the most polluting and resource-intensive sectors globally. It contributes to environmental degradation through excessive water consumption, greenhouse gas emissions, and textile waste, and continues to face persistent issues related to labor exploitation and production ethics. These challenges are particularly evident in fast fashion, which is built on high-volume production, short product life cycles, and low-cost materials. In this context, sustainability emerges not as an option, but as an urgent necessity - one that requires structural change across the entire value chain. Financial data show an evolving landscape in which luxury brands have gained market strength, indicating a shift in consumer expectations toward higher quality and more durable products. However, solving the industry's issues takes more than a change in how brands position themselves. The adoption of emerging technologies offers specific tools to support this transformation. Blockchain enables traceability and ethical oversight across complex supply chains. Artificial intelligence helps reduce waste and improve efficiency through data-driven planning. Meanwhile, 3D printing presents new opportunities for zero-waste production and material innovation. To ensure long-term resilience, fashion companies must integrate these technologies within a broader commitment to circularity, transparency, and responsible growth. Only through this kind of systemic adaptation can the industry move toward a future that is economically viable, socially just, and environmentally sustainable.

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