

Beyond the virtual: embracing tangible innovations in fashion technology and sustainability

Abstract

The rapid ascent of artificial intelligence (AI) and virtual reality (VR) technologies has transformed how fashion is imagined, prototyped, merchandised, and consumed. Yet fashion remains a physical practice grounded in materials, construction, comfort, safety, and cultural meaning. This opinion essay argues for an approach that integrates digital capabilities with advances in textiles, manufacturing, and circular design. The author outlines the specific strengths and limitations of virtual tools; propose a digital-physical value loop that links data, design, materialization, and feedback; and highlight sustainability and economic rationales for investment in low-impact materials and on-demand production. The discussion examines fit and sizing as a persistent gap between digital prototypes and physical garments, especially in fit-critical categories. It then surveys promising material innovations. The essay concludes with a pragmatic roadmap for educators, brands, and policy stakeholders that prioritizes scalable steps – data standards for body measurements and product passports, micro-factory trials, and curricular integration – so that fashion remains both expressive and materially responsible in a world that is still, and will remain, profoundly physical.

Keywords: fashion technology, sustainability, digital-physical integration, fit and sizing

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Abbreviations: AI, artificial intelligence; VR, virtual reality; 3D, three-dimensional

Introduction

The cultural imagination often celebrates Artificial Intelligence (AI), virtual reality (VR), and other digital breakthroughs as if they could replace the physical world. Fashion does not fit that narrative. No matter how convincing a virtual rendering may appear, clothing ultimately functions on bodies in motion. Garments must resist abrasion, manage moisture, allow heat to dissipate, stretch or stabilize where appropriate, and communicate identity within social context. These qualities arise from fibers, yarns, structures, finishes, and construction methods that interact with human bodies and environments. The future of fashion therefore requires a synthesis: digital tools that accelerate ideation and reduce waste, and material innovation that improves performance and sustainability in physical products.

Transformative impact of digital technologies

Digital technologies have reshaped every stage of the fashion pipeline.¹ Generative AI models can expand design search, which allows teams to explore silhouettes, surface treatments, and colorways far faster than traditional methods. Three-dimensional (3D) garment visualization can reduce the number of physical prototypes that a team would otherwise cut and sew. Virtual showrooms can present collections without travel constraints, which creates broader access for buyers and media.² E-commerce platforms that sit atop recommendation systems can match products to customer preferences with greater accuracy, and AI-driven service agents can resolve routine requests at scale.

These capabilities matter for sustainability as well as efficiency. When a design team converges on a direction with fewer iterations, it can reduce material, labor, and time waste. When users use predictive models to better align inventory with demand, unsold stock and associated markdowns can be greatly reduced. When retailers employ

virtual try-on, size guidance, or style recommendations, return rates can be significantly lowered, which in turn reduces the carbon and financial costs of reverse logistics.³

The enduring value of physical garments

Despite these gains, physical garment still determines actual value. A consumer judges comfort, drape, durability, and aesthetics through touch, movement, and wear over time. Digital proxies can approximate these experiences, but they do not fully capture fiber morphology, yarn hairiness, seam bulk, lining friction, or the micro-pressures that boning, interfacing, and closures apply to the body, at least not at current stage. Many technical production details remain artisanal or tacit: how a slippery chiffon feeds under a presser foot, how a bias panel relaxes after steaming, or how a knit waistband recovers after repeated stretch. These details still rely on skilled workers and robust quality systems, which will likely remain true for the next decade even as automation advances.

Among those challenges, fit presents a persistent gap. A digital pattern that appears to fit on an avatar may still strain at the bust or collapse at the knee when translated to actual fabric on diverse bodies. Protective apparel and other fit-critical categories make this point clear: safety outcomes depend on material behavior and construction quality that only physical testing can validate. Until the industry closes this gap, physical sampling, wear testing, and iterative refinement will remain essential.

Linking digital tools with physical production

Rather than framing virtual and physical methods as opposing approaches, the industry should connect them in a continuous loop. The process begins with data, which captures body measurements, motion ranges, climate conditions, and use contexts. This data then informs the design stage, where digital exploration and rule-based modeling narrow the possibilities toward viable options. The next step is materialization, in which digital concepts are translated into textiles, trims, and construction details that meet functional requirements.

Finally, feedback from user experiences, including return reasons, repair records, and durability assessments, flows back into the data stage, completing the loop and driving further refinement.

This loop converts inspiration into information and then back into better physical products. It also creates the foundation for circularity: when a garment carries a digital record of composition and assembly, it becomes easier to repair, disassemble, or recycle that item at end of life.

Sustainability and economic case

Sustainability in fashion extends beyond visual presentation and has become a fundamental consideration for supply-chain resilience and long-term profitability. Brands that align supply with demand reduce waste and protect margins. Garments that last longer have positive impact on both the environment and consumer trust. Selecting materials with lower water, chemical, and energy use can help limit environmental impact and reduce compliance risks as regulatory standards tighten. Brands that already treat sustainability as a design factor to consider in advance, rather than as an afterthought, often can reinforce both profitability and responsibility.

Digital tools support this shift, but only when connected to physical decisions. A forecast that reduces overproduction works best when it pairs with on-demand or small-batch manufacturing. The sustainability benefits of a digitally rendered, multi-material design are greater when the garment can be re-engineered into a mono-material construction or into assemblies that allow easy separation for repair or recycling. The intersection of analytics with manufacturing therefore deserves priority investment.

Material innovation and construction practice

Material innovation has accelerated, which creates new options for responsible design. Bio-based alternatives such as mycelium-derived leather substitutes or seaweed-infused cellulosic fibers could offer intriguing performance profiles that continue to improve. Recycled synthetics can reduce dependence on virgin petrochemicals when sourced and processed with care. Wool, cotton, and bast fibers still offer proven performance when growers and mills apply better practices and transparent traceability. Beyond inputs, the structure matters: spacer knits, engineered jacquards, or whole-garment knitting can deliver comfort and reduce cut-and-sew waste.

Construction methods also evolve. Bonding and ultrasonic seaming can remove bulky allowances in specific zones, which improves comfort and reduces chafe.³ Modular designs that allow replacement of high-wear components, such as cuffs, collars, knee panels, can extend service life. Pattern strategies that avoid tiny, hard-to-recover parts improve recyclability. Each decision ties back to the digital–physical loop: the digital file can embed the rationale for these choices so that factories, repair partners, and recyclers understand what to do decades later.

Closing the fit and sizing gap

Better fit requires better data and better translation. Several practical steps are within reach. First, privacy-preserving body measurement standards would allow consumers to share dimensions relevant to fit without revealing their identities. Building on this data, parametric pattern blocks could then adapt to individual measurements while still maintaining critical fit evaluation criteria such as ease, balance, and grain. Equally important are material libraries that capture material properties like stretch, recovery, shear, drape, and thickness, which

would help digital models more accurately reflect how garments behave on real bodies.² Finally, feedback analytics could be used to link customers' opinions directly to pattern and grading adjustments, moving beyond generic size advice and making fit improvements more precise and responsive. These steps would support mass customization that avoids the lengthy and expensive bespoke processes. They would also help the industry serve a broader range of bodies with dignity, which strengthens both inclusion and commercial outcomes.

Production futures: From heavy mechanization to smart, localized making

Large, centralized cut-and-sew operations will continue to supply many categories. However, new models of production are reshaping how garments are made. Micro-factories, which combine 3D design, automated cutting, and agile assembly, allow for short production runs close to the point of use. In parallel, on-demand production, which begins only after an order is confirmed, can potentially help reduce inventory risk, especially for fashion-forward or niche products. Finally, additive approaches, such as 3D printing for soft, flexible components and whole-garment knitting, not only reduce waste but also enable complex forms that traditional methods cannot achieve. The goal is not to replace skilled labor but to improve it. Patternmakers, sample makers, and sewers remain essential. Their tacit knowledge should inform digital rules and machine instructions so that the next generation of tools reflects real craft.

Education and collaboration: Preparing the talent pipeline

In the author's opinion, education programs within the fields of fashion should teach both material literacy and digital fluency. Students who understand materials, patternmaking, fit and sizing, and construction quality can judge when a digital idea is physically viable. Students who master digital design, visualization, and data basics can move ideas through the value loop, which is explained above, efficiently. Programs can therefore strengthen students' learning experience and outcomes by requiring projects that move from digital concepts to physical prototypes, with clear documentation of sustainability decisions. They can also incorporate modules on fit diagnostics, which connect measurement, grading, and material behavior. In addition, introducing life-cycle thinking and costing helps students link design choices to both environmental and financial outcomes. Finally, partnerships with local industry, potentially through micro-factory trials or repair clinics, can offer students the chance to engage directly with real-world constraints and opportunities.

Policy and infrastructure: Enablers that accelerate progress

Policymakers and industry groups can remove friction through standards and incentives. An example incentive could be a requirement to ask manufactory to attach a 'product passport' to products. This document can record the composition, finishes, and construction details of a garment. It can provide essential information for repair services and recyclers to people or organizations that need to handle the garment after its initial sale and use. At the same time, updated measurement and size standards that replace outdated tables would help reduce consumer confusion and minimize waste from product returns. Additional incentives for repair and small-scale manufacturing could diversify local capacity and build greater supply chain resilience. Finally, green procurement criteria in uniforms and public contracts would reward designs that are durable, repairable, and low impact, reinforcing sustainability across the industry. These

steps do not require a speculative future. They require coordination around well-known practices and existing technologies.

Conclusion

Digital tools now expand creative possibilities and reduce production lead time. They help design teams be more creative, plan more precisely, and sell more intelligently. Yet the ultimate test still occurs on the body, in movement, and over time. The industry therefore needs a synthesis in which digital power aligns with material truth. The path forward pairs digital information with physical manufacturing. In the author's opinion, if the fashion industry invests in better garment fit, sustainable materials, designs that are easy to repair, and production that happens only when there is real demand, it can deliver garments that fit better, last longer, and waste less. That outcome serves consumers, protects ecosystems, and strengthens economic resilience. It also honors what fashion has always been: a material practice that dresses real people in a physical world.

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Conflicts of interest

The author declares that there is no conflict of interest.

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