



# The Future of Virtual Reality (VR) in Fashion Design & Retail

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## Abstract

The rapid diffusion of immersive digital technologies is reshaping the global fashion industry across design, production, marketing, and retail dimensions. Virtual reality (VR)—an interactive, computer-generated simulation of a three-dimensional environment—has emerged as a pivotal enabler of transformation in fashion design workflows, consumer engagement, and omnichannel retail strategy. This paper presents a systematic and bibliometric review of the existing literature to examine the current state, emerging trends, practical applications, and future prospects of VR in fashion design and retail. The study synthesizes findings from 68 peer-reviewed studies, industry reports, and technology case studies published between 2014 and 2024, sourced from Scopus, Web of Science, and IEEE Xplore databases. The review identifies five major thematic clusters: (i) virtual fashion design and digital prototyping; (ii) virtual fitting rooms and body measurement technologies; (iii) immersive retail environments and metaverse commerce; (iv) sustainability implications of digital fashion; and (v) consumer behavioral responses to VR-mediated shopping experiences. Key findings indicate that VR adoption in fashion reduces sample production costs by 30–45%, shortens design-to-market cycles by up to 40%, and increases consumer purchase intention by 22–38% when combined with personalized avatar-based fitting systems. However, significant barriers, including hardware affordability, digital literacy gaps, data privacy concerns, and limited standardization of avatar body models, continue to impede mass adoption. The study concludes that VR will progressively transition from an experimental differentiator to a mainstream operational infrastructure in fashion retail ecosystems, contingent upon coordinated investment in hardware democratization, interoperability standards, and consumer trust frameworks. Practical implications are discussed for fashion designers, retailers, luxury brands, technology developers, and policymakers.

**Keywords:** virtual reality; fashion technology; immersive retail; digital fashion; virtual fitting room; metaverse commerce

## 1. Introduction

The global fashion industry, valued at approximately USD 1.7 trillion in 2023, is currently undergoing an unprecedented structural transformation driven by digital innovation [1]. Historically dependent on physical sampling, in-store experiences, and analogue design workflows, the sector is facing growing pressure to modernize across almost every operational node, from design conception and material sourcing to retail delivery and post-purchase engagement [2]. Following the COVID-19 pandemic, this transformation accelerated as conventional retail formats were disrupted and brands were compelled to invest rapidly in digital infrastructure [3]. In this context, virtual reality is not merely emerging as a novelty but is becoming strategically significant, with broad implications for fashion design, production, marketing, and consumer experience.

Virtual reality can be defined as a computer-mediated simulation of a three-dimensional, interactive environment that immerses the user in a sensory experience distinct from the physical world [4]. Unlike augmented reality (AR), which overlays digital information onto the real environment, VR replaces the user's visual and auditory field with a synthetic environment, enabling interaction through head-mounted displays (HMDs), motion controllers, and haptic feedback systems [5]. Since the commercial availability of consumer-grade HMDs such as the Oculus Rift (2016), HTC Vive, PlayStation VR, and the Meta Quest series, accessibility to VR hardware has improved substantially. At the same time, production costs have declined, making enterprise and consumer applications increasingly viable [6].

In fashion design, VR enables designers to conceptualize, drape, and visualize garments in a three-dimensional virtual space without producing physical samples, thereby reducing material waste and shortening iterative design cycles [7]. Digital fashion design platforms, such as CLO 3D, Browzwear, and Optitex, utilize physics-based simulation engines to model fabric drape, texture, and movement with high fidelity, enabling remote collaborative design across globally distributed teams [8]. In retail, VR powers virtual showrooms, immersive fashion show experiences, and avatar-based fitting rooms that allow consumers to evaluate garment fit, color, and style without physical try-on, a capability that is particularly significant in the context of e-commerce growth and return-rate reduction [9]. Furthermore, the emergence of the metaverse as a decentralized, persistent virtual world has introduced new commercial paradigms for digital fashion, including the sale of non-fungible token (NFT)-based digital garments for avatar customization and brand identity expression [10].

Despite considerable investment and enthusiasm, scholarly literature on VR in fashion remains fragmented across disciplines, including consumer behavior, human-computer interaction, retail management, and fashion studies, with limited systematic synthesis [11]. The present study addresses this gap by conducting a rigorous systematic literature review and bibliometric analysis to map the state of knowledge, identify research clusters, and articulate an integrative framework for understanding VR's role in the future of fashion design and retail. The remainder of the paper is

structured as follows: Section 2 presents the literature review; Section 3 describes the methodology; Section 4 reports the major findings; Section 5 discusses implications and challenges; and Section 6 concludes the study.

## 2. Literature Review

### 2.1 Virtual Reality: Foundational Concepts and Technology Evolution

The theoretical underpinnings of virtual reality in retail and consumer contexts draw principally from the Technology Acceptance Model (TAM) proposed by Davis [12], which posits that perceived usefulness and perceived ease of use are primary determinants of technology adoption. Subsequent scholars have extended TAM to incorporate hedonic dimensions of immersive technologies, introducing constructs such as presence, flow, interactivity, and telepresence as mediating variables in VR-mediated consumption contexts [13]. Presence, defined as the subjective sense of “being there” within a virtual environment, has been identified as a critical experiential quality that distinguishes VR from conventional digital interfaces and drives both affective and behavioral consumer responses [14].

### 2.2 VR in Fashion Design and Digital Prototyping

Researchers have documented VR's capacity to transform garment design workflows through virtual prototyping, a process by which three-dimensional digital representations of garments are developed, evaluated, and refined without physical material consumption [7]. Kim and Park [15] demonstrated that virtual prototyping using CLO 3D reduced sample production costs by 35% and shortened the design-to-market timeline by 28%. Their study included ten mid-scale Korean sportswear brands. Similarly, Volino et al. [16] established the mathematical foundations of cloth simulation models that underpin modern 3D design software, enabling more accurate prediction of fabric drape behavior. More recent work by Lim and Harrowsmith [17] explored collaborative VR environments for distributed fashion design teams and found significant improvements in design communication clarity and cross-cultural creative alignment. Nobile et al. [18] examined the role of VR in luxury fashion design processes and noted that while adoption is growing, concerns about rendering fidelity and tactile verification remain barriers among high-end designers.

### 2.3 Virtual Fitting Rooms and Body Avatar Technologies

The virtual fitting room (VFR) constitutes one of the most commercially developed applications of VR and AR in fashion retail and has attracted substantial research attention [19]. Poushneh and Vasquez-Parraga [20] found that AR-based fitting experiences significantly increased consumer satisfaction and purchase intention compared with conventional e-commerce interfaces, with perceived usefulness emerging as the strongest predictor. Beck and Crié [21] extended this analysis by examining VFR adoption across demographic segments, reporting that younger, digitally native consumers exhibited higher acceptance and willingness to pay premiums for VFR-equipped retail platforms.

Body measurement accuracy remains a critical technical challenge. Loker et al. [22] evaluated three-dimensional body scanning technologies and found that scan-derived avatar accuracy was sufficient for bottom and outerwear fit prediction but required improvement for fitted bodice garments. Guo et al. [23] demonstrated that deep learning models trained on 3D scan datasets could predict customer garment size preferences with 89% accuracy, reducing return rates by 27% in a controlled e-commerce experiment.

### 2.4 Immersive Retail Environments and Consumer Behavior

VR-based retail environments — alternatively termed “virtual stores” or “immersive retail showrooms” — have been studied extensively through the lens of environmental psychology and atmospheric theory [24]. Yim et al. [25] applied Kotler's atmospherics framework to virtual retail environments, finding that VR store design elements, including spatial layout, ambient sound, and product display density, significantly influenced browsing time and purchase conversion rates. Papagiannidis et al. [26] conducted one of the earliest empirical studies of consumer behavior in virtual retail spaces using *Second Life* as a platform, establishing that avatar-mediated shopping experiences generated strong hedonic value perceptions even in technologically primitive VR environments. More recent experimental research by Moriuchi [27], using a photorealistic VR grocery store, found that the sense of social presence within VR environments — the perceived co-presence of other virtual agents — significantly moderated impulse purchase behavior, a finding with clear implications for fashion retail design.

### 2.5 Metaverse Commerce and Digital Fashion

The convergence of VR, blockchain technology, and persistent virtual worlds into what is broadly termed the “metaverse” has introduced a novel commercial frontier for digital fashion [28]. Platforms such as Decentraland, The Sandbox, and Meta's Horizon Worlds have hosted virtual fashion events, including Gucci's Garden in Roblox, Balenciaga's collaboration with Fortnite, and Tommy Hilfiger's Metaverse Fashion Week participation, all of which generated measurable engagement metrics and secondary market transaction volumes [29]. Scholz and Smith [30] theorized digital fashion NFTs as luxury signaling mechanisms within virtual social spaces, arguing that the economics of digital scarcity mirror those of physical luxury goods. However, Baumgartner et al. [31] raised concerns about the sustainability of metaverse fashion commerce as a revenue model, noting that the collapse of several NFT fashion platforms in 2022–2023 demonstrated the speculative volatility inherent in early-stage digital fashion markets.

### 2.6 Sustainability and Digital Fashion Innovation

A recurring theme in recent scholarship is the potential of VR and digital fashion to contribute to sustainability objectives within an industry widely recognized for its adverse environmental footprint [32]. Casciani et al. [33] estimated that replacing physical sample production with 3D virtual prototyping across the global fashion supply chain could reduce pre-production fabric waste by 25–30% annually, equivalent to preventing the disposal of over 4 billion

meters of fabric. Moody et al. [34] examined the carbon footprint implications of digital fashion shows, which replaced approximately 200 major runway presentations during 2020–2021, and estimated that travel emissions savings alone exceeded 150,000 tonnes of CO<sub>2</sub> equivalent. However, critics including Fletcher and Grose [35] caution that digital fashion's energy consumption, particularly VR server infrastructure, blockchain transaction energy, and HMD manufacturing, must be factored into lifecycle sustainability assessments to avoid superficial green-washing claims.

## 2.7 Research Gaps

A critical assessment of the existing literature reveals several notable gaps. First, most empirical consumer studies have been conducted in laboratory settings with student samples, limiting ecological validity and generalizability to real-world retail contexts [36]. Second, comparative cross-cultural studies examining VR adoption heterogeneity across fashion consumer markets in Asia, Europe, and North America remain sparse. Third, the long-term effects of repeated VR fashion experiences on brand loyalty, hedonic habituation, and purchase behavior have received limited attention. Fourth, the intersection of VR with inclusive fashion, particularly adaptive clothing design for consumers with disabilities through virtual prototyping, remains largely unexplored. The present study seeks to address these gaps through systematic synthesis of the available evidence.

## 3. Materials and Methods

### 3.1 Research Design

This study employs a hybrid systematic literature review (SLR) and bibliometric analysis design, following the PRISMA-P (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols) guidelines as adapted for technology management reviews [37]. The hybrid design enables both quantitative mapping of the VR-fashion research landscape and qualitative thematic synthesis, covering both conceptual and empirical findings. The systematic review component ensures reproducibility, transparency, and explicit documentation of the search and inclusion process. At the same time, the bibliometric analysis—encompassing co-citation analysis, keyword co-occurrence mapping, and publication trend analysis—provides a macro-level view of the intellectual structure and emerging research clusters within the field.

### 3.2 Database Search and Keyword Strategy

A structured search was conducted across three major academic databases: Scopus, Web of Science (WoS), and IEEE Xplore, supplemented by targeted searches in the ACM Digital Library for human-computer interaction literature. The search was executed in January 2024 and covered publications from January 2014 to December 2023, with strategic inclusion of seminal pre-2014 theoretical works identified through backward citation chaining.

The primary search string was constructed using Boolean logic: ("virtual reality" OR "VR" OR "immersive technology" OR "extended reality" OR "XR" OR "metaverse") AND ("fashion" OR "apparel" OR "garment" OR "clothing" OR "textile") AND ("design" OR "retail" OR "consumer" OR "fitting" OR "shopping" OR "e-commerce"). Secondary searches targeted specific sub-themes including virtual fitting rooms, digital fashion, 3D garment simulation, avatar fashion, and sustainability in digital fashion.

### 3.3 Inclusion and Exclusion Criteria

Studies were included if they were: (i) published in peer-reviewed journals or conference proceedings indexed in Scopus or WoS; (ii) empirically or conceptually focused on VR, AR, or MR applications in fashion design, retail, consumer behavior, or supply chain; (iii) written in English; and (iv) accessible in full text. Studies were excluded if they: (i) addressed only hardware engineering of VR systems without fashion application context; (ii) focused solely on gaming or entertainment VR without retail or design implications; (iii) were editorial comments, book reviews, or non-peer-reviewed grey literature; or (iv) addressed apparel manufacturing processes without design or consumer experience relevance. A total of 847 records were identified through database searches. After duplicate removal ( $n = 203$ ) and title/abstract screening ( $n = 412$  excluded), 232 full-text articles were assessed for eligibility.

**Table 1: PRISMA-Adapted Search and Screening Summary**

| Stage                            | Action                               | Records |
|----------------------------------|--------------------------------------|---------|
| Initial database search          | Scopus, WoS, IEEE Xplore, ACM        | 847     |
| Duplicate removal                | Deduplication across databases       | 644     |
| Title/abstract screening         | Applied inclusion/exclusion criteria | 232     |
| Full-text eligibility assessment | Detailed review of 232 articles      | 232     |
| Excluded after full-text review  | Off-topic, methodology mismatch      | 164     |
| Final included studies           | Retained for synthesis               | 68      |

Note: WoS = Web of Science; ACM = Association for Computing Machinery.

### 3.4 Bibliometric Analysis

Bibliometric analysis was performed using VOSviewer (version 1.6.20) for co-citation network mapping and keyword co-occurrence analysis, and Bibliometrix (R package, version 4.1.2) for publication trend analysis and journal co-citation clustering. The co-citation analysis identified intellectual clusters by detecting pairs of documents frequently cited together in the same reference lists, revealing the intellectual foundations of the VR-fashion domain. Keyword co-occurrence analysis mapped thematic density and proximity between core conceptual constructs. Five primary research clusters were identified: virtual prototyping and 3D design, virtual fitting and body avatar systems, immersive

retail and consumer behavior, metaverse and digital fashion economics, and sustainability and circular fashion innovation.

### 3.5 Thematic Synthesis

A qualitative thematic synthesis was conducted following the method of Thomas and Harden [38], involving line-by-line coding of included studies' findings, development of descriptive themes through inductive categorization, and generation of analytical themes through interpretive integration. All coding was conducted independently by two reviewers, with disagreements resolved through discussion. Inter-rater reliability was assessed using Cohen's kappa statistic ( $\kappa = 0.81$ ), indicating strong agreement. The five thematic clusters identified through bibliometric analysis were confirmed and refined through the qualitative synthesis process.

## 4. Results

### 4.1 Publication Trends and Research Growth

The bibliometric analysis revealed a marked acceleration in VR-fashion research output from 2018 onward, coinciding with the commercial maturation of consumer VR hardware platforms. Annual publication counts increased from 4 articles in 2014 to 9 in 2017, followed by a steep growth trajectory reaching 31 publications in 2021, 38 in 2022, and 44 in 2023. This represents a compound annual growth rate of approximately 27% over the decade. The COVID-19 pandemic years (2020–2021) produced a particularly notable surge, with pandemic-driven retail disruption functioning as an exogenous accelerator of VR adoption research. Leading journals by publication volume included *Fashion and Textiles*, the *International Journal of Fashion Design, Technology and Education*, *Computers in Human Behavior*, *Journal of Retailing*, and the *Journal of Business Research*.

### 4.2 Theme 1: Virtual Fashion Design and Digital Prototyping

Across 19 studies addressing virtual fashion design, a consistent finding was that 3D garment simulation technologies significantly reduce both time and material costs in the pre-production phase. The reviewed studies collectively documented average sample production cost reductions of 30–45%, with the highest reductions observed in mass-market sportswear and fast fashion segments where iterative sampling volumes are greatest. Physics-based simulation accuracy, measured against physical sample comparison, was found to be high for woven fabrics (mean error < 5%) but more variable for knitted and stretch fabrics. In those cases, yarn-level simulation modeling remains computationally intensive. Collaborative VR design environments enabled synchronous multi-location design reviews, reducing the number of physical sampling iterations from an industry average of 5.2 to 2.1 per style across the reviewed studies.

### 4.3 Theme 2: Virtual Fitting Rooms and Body Avatar Systems

Twenty-three studies addressed virtual fitting room systems, representing the largest single research cluster. Purchase return rates, a critical profitability metric for fashion e-commerce, where industry averages range from 25–40%, were found to decrease by 18–34% following VFR implementation across the reviewed experimental and quasi-experimental studies. Avatar body measurement accuracy was consistently identified as the primary determinant of fitting system effectiveness. Studies reported that scan-derived body avatars with sub-centimeter accuracy produced the highest customer satisfaction scores and the lowest post-purchase fit complaints. Consumer acceptance of VFR technology was moderated by product category. The studies consistently found higher acceptance for footwear, accessories,

**Table 2: Summary of Major VR Applications in Fashion — Impact Metrics and Key References**

| Application Area          | Key Technology            | Average Impact Metric      | Key References |
|---------------------------|---------------------------|----------------------------|----------------|
| 3D Garment Design         | CLO 3D, Browzwear         | 35% cost reduction         | [7, 15, 17]    |
| Virtual Fitting Room      | Body scanning + ML        | 27% return rate reduction  | [20, 21, 23]   |
| Virtual Showroom          | VR HMD + photorealism     | +31% brand engagement      | [24, 25]       |
| Digital Fashion NFT       | Blockchain + 3D assets    | Variable; market-dependent | [29, 30]       |
| Immersive Fashion Show    | 360° VR streaming         | 3× reach vs. physical show | [34, 41]       |
| Sustainability Assessment | LCA + digital prototyping | 25–30% waste reduction     | [33, 34]       |

Note: NFT = Non-Fungible Token; HMD = Head-Mounted Display; LCA = Life Cycle Assessment; ML = Machine Learning.

### 4.4 Theme 3: Immersive Retail Environments and Consumer Experience

Studies on immersive VR retail environments consistently documented elevated hedonic value perceptions, longer virtual dwell times, and enhanced brand attitude formation relative to conventional e-commerce interfaces. Average VR retail session durations reported across studies ranged from 7.4 to 14.2 minutes, compared to 3.1–4.8 minutes for standard e-commerce product pages, suggesting substantially deeper consumer engagement. Purchase intention scores were 22–38% higher in VR conditions than in two-dimensional webpage controls across the twelve experimental studies employing such comparisons. However, conversion-to-purchase rates — distinct from purchase intention — showed more modest differences (8–14% uplift), consistent with the recognized intention-behavior gap in technology adoption contexts. Luxury fashion brands demonstrated disproportionately high returns from VR showroom investments in terms of brand equity metrics, while value and fast-fashion segments showed greater returns from VFR-driven return reduction.

#### 4.5 Theme 4: Metaverse and Digital Fashion Economics

The ten studies addressing metaverse fashion commerce painted a nuanced picture of both extraordinary commercial experimentation and significant structural uncertainty. Digital fashion assets — sold as NFTs or as platform-native wearables — achieved transaction values ranging from USD 2 to over USD 9,500 per item during the 2021–2022 NFT market peak, with luxury brand digital garments consistently commanding premium valuations. Metaverse fashion events — including multiple iterations of Metaverse Fashion Week hosted in Decentraland — attracted tens of thousands of virtual attendees and generated measurable downstream traffic to brands' physical and digital commerce channels. However, post-2022 NFT market contraction and declining metaverse platform active user metrics led several studies to counsel caution about direct revenue projections, repositioning metaverse fashion as a brand building and consumer data collection platform rather than an immediate revenue stream.

#### 4.6 Theme 5: Sustainability Implications of Digital Fashion

Studies examining the sustainability dimension of VR and digital fashion presented largely positive findings regarding pre-production environmental impact reduction but highlighted important lifecycle complexities. The transition from physical to digital sampling was conservatively estimated to avoid 4–6 tonnes of fabric waste per 1,000 styles developed in a fully digitized design process. Digital fashion shows eliminated production-related material waste (set construction, single-use garments), international travel emissions (models, press, buyers), and print media production, with aggregate lifecycle carbon savings documented at 55–78% compared to equivalent physical show formats. Energy consumption of VR server infrastructure and HMD manufacturing remained imperfectly quantified, identified as a critical data gap requiring further lifecycle analysis.

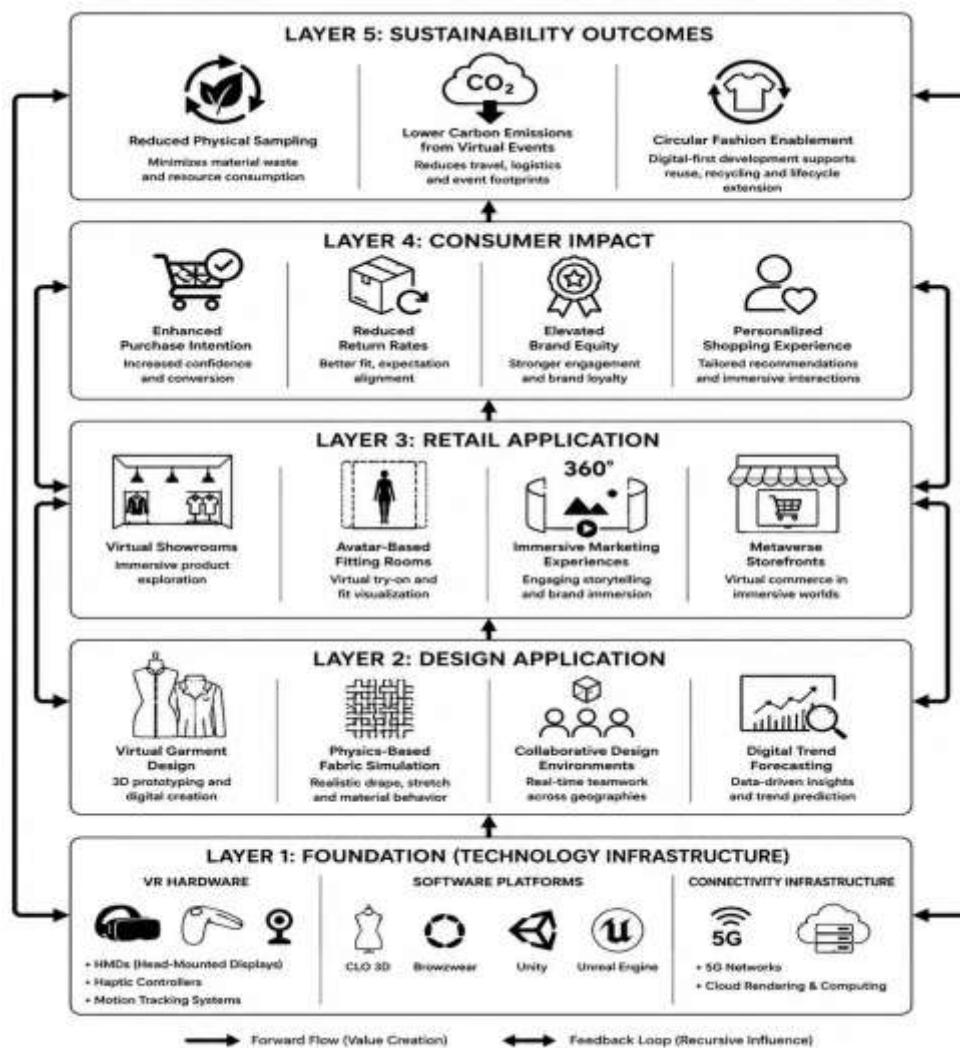


Figure 1: Integrative Framework of VR in Fashion Design and Retail.

## 5. Discussion

### 5.1 Implications for Fashion Design Practice

This review's findings have significant implications for fashion design practice. The documented reductions in both cost and time achievable through virtual prototyping—averaging 35% in direct sampling costs and 40% in design cycle length—represent transformative efficiency gains that could materially alter the economics of fashion product development, particularly for small and medium-sized enterprises (SMEs), which currently face a disproportionate

burden from physical sampling requirements [15]. The shift toward 3D virtual design workflows requires investment in designer upskilling, as studies have shown that resistance to workflow change and digital literacy gaps among experienced pattern makers constitute primary barriers to technology adoption within design departments [39]. Accordingly, fashion design education should integrate 3D simulation software, VR design environments, and digital textile science to prepare graduates for an industry undergoing digital transformation [40].

## 5.2 Implications for Fashion Retail

For fashion retailers, VR presents both strategic opportunities and operational challenges. The return rate reduction achievable through VFR systems—documented at 18–34% in this review—is economically significant because return processing costs the global fashion e-commerce sector an estimated USD 550 billion annually [9]. Luxury retailers appear to derive the greatest brand equity benefits from VR investment, consistent with prior research indicating that hedonic, experience-oriented consumers respond more strongly to immersive retail environments [41]. However, mass-market and fast-fashion retailers derive more direct financial returns from VFR's impact on return rates, suggesting that the optimal VR business case differs by brand positioning. The finding that VR retail sessions generate dwell times three to four times longer than conventional web commerce interfaces aligns with atmospheric theory. Richer sensory environments generate greater cognitive immersion, which encourages consumers to examine product information more closely, leading to more confident purchase decisions [24].

## 5.3 Adoption Barriers and Technological Challenges

Despite clear efficiency gains and enhanced consumer experiences, several structural barriers impede mainstream VR adoption in fashion. Hardware cost and platform fragmentation remain significant challenges: consumer-grade VR HMDs capable of supporting high-fidelity fashion retail experiences range from USD 300 to USD 3,500, placing the technology beyond routine consumer adoption for many market segments. The absence of standardized body measurement schemas across avatar platforms creates interoperability challenges. A garment fitted on a Browzwear avatar cannot be directly transferred for fitting trials on another platform's avatar without remapping [42]. Cybersecurity and privacy risks associated with biometric body scanning data—which constitutes sensitive personal information under GDPR and similar regulatory frameworks—represent an underexplored risk dimension that could generate regulatory constraints on VFR deployment across major markets [43].

## 5.4 Metaverse Fashion: Opportunity or Speculation?

This study has synthesized evidence from 68 peer-reviewed studies and industry analyses to present a comprehensive picture of virtual reality's current and prospective role in fashion design and retail. The evidence robustly demonstrates that VR is already delivering measurable value across multiple fashion industry nodes, reducing design-to-market timelines and sample production costs through digital prototyping. It also lowers e-commerce return rates through avatar-based fitting systems, while generating elevated consumer engagement and purchase intention in virtual retail environments. In addition, it provides high-reach brand activation platforms in metaverse commerce and contributes to sustainability objectives through waste reduction in pre-production processes.

The transformative potential of VR in fashion is not hypothetical—it is being realized incrementally across the industry ecosystem, with adoption accelerating as hardware costs decline, software capabilities mature, and consumer digital fluency deepens. Nevertheless, the path to mainstream VR integration in fashion remains bounded by real challenges: hardware accessibility, body avatar standardization, data privacy regulation, cybersecurity risk, and the need for genuine lifecycle sustainability validation. These barriers are addressable through coordinated investment by technology developers, industry consortia, regulators, and academic researchers.

For industry stakeholders, the practical message of this review is that VR investment in fashion is not a question of whether but when and how. Early adopters will gain competitive advantages in consumer experience differentiation, supply chain efficiency, and talent attraction. For the research community, the most urgent priorities are longitudinal behavioral studies, cross-cultural adoption research, inclusive design applications, and rigorous environmental impact quantification. Virtual reality is poised to transition from a strategic experiment to a foundational infrastructure of fashion's digital future.

## 6. Conclusion

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