



# Sustainability Through Digitalization: Leveraging Digital Technologies to Transform the Textile and Apparel Industry for a Resilient Future

## Executive summary

This article highlights the potential of digitalization to enhance sustainability in the textile and apparel industry by integrating digital technologies in core operations. However, significant research gaps remain, including challenges in tool deployment, skill deficiencies, and organizational resistance to change. Strong collaboration between apparel industry professionals and computer scientists is essential to develop robust, relevant digital solutions that lead to sustainability.

In 2025, the apparel industry, valued at \$1.84 trillion and contributing nearly 1.6% of global GDP, holds immense significance within global manufacturing [1]. However, the textile and apparel industry causes significant environmental impact, accounting for approximately 20% of global pollution [2], which is a growing concern. The apparel industry has been grappling with an excessive volume of production and consumption due to the rise of fast fashion, seasonal assortments, and personalized clothing preferences. Meeting such demands is challenging, as this industry remains one of the slowest to automate compared to other manufacturing sectors. With approximately 430 million people employed in textile, clothing, and fashion production, the sector is heavily reliant on manual labor [3]. However, modern and competitive ap-

parel organizations have shown that investing in digital transformation enables them to adapt and maintain their competitiveness in the market.

This article aims to highlight the potential of digital technologies in supporting the sustainability of the apparel industry and fostering a resilient future. Therefore, this article explores the transformation of traditional processes across research, design, product development, planning, production, and distribution through the use of Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Internet of Things (IoT), Artificial Intelligence (AI) and Machine Learning (ML), blockchain, big data analytics, Augmented Reality (AR) and Virtual Reality (VR), metaverse, and automation. Figure 1 illustrates the applications of digital technologies across different stages of the apparel business.

## Research, Customer requirements identification, and Fashion Design

AI, big data analytics, and Machine Learning (ML) can be effectively used in trend analysis, market and material research by analyzing extensive datasets, identifying patterns, and forecasting fashion developments. VR technologies can be used to virtually attend fashion shows, trade fairs, and virtual showrooms.

In 2021, Helsinki Fashion Week in Finland transitioned to a fully digital format, becoming a benchmark for sustainable fashion events and reducing the carbon footprint per attendee from 137 kg to 0.66 kg [8].

Generative AI has become popular among fashion designers for facilitating ideation and reducing repetitive manual work, enabling designers to focus on creativity while minimizing waste. Consequently, it can accelerate the design process, enhancing agility from trend detection to product development, while leveraging analytical data to rapidly generate a large number of design iterations [4].



Figure 1: Applications of digital technologies in different operations of the apparel business.

## Product development, Testing, and Evaluation

Transitioning from manual to CAD-based digital pattern engineering revolutionized the apparel product development process by reducing physical resource consumption, improving accuracy, and faster iterations. In past decades, 2D CAD tools were mostly used for pattern making for new garments, and synchronized with automated cutting and manufacturing [5]. The advanced applications of 2D CAD technology, integrated with 3D body scanning to capture precise body measurements, enhance digital pattern making by improving accuracy and efficiency while facilitating automation.

Combined with 3D CAD technologies, it offers advanced capabilities such as digital fit assessments, pattern unwrapping, and 3D-to-2D reverse engineering, which also allow the generation of patterns from pre-determined virtual human avatars. An automated 2D pattern making and AI/ vision integrated marker making are used to manage pre-consumer waste. There is limited evidence of CAD being applied to manage

The use of CAD/CAM systems, compared to manual methods, reduced cutting waste by 10%, shortened production lead time from 55 days to 39 days, and significantly increased daily output from 4,013 to 15,856 pieces/day [2].

post-consumer waste in the refashioning and remanufacturing of second-hand clothing in the fashion industry. Interestingly, AI-powered fit validation methods will automatically assess how well a garment fits a specific body shape or size without employing physical prototypes. Moreover, 3D modelling combined with Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) enables immersive visualization and interactive simulations for the user. VR, AR, or MR platforms mimic the real 3D environment, facilitating customer engagement without physical prototypes.

The textile industry estimated that 85% of textiles are discarded in landfills every year [6]. Non-Fungible tokens (NFTs), when combined with digital twins and the metaverse, have the potential to shift consumer behavior, such as reducing demand for fast fashion and overconsumption towards digital alternatives, thereby promoting new sustainable practices. NFTs can serve as a 'digital twin' of a physical product, confirming ownership and authenticity, which is particularly useful in fashion, collectibles, and luxury goods. By enabling traceable attribution, NFTs support extending product life cycles and reducing waste through resale, rental, or recycling of garments [7].

### Planning, Production, Quality Inspection, Promotion, and Distribution

Digitalization of the planning, production, quality inspection, promotion, and distribution in the apparel industry employs integration of advanced technologies such as IoT, AI, blockchain, and big data analytics into modern manufacturing. IoT sensors can monitor and optimize automated sewing systems and energy consumption, while blockchain can ensure the traceability of materials, promote ethical sourcing, and reduce waste

[2]. Together, these technologies facilitate smart decision-making and improve supply chain transparency. Apparel distribution channels are complex in global business; therefore, IoT enables the consistent transportation of physical goods while accurately sharing real-time information. IoT can also be used to store records and disclose product data throughout the lifecycle, from production to first sale, and support sustainable business models such as resale, rental, and recycling, thereby enabling retailers to transition to more circular models with improved transparency, efficiency, and productivity.

Digital Product Passports (DPPs) enable product identification using comprehensive product information supporting circular textiles and fashion practices by facilitating multiple lifecycles and efficient reuse and recycling. Companies like TrueTwins, EON, Niaga, Circular Fashion, and AURA Blockchain have developed and tested DPP models in collaboration with brands such as H&M, Zalando, and Prada [8].

The metaverse is another emerging technology that merges physical and digital space within a virtual world, which can be employed in fashion e-commerce and retailing, aiming to facilitate consumer decision-making processes, ranging from user experience to customer experience [8]. The metaverse creates a digital replica of fashion enterprises, which can be used to facilitate buying and selling apparel, gather user information, adjust forecasts, and deliver services, among others. Likewise, the metaverse can be applied to establish an environmentally sustainable brand and to support suppliers that adhere to sustainable practices.

### Challenges in adopting digitalization in the apparel industry

Even though digitalization promises numerous advantages, adopting it in the apparel industry is challenging due to the unique demands of the

consumers, small batch size, frequent fashion changes, inherent complexity of handling the flexible textile materials, and consumers expect more tactile experience in buying clothing. On average, there are 350 different product variations, which makes it difficult to automate and standardize the product development and production processes. In addition, employing digital tools in the textile and apparel sector will lead to overall job losses and reduced demand for traditional labor [9]. However, it also creates new opportunities in technology management and data analytics. Continuous training and upskilling programs are essential to equip the workforce with the necessary competencies [9].

## Conclusion

Digitalization enables greater design flexibility, shortens production cycle time, enables personalization, waste minimization, material optimization, and real-time collaboration. Therefore, transitioning from traditional methods to digital systems is necessary to promote a circular economy and resource efficiency, ensuring a resilient future for the apparel industry.

Digitalization is no longer a luxury for the Apparel industry; it is a necessity for building a resilient Future of the industry.

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