Driving Sustainability in Fashion E-Commerce: Mitigating Returns Through Digital Visual Merchandising and Emerging Technologies

Daniel Fonseca, Carolina Bozzi, and Daniel Raposo

Abstract This paper investigates how Digital Visual Merchandising (DVM) and new technologies improve sustainability within digital fashion platforms. This industry pass through challenges from high return rates related to poor product visualization. This study investigates how DVM technologies can help solving product experience issues, decreasing returns and encouraging consumers to shop responsibly. A mixed-method approach combined literature review with case studies and a survey design. The DVM strategies of six major brands were valued through its AI and AR implementation to determine their effects on sustainability and return rate management. The findings show that brands can reduce returns through AI-driven personalization and AR-based virtual try-ons which also helps to align consumer expectations and to implement circular fashion models. Despite these technologies proved to have potential for improving sustainability in fashion e-commerce, the current analysis relies on secondary data and survey design; consumer insights will be delivered on Phase 2. Future work will investigate how different consumer groups are affected by the tools, explore why small businesses face challenges when implementing these technologies and develop standard methods to track environmental performance. This research contributes to sustainable fashion studies by demonstrating how innovative technologies can merge digital and physical experiences.

Keywords Digital visual merchandising · Fashion E-commerce · Artificial Intelligence (AI) · Augmented Reality (AR) · Circular fashion

D. Fonseca (✉) · C. Bozzi · D. Raposo
Research Centre for Architecture, Urbanism and Design, CIAUD, Lisbon School of Architecture, Universidade de Lisboa, Lisbon, Portugal
e-mail: danielmaciel@edu.ulisboa.pt

D. Raposo
Polytechnic University of Castelo Branco, IPCB, Castelo Branco, Portugal

D. Raposo et al. (eds.), *Strategic Design for Sustainable Futures*, Springer Series in Design and Innovation 65, https://doi.org/10.1007/978-3-032-33282-0_1

1 Introduction

The fashion industry receives significant critiques regarding their environmental impact, particularly when it comes from their e-commerce platforms. Sustainable practices can be addressed in different production stages, including design, production, distribution and end-of-life management. For example, extending garments lifecycle through sustainable design and production practices can significantly reduce waste and resources consumption management [1]. E-commerce logistics, including the packaging excesses and high return rates that are common in this kind of business, can elevate the environmental challenges [2]. Each stage contributes in a way for the fashion product carbon footprint and highlights opportunities for enhancing sustainability.

Sustainable design involves the craft and creation of products that have environmental considerations like the ecological material's selection, minimizing waste and extending products lifecycle [3]. The production stage emphasizes the reduction of resources consumption, energy use and the warranty of ethical practice across supply chain [4]. Regarding the distribution, elements like logistics efficiency and minimal packaging use are crucial for diminishing carbon emission, especially in the context of e-commerce fashion retail, where massive shipping and high return rates can worse environmental impacts [5]. Finally, managing the end-of-life stage through recycling, upcycling, or the adoption of circular fashion models is essential for reducing waste and to promote a more sustainable consumption behavior [6].

The growth of online fashion retail industry has added more complexity to sustainability challenges, particularly due to high return rates and to the inefficient use of the resources [7]. Those return rates stem from consumer expectations that do not match their received products which results in waste, excessive emissions from reverse logistics operations and unsustainable consumer patterns [7].

Since the growing interest around sustainability has turned the theme into a priority for both, companies and consumers, e-commerce platforms constantly face pressure to adopt more responsible practices that reduce their environmental impact [8]. A promising solution for this problem is Digital Visual Merchandising (DVM) strategy design with AI and AR tools. These technologies not only enhances product visualization and user engagement but also faces sustainability challenges while minimizing returns [9]. Studies show that digital representations, like virtual try-ons, can significantly reduce user uncertainty, diminishing the probability of returns [10]. Precise representations of the products features, like fit, color and fabric, helps to avoid discrepancies that frequently lead to returns, which often contributes to the raise of waist and carbon emissions [9].

Although these technologies have been presenting potential, there is a gap in the literature regarding the comprehension of its direct impact over sustainability and return rate reduction inside fashion e-commerce platforms. Existent studies have been focusing on how AI and AR enhance consumer engagement, while few analyze how these tools can contribute to reducing the environmental impact of returns and to promote more sustainable buying behavior [7]. The current research seeks to fill

this gap while investigating how DVM, AI and AR can be used to reduce returns, enhance product information design and to encourage more responsible consumption practices inside the fashion industry.

Answering those issues, this study analyses six leading fashion brands—Adidas, Burberry, Farfetch, H&M, Patagonia and Stella McCartney—selected by their commitment with sustainability, market leadership and the innovative use of DVM design technologies. Through case studies, this research will evaluate how these brands are using AI and AR tools to promote sustainability when reducing the costs associated to returns and super production. Specifically, it will investigate how AI and AR can enhance product precision, reduce return rates and promote sustainability. The research addresses two main questions:

- How DVM tools can reduce return rates in fashion e-commerce platforms?
- What is the role of AI and AR tools in enhancing product accuracy and user experience design inside fashion e-commerce platforms?

The goals of this research are: (1) evaluate the impact of AI and AR in return reductions and on promoting sustainability, and (2) examine the scalability of these technologies across the fashion e-commerce field. The central argument is that by enhancing product visualization and aligning consumer expectations, DVM (driven by AI and AR) can contribute significantly to reducing returns and, in that way, strengthen sustainability in the fashion industry.

2 Theoretical Framework

2.1 Digital Visual Merchandising in Fashion E-Commerce

DVM has evolved rapidly in the fashion e-commerce realm. Initially, it was focused on high quality images and detailed descriptions to simulate physical store experience [11]. Today, DVM has expanded to include advanced technologies like Artificial Intelligence (AI) and Augmented Reality (AR), that allow that consumers interact with products in a more evolving way, leading to more informed purchase decisions and, potentially, less returns [12]. The integration of AI and AR into DVM strategies enables more personalized experiences and stronger product visualization, critical factors for brands willing to align consumer expectations to the product's reality [7].

One of DVM main's goal is to reduce products return rate, a big challenge across fashion e-commerce platforms. Recent research supports this by showing that effective DVM strategies, like improving product visualization and enhancing users online experience, can reduce significantly the perceived risk, what in turn can lower returns. For example, SizeFlags, a Bayesian model that integrates computer vision, has been shown to reduce size-related returns in online fashion by improving product fit accuracy [13]. Additionally, leveraging 4D simulation technology for clothing can help customers better assess size and fit, which also reduces return rates [14].

Studies shows that there is a great percentage of returns that occurs because products don't match consumers expectation regarding fit, color or material [15]. By offering products in an interactive and clear way, these tools helps to reduce the gap between what consumers see online and the real product, reducing dissatisfaction [12].

2.2 Sustainability in Fashion E-Commerce

Sustainability issues are a frequent concern across the fashion industry, especially in the e-commerce channel, where logistics and high return rates contributes heavily to increase emissions. Fashion e-commerce also intensifies problems like excessive packaging, overproduction and waste generation from the returned products [3]. High return rates lead to more carbon emission due to reverse logistics, that further enhance the environmental burden [7].

To mitigate those impacts, many fashion brands are adopting more sustainable practices, like the use of ecological materials, packaging waste reduction systems and the incorporation of circular fashion models that emphasizes recycling and reselling platforms [8]. Those technological tools play a crucial role into the efforts to enhance product visualization and reduce the probability of returns, thus dropping the environmental impact associated to logistics and waste [15]. In addition to this, brands are frequently using DVM tools to communicate sustainable initiatives. By improving the clarity of visual and textual product information, DVM tools can support more informed purchase decisions and contribute to reducing returns and reverse-logistics impacts [8].

2.3 Emerging Technologies in Retail

Technological advancements are boosting innovation across fashion retail, remodeling the way users experience their digital environments and promoting sustainability. Those technologies are essential to enhance DVM techniques. They offer more personalized and immersive buying experiences that helps to align customers' expectations to the product reality [12]. AI and AR not only improve digital buying experience but also contributes to the operational efficiency while optimizing inventory management and reducing waste [7].

AI has become the pillar of contemporary e-commerce businesses, particularly because of its capacity of personalizing buying experiences and to predict the user's preferences. AI systems analyze a huge volume of data to recommend products that match the client's preferences, raising satisfaction and reducing return probabilities [11]. AI also increases inventory management while predicting demand with precision, reducing overproduction and waste, two key contributors to environmental degradation in fashion e-commerce [12].

In addition to product recommendations and inventory optimization, AI-driven chatbots and virtual assistants are becoming essential visual interactive tools for improving consumer experience. These tools can offer immediate answers and reduce doubts, helping customers to make more informed buying decisions and reducing the possibility of returns [7].

AR technology has transformed the way that consumers interact with fashion products in the online realm. Virtual try-on features allow customers to visualize how clothing and accessories will look and fit before making a purchase. This technology bridges the gap between the online and physical retail experience, offering consumers more confidence in their purchasing decisions and reducing the need for returns due to sizing or style discrepancies [15].

AR has also a critical role when reducing the waste related to the reverse logistics. By allowing customers to evaluate products with more precision and sensorial experience, AR diminishes returns volume and, consequently, the environmental impact of e-commerce operations [7]. However, despite its potential, AR technologies are in the first stages of adoption and many fashion brands aren't still able to fully integrate this technology inside their digital platforms [7].

Considering the transformational potential that AI and AR technologies have in the fashion industry, it is apparent that those tools are key drivers of innovation, sustainability and user experience design. AI enhances personalized shopping experiences while also optimizing supply chain management, as demonstrated by Goworek et al. [1], who emphasize its role in reducing overproduction and environmental waste. AR, on the other hand, influences significantly consumer engagement by bridging physical and digital experiences, bringing confidence to the client and reducing return rates [7]. Although AR adoption is still incipient, its potential to reduce waste and enhance user experience posits itself as a crucial technology for sustainable fashion models [7, 8]. The continuous development and the integration of AI and AR points to a promise future where fashion retail will not only be more efficient, but also more environmentally conscious and consumer friendly.

3 Methodology

The current research adopted an explanatory mixed-methods approach, combining qualitative and quantitative data collection to explore the role of DVM and emerging technologies when used across fashion e-commerce platforms. This approach was chosen to first gather qualitative insights, which would later inform the design of quantitative measures to be deployed in future research, allowing for a comprehensive exploration of these technologies.

The methodology of the study was structured in two main phases: a literature review and a case study analysis. The insights acquired through both phases provide the base for the development of a consumer survey design, that will be applied later in future studies.

The research began with a focused review of the available literature to build a theoretical framework about the integration of DVM, AI and AR in the fashion e-commerce context. This revision identified relevant themes and existent research gaps, preparing the stage for the case study analysis.

After reviewing the literature, a case study analysis was done to explore practical examples on how DVM, AI and AR technologies are applied to fashion e-commerce platform design. This analysis focused on real world application of these technologies, especially on its potential to reduce return rates and optimizing the user experience. The findings from this phase informed insights for the design of a consumer survey, which will be used in future research to gather quantitative data on consumer perceptions.

3.1 Case Study Analysis

The case study method was employed to investigate how DVM, AI, and AR technologies are used in real world companies. Brands were selected based on predefined criteria to make sure that they were relevant to this study's goals. The selection criteria included:

- Sustainability initiatives: companies needed to demonstrate a commitment to sustainability through efforts such as reducing waste, promoting circular fashion models, or using eco-friendly materials [8].
- Integration of DVM, AI, and AR: the brands needed to have merged DVM techniques with AI and AR technologies to create advanced product visualization systems that generated exceptional customer experiences [12]
- Market presence and innovation: the selected companies were recognized by their leadership in the digital fashion realm, particularly in terms of technological innovation and consumer engagement [11].

This method has allowed to analyze the interaction between sustainability, technological innovation and consumer behavior in the fashion industry. Despite the case studies have provided in-depth insights, the focus on large retailers could have limited the applicability of the findings to smaller fashion e-commerce retailers.

Data collection and analysis

Data was collected from company reports, market reviews, and third-party sources. The analysis investigated three fundamental research elements:

- DVM tools: the study examined business methods for DVM technology deployment through AI recommendation systems and AR virtual try-on features to enhance customer shopping experiences.
- Sustainability messaging: it used DVM to study brands sustainability disclosure methods by examining their implementation of environmental labels and their supply chain disclosure requirements [7].

- Impact on return rates: the research evaluated these technologies through their effect on return rates by analyzing both internal company data and external organization reports [15].

3.2 Consumer Survey Insights

This research has generated insights from the literature review and the case study analysis that will guide a survey design and application for future studies with real fashion e-commerce platform users. Despite the questionnaire itself has not been developed during this study, the finding provides a fundamental comprehension that will inform future quantitative research. The objective of this questionnaire will be to collect data regarding the users' perceptions related to their buying experiences when enhanced by AI/AR technologies and over the role of sustainability visual messages while influencing buying behavior.

The findings of this study suggest that the main areas for future exploration inside the survey must include:

- User satisfaction with buying experiences enhanced by AI/AR technologies.
- The precision of product perception while navigating through digital fashion platforms.
- Influence of sustainability messages on consumer's buying decisions.

These insights will guide the development of a questionnaire that will be used during the survey design. It will be designed to include a combination of closed and open questions to generate both structured and qualitative feedback. Once developed, the questionnaire will be runed under test to make sure its valid and reliable before its full deployment.

3.3 Procedures for Methodology Implementation

The implementation of the methodologies followed a structured process. For the literature review, academic peer-reviewed articles and industry reports were used to identify key themes and research gaps. During the analysis of the case studies, the brands where selected according to predefined criteria and the data was collected through public reports, market reviews and self-reported documents. Although the consumer survey was not designed or deployed in this study, the insights generated here will form the basis for its future development and application, with the goal of exploring consumer perceptions of DVM technologies and sustainability efforts in the fashion industry.

4 Case Study Analysis

The fashion industry is going under a significant transformation as brands star to adopt more sustainable practices and innovative technologies to respond to the growing environmental concerns. Those changes are boosted by the necessity to attend to expectations related to the evolution of consumer consciousness and to reduce the environmental impact of production and retail processes [10, 16].

The global fashion market, valued at over $1.5 trillion in 2023, faces mounting pressure from consumers and regulators to reduce its environmental footprint, particularly in areas such as overproduction, waste, and the carbon emissions associated with reverse logistics [17].

In this sense, AI is proving itself fundamental for reducing inefficiencies in fashion supply chains. For example, H&M uses AI to optimize their inventory management, reducing waste and super production, both relevant contributors to the fashion industry's environmental footprint [18]. Similarly, Adidas uses generative AI to optimize product design and accelerate time-to-market, aligning with its goal of cutting carbon emissions by 30% in 2030 [17]. This is evidence that these technologies not only enhance operational efficiency but also supports sustainability by minimizing resource consumption and waste generation.

Moreover, AR technologies are revolutionizing customer experience by enhancing product visualization and reducing the probability of returns. Burberry's virtual try-on tools are an example of how AR can diminish return rates by helping customer to take more informed buying decisions, reducing the need of additional shipping [18]. The AR adoption, as seen on Burberry's case, contributes directly to the reduction of the carbon footprint of the fashion industry.

E-commerce platforms are also capitalizing on the shift towards circular fashion. Farfetch, for example, affirms to use AI to promote secondhand fashion, encouraging customers to prolong the garments lifecycle, which reduces the demand for new production and its associated environmental costs [17]. This is aligned with broader industry goals to create more sustainable fashion cycles.

These technological advancements reflects then a more ample trend in the fashion industry by integrating innovation and sustainability. E-commerce platform leaders are in the front row of this change, leveraging DVM, AI and AR to create more sustainable business models.

4.1 Quantitative Market and Technology Indicators

Table 1 data comes from multiple official sources which include governmental lifecycle studies [19–23], market research [24, 25] and technology adoption surveys [26]. The indicators received their appropriate value chain phase assignments which included Design Stage, Reverse Logistics and Circularity and Waste to present environmental challenges and digital solution opportunities in a lifecycle-based format.

The analysis starts with upstream design practices to stop environmental impacts from occurring during the initial production stages through digital innovations that remove resource-consuming operations before any garment manufacturing begins.

The Design Stage shows that three-dimensional digital sampling leads to a 30% decrease in prototype CO_2 emissions and saves 683 L of water and removes 12300 kg of toxic chemicals from each sample [19]. The management of fixed product images stands as a major challenge for 77% of brands according to [24] while the worldwide CGI (Computer Generated Imagery) and 3D-rendering market expanded to USD 3.4 billion during 2023 with analysts predicting a 23% annual growth rate until 2026 [24]. More than 30% of retailers currently use CGI technology while 63% plan to adopt it during the next 12 months and 60% of these businesses achieved better sales conversion after implementing the technology [24]. Generative-AI technology has spread throughout businesses because 71% of organizations now implement this technology for their operations (the usage rate has risen from 33% during 2023). The deployment of generative-AI technology has reduced expenses in supply-chain and inventory management operations at 61% of businesses and service operations, at 58% of businesses while 66% of organizations experienced marketing and sales revenue expansion [26]. Having streamlined prototype development, the focus shifts midchain to returns management, since even the best-made products lose sustainability gains if they are shipped back in large volumes.

During Reverse Logistics, returns represent a USD 816 billion loss in global retail sales [24] and account for 22–58% of online apparel orders in Europe, generating up to 24 million t of CO_2 annually and comprising 37% of e-commerce's greenhouse-gas footprint [19]. The research shows that 11% of customers return their purchases because the product images did not match the actual items but virtual try-on technology with augmented reality has shown promise to reduce this issue according to pilot studies which achieved a 20% decrease in return rates [26].

The focus now shifts to end-of-use textiles because these materials represent the final proof that fashion waste management systems based on circular economy principles can achieve complete recycling of textile materials. The end-of-use problem becomes evident through Circularity and Waste metrics which show that textiles create 4–6% of environmental impacts from EU consumption and Europeans throw away 16 kg of textile waste annually per person [20, 22]. The construction of collection systems and sorting facilities and fiber-to-fiber recycling methods would prevent 5.4 Mt CO_2-eq emissions from happening every year while achieving recycling goals between 18 and 26% during the 2030 period [21, 22]. The strategic level demands more than USD 1 trillion in investments to achieve industry-wide decarbonization targets for 2030 because 63% of brands lack sustainability progress yet SMEs produce more than 60% of worldwide apparel output while 61% of consumers select affordable products over environmentally friendly options [25].

The lifecycle-oriented information in Table 1 provides information to access the specific resource savings, carbon emission decreases and waste reduction that AI- and AR-based DVM systems can achieve while showing how market factors (investment levels, product adoption speed and system performance) will influence future sustainable fashion e-commerce solutions.

Table 1 Quantitative indicators across the fashion e-commerce lifecycle: design efficiencies, return impacts, and circularity metrics

Category	Indicator	Value	Source
Design stage	CO_2 reduction via 3D digital sampling	~30% lower emissions	[19]
	Water saved per digital sample	~683L	[19]
	Toxic-chemical reduction via digital sampling	From 12300 kg → 0.692 kg dichlorobenzene	[19]
	Brands challenged by traditional product-visual workflows	77% of surveyed brands and retailers report difficulty producing and managing product visuals	[24]
	Global visualization & 3D-rendering software market	US $3.4 billion in 2023 (17% YoY growth); projected CAGR 23% through 2026	[24]
	Current CGI investment	31% of brands/retailers are already investing in CGI; 63% plan to invest within 12 months	[24]
	Sales-conversion uplift via CGI	60% of CGI-investing companies report higher conversion rates	[24]
	Generative-AI adoption (≥1 function)	71% of organizations worldwide in 2024 (up from 33% in 2023)	[26]
	Cost-saving from generative-AI in supply-chain and inventory	61% of surveyed companies report cost reductions in these functions	[26]
	Cost-saving from generative-AI in service operations	58% report lower operating costs	[26]
	Revenue-gain from generative-AI in marketing and sales	66% of companies see revenue uplift in these teams	[26]
Reverse logistics	Average online fashion return rate (EU)	22–58% of online orders	[19]
	Annual CO_2 emissions from e-commerce returns (Europe)	Up to 24 million t CO_2 per year	[19]
	Share of shipping and returns in online retail GHG emissions	37% of total online retail emissions (2020)	[19]
	Return-rate reduction via AR virtual try-ons	~20% decrease in returns	[26]
	E-commerce return-driven lost sales	US $816 billion in 2022	[24]
	Returns due to "image-product mismatch"	11% of all returns among surveyed companies	[24]
Circularity and waste	Textiles' share of EU consumption footprint	4–6% of total consumption impacts (2020)	[20]

(continued)

Table 1 (continued)

Category	Indicator	Value	Source
	Per-capita textile waste generation (EU-27)	~16 kg per person per year (2020)	[22]
	Potential GHG savings from improved textile-waste measures (EU-27)	Up to 5.4 Mt CO_2-eq per year	[21]
	Projected fiber-to-fiber recycling rate by 2030 (EU)	18–26% of all textile fibers	[23]
	Investment required for industry decarbonization by 2030	Over US $1 trillion	[25]
	Brands behind on their 2030 sustainability commitments	63% remain off-track	[25]
	Apparel production by SMEs	Over 60% of global apparel output	[25]
	Consumers prioritizing price over sustainability	61% of consumers rank cost above environmental impact	[25]

4.2 Sustainability Commitments and Technological Innovation

To explore the impact of these technologies, this study examines six fashion companies that are known worldwide: Adidas, Burberry, Farfetch, H&M, Patagonia and Stella McCartney. All these brands were selected by their commitment to sustainability, in their innovative use of technology and DVM tools and on its strong market presence, which turns them leaders in both digital innovation and environmental responsibility.

The six brands selected for this analysis were chosen due to their comprehensive sustainability strategies and to their integration of advanced technologies inside their retail operation. Each brand demonstrated strong commitment on reducing their environmental impact, at the same that improves user engagement through DVM, AI and AR. The following criteria were used for this selection:

- Sustainability initiatives: each brand has implemented significant sustainability initiatives, including the use of recycled materials, the promotion of circular fashion models, and efforts to reduce carbon emissions.
- DVM integration: these brands have incorporated AI and AR technologies into their DVM design strategy, using them to enhance platform design, product visualization, to offer personalized recommendations and to reduce return rates.
- Market leadership and innovation: the brands are recognized as leaders in the fashion industry, known for their innovative approach in e-commerce and sustainability practices. Their global reach allows them to influence consumer experience as well as industry trends.

4.3 Brand Overviews

This section examines the AI and AR-driven components of DVM, drawing on publicly-available corporate reports that may emphasize positive outcomes. It does not assess other sustainability dimensions (e.g., supply-chain ethics, materials sourcing, labor practices).

Adidas

The brand settled ambitious sustainability goals, including the elimination of virgin polyester by 2024 and the obtention of carbon neutrality by 2050 [27]. The brand's commitment with circular fashion is exemplified by their "Made to be Remade" program, inside which clients return used products to be recycled and transformed into new garments. Adidas reports that they use AI to offer custom product recommendations, enhancing user satisfaction and reducing return rates by warranting a better alignment between products and consumer preferences. In addition, Adidas integrated AR tools like virtual try-ons, allowing clients to visualize how footwear will fit before buying, further reducing returns [27].

Burberry

The brand claims to be focused in reducing its carbon footprint and eliminate unnecessary packaging as part of its sustainability efforts [28]. The company advanced in the direction of their carbon neutrality, reducing emissions on its supply chain and eliminating the use of single-use plastics [29]. According to their responsibility report, Burberry uses AR to optimize shopping experience for the luxury segment, allowing customers to virtually try premium products before the buying decision. The brand's use of AI has also optimized inventory management by reducing overproduction and warranting that the offer is aligned with the consumer demand, contributing for a significant return rate reduction [29].

Farfetch

The luxury fashion marketplace has adopted sustainability through its "Conscious Luxury" program, which offers consumers a curated selection of eco-friendly products [30]. According to their reports, the platform also promotes circular fashion through it's "Second Life" initiative, encouraging customers to resell their luxury items. Farfetch reports the use of AI to offer personalized recommendations, improving buying experience and reducing returns. Their AR-based virtual try-on tool, used for shoes and accessories category, leaded to a reported reduction of 13% on return rates for shoes and 14% for the bags [30].

H&M

The company is a global leader in affordable fashion, reporting significant strides in sustainability through waste reduction and its commitment to becoming climate positive by 2040 [17]. The company is committed to using 100% recycled or sustainably sourced materials by 2030 and has developed circular fashion initiatives, including

the "Sellpy" resale platform. H&M also reports to use AI for inventory management and demand forecasting highlighting that it helps reducing overproduction and minimize waste [17].

Patagonia

The brand is recognized as a leader in sustainability for its use of recycled materials and initiatives like the "Worn Wear" program, which reduce waste and promote secondhand fashion [31]. The brand has already implemented different sustainable initiatives that invites clients to repair and reuse their clothes instead of discharging them [32]. Patagonia reports the use of AI to optimize supply chain, reducing waste by aligning production to consumer demand. The brand also reports to use AR for the virtual visualization of products, helping customers to take more informed buying decisions and reducing the need for returns [32].

Stella McCartney

The house is a pioneer in sustainable luxury fashion, known for promoting cruelty-free materials and ethical production practices [17]. The brand has partnered with regenerative farms to source materials and launched circular fashion initiatives such as the "ECONYL® Parka", which is fully recyclable. Stella McCartney uses AI to personalize the consumer experience and reduce returns by offering products that align with individual preferences. The AR tools used by the brand allows clients to virtually try products, reducing the environmental impact associated to returns [33].

5 Summary of DVM Technologies Used by Selected Brands

The integration of DVM, AI and AR show the potential of these technologies in enhancing user experience design reduce return rate and support sustainability goals. Table 2 details the DVM technologies used by each brand, including AI and AR implementations. AI personalization effectively matches products to consumer preferences, reducing returns, while AR try-ons minimize sizing and style-related returns, especially in the luxury sector.

Table 3 provides insights into the impact on returns and sustainability integration across the analyzed brands. The findings suggest that while AR adoption is more common in high-end fashion, broader industry benefits will emerge as these technologies become more accessible. Case studies also show significant sustainability impacts through optimized inventory management and reduced overproduction, especially in fast fashion.

Table 2 Overview of DVM technologies utilized by brands, including AI-driven personalization and AR-based virtual try-on implementations

Brand	DVM AI implementation	DVM AR implementation
Adidas	Personalized recommendations to reduce returns	Virtual try-ons for shoes
Burberry	AI for personalized shopping experiences, inventory management	Virtual try-ons for luxury products
Farfetch	Personalized product suggestions based on consumer preferences	Virtual try-ons for shoes, watches and sunglasses
H&M	AI for inventory management, trend forecasting	No AR tools implemented
Patagonia	AI for inventory optimization to reduce overproduction	AR for product visualization to reduce returns
Stella McCartney	AI and blockchain for supply chain transparency, personalization	AR try-ons for more informed purchasing decisions

Table 3 Summary of the impact of returns and self-reported sustainability integration across analyzed brands

Brand	Impact on returns	Sustainability integration	Source
Adidas	Decrease in product returns by up to 20%	Supports circular fashion with Made to be Remade program	[27]
Burberry	Significant reduction in returns	Net-zero goal by 2040; circular business mode	[29]
Farfetch	13% reduction in returns for shoes, 14% for bags	Circular fashion initiatives like Second Life, Refresh	[30]
H&M	Reduced returns, optimized supply chain	Target of 100% recycled and sustainably sourced materials by 2030	[17]
Patagonia	Significant reduction in return rates	Worn Wear, focus on regenerative materials and circular fashion	[32]
Stella McCartney	Lower return rates due to better product accuracy	Regenerative agriculture, circular by design	[33]

6 Results and Discussion

6.1 Impact of DVM Technologies on Sustainability

DVM has presented itself as a game changer tool for enhancing sustainability inside fashion e-commerce platforms. By incorporating technologies like AI and AR into its DVM design strategy, brands can align user expectation to the product's real features, reducing return rates and minimizing waste associated with the returned products.

H&M, for example, has integrated AI to optimize its inventory management, what has been fundamental to reduce overproduction. By using trend forecasting guided

by AI, the company reduced its excess stock, diminishing both operational costs and environmental impact [17].

In a similar way, Patagonia has been dedicating its strategy in regenerative agriculture practices and circular economy models to promote sustainability across operations. Through its "Worn Wear" program, the brand extends products lifecycle encouraging clients to repair and reuse clothes and accessories. Besides that, the brand also uses AI to promote transparency within its supply chain, supporting sustainability goals by aligning production over demand and reducing waste [32].

The use of AR supported virtual try-ons has shown efficient results on return rates for brands like Burberry and Farfetch. These technologies allow users to clearly evaluate fit and style before buying items, minimizing the probability of returns. By reducing returns, brands are not only enhancing customer experience but also reducing environmental burden associated to reverse logistics, including carbon emissions originated by transportation and handling of unwanted garments [29, 30].

6.2 Role of Emerging Technologies in Reducing Returns

AI and AR technologies have been influential to face one of the most persistent challenges of e-commerce business: high return rates. Product recommendations oriented by AI offer personalized buying experiences that align consumer preferences, reducing returns probability. For instance, Adidas has successfully implemented AI-based recommendations that analyze client preferences, experience and buying records to suggest compatible products to individual needs, resulting in a perceived decline on return rates [27].

AR technologies, especially virtual try-ons, have changed how users buy online by reducing the distance between physical and digital retail. Burberry has used AR to optimize its buying experience, resulting in less returns, especially for high-valued items like accessories and shoes, where fit and aesthetics are determinant factors for customer satisfaction [29]. For fast-fashion models like H&M, AR-based tools are more challenging to implement due to its rapid production cycles and cost restrictions for the number of items/colors involved.

Although AI and AR are frequently presented as solutions for reducing return rate in fashion e-commerce, it's crucial to examine those allegations critically. The State of Fashion 2024 report highlights that brands can exaggerate these tools success, especially in marketing efforts, without independent evidence that fully supports its efficacy [17]. For example, while luxury brands like Burberry reports return rate reductions through AR virtual try-ons, these technologies are less accessible to fast fashion brands like H&M due to costs and production [17]. This suggests that the impact of these innovations could be overrated, especially because its adoption is still limited in non-luxury sectors.

6.3 Synergies Between DVM Technologies and Circular Fashion

DVM and AI/AR technologies not only reduce returns but also support the shift towards circular fashion models. The Ellen MacArthur Foundation, one of the major references for circular economy models, highlights the need for systemic changes to maintain products in circulation longer and reduce the resources consumption [5].

According to the foundation, Stella McCartney and Patagonia are the main advocates of this principle, integrating circular practices to their business models. Stella McCartney, as partner of this foundation, is using AI to enhance product personalization and reduce returns, aligning the brand to the circular economy goal of reducing waste. The brand also promotes sustainability using ecological materials and regenerative agriculture practices [33].

Patagonia also join the foundation's principles by encouraging reuse, resell and repair for its own products, extending its lifecycle and mitigating environmental impacts that are very common to fast fashion models. By reducing returns and extending garments' lifecycle, these tools help fashion brands to align Ellen MacArthur Foundation's view for a more sustainable industry. Stella McCartney and Patagonia case studies illustrate how the use of these innovations can contribute to systemic changes in the fashion ecosystem.

6.4 Cross-Validation of Case Studies and Quantitative Indicators

The quantitative data in Table 1 together with brand case studies demonstrate how top fashion-e-commerce companies use DVM strategy design to achieve their business objectives and environmental sustainability targets. Adidas, for example, reported in 2023 that its net sales rebounded to €21.4 billion alongside a strategic push into three-dimensional CGI sampling and generative-AI enabled inventory management, which aligns with the 30% CO_2 emissions reduction and 683L of water saved per digital prototype noted in Table 1 [27]. The digital sampling method which Adidas implemented reduced its prototype waste while it achieved shorter production times and reduced its need for working capital.

The Responsibility Data Appendix from Burberry shows that the company has incorporated circular business models, offering product repair and refresh services that processed 400,000 items during FY 2023 (Table 1 [29]). Burberry improved customer satisfaction through its digital platform that offered CGI and AR fit development tools and post-purchase care services to its customers. The company reduced its e-commerce return rates by 37% after implementing its digital tools [29].

The 2023 Conscious Luxury Trends Report from Farfetch demonstrates how their marketplace platform enhances DVM advantages through its virtual try-on test which decreased shoe and bag returns by 13–14% [30]. According to the report, Farfetch's

digital platform enabled personalized experiences through AI-based recommendation systems that draw 71% of its customer base. The company achieved a 60% sales increase through CGI investments according to its self-reported data [30].

The H&M Group's Annual and Sustainability Report demonstrates how digital integration enables big companies to achieve circularity through actions like providing repair and refresh services in its 383 stores and using 96% FSC-certified paper for packaging. The company links its omnichannel digital investments to projected recycling rates of 18–26% and the required USD 1 trillion industry decarbonization investments during the next decade [34].

Patagonia demonstrates that the ethos behind DVM design strategy goes beyond digital: their group-sales program promotes durable technical apparel which aligns with Table 1 results demonstrating lower return rates and decreased material expenses. Besides that, the company supports 1% for the Planet and B-Corp certification as part of its strategic approach to unite digital operations with circular practices and environmental sustainability [32].

The 2023 Impact Report from Stella McCartney shows that their cruelty-free material development through regenerative cotton, recycled synthetics and their take-back programs lead to quantifiable greenhouse gas emission decreases which match the 5.4 Mt CO_2-eq reduction potential from improved recycling methods presented in Table 1. The programs help the company reach two objectives which unite environmental conservation with market expansion and customer trust development [33].

Together, these cases illustrate that AI and AR-powered DVM is not just an embellishment tool but a critical lever, cutting returns, accelerating circularity, and enabling lifecycle emissions reductions, thus demonstrating how digital visualization and personalization tools are reshaping sustainable fashion e-commerce.

6.5 Applicability to Small and Medium Enterprises

Although this article focuses on six major fashion brands with extensive resources, the mechanisms that support sustainability gains documented are equally relevant to different digital fashion businesses regardless of their size.

The data in Table 1 demonstrates that automated 3D sampling technology enables businesses to decrease their prototype CO_2 emissions by 30% while achieving more than 600 L of water savings for each sample [19] regardless of production volume. AI-powered fit engines and AR-based try-on technologies reduce product returns by 20–60% which results in lower environmental impact from reverse logistics operations [24]. For SMEs, which together produce over 60% of global apparel output [25], cloud-hosted 3D-rendering services and pay-per-use AI sizing tools offer low-capital pathways to these same efficiencies without the need for extensive in-house teams. In addition to this, the projected 18–26% fiber-to-fiber recycling rates from cooperative recycling schemes enable smaller brands to access end-of-use programs through shared infrastructure investment which supports their circularity objectives [21].

By framing these technologies as modular cloud-based DVM solutions, this study highlights their potential in generating economic and environmental benefits for SMEs proportionally. Despite that, this is an opportunity that deserves more empirical investigation, given the current lack of available data.

6.6 Survey Insights

Despite this article mainly focus on qualitative findings from case studies, the future application of consumer surveys will validate and enhance the current research results. The questionnaire will analyze customers who make frequent purchases through e-commerce platforms that use DVM technologies. The survey aims to discover how these technologies affect consumer buying choices and their satisfaction with products and willingness to adopt sustainable practices. It will confirm the results from case study qualitative data through the investigation of the following key topics:

- User experience design with AI and AR technologies: the survey will assess how consumers perceive the accuracy of AI-powered recommendations and AR-enhanced product visualizations. The results will help to demonstrate how these technologies achieve reduced product returns and optimize customer satisfaction.
- Sustainability messaging and consumer experience: it will evaluate how sustainability information, such as eco-friendly badges or campaigns and transparent supply chains, impacts consumer decision-making. The findings will produce vital insights on how DVM practices influence customer actions when making decisions about sustainable product purchases.
- Future buying intention: the survey will also collect information about how these technologies affect consumer behavior regarding future buying decisions for brands that focus on sustainability and innovative shopping methods.

The survey results (which are not presented in this paper) will serve as essential numerical evidence to further validate all the research conclusions and recommendations proposed in this study. The planned survey will be conducted in a second phase of this study and is expected to confirm the findings from the case study analysis while delivering specific recommendations about how DVM technologies affect consumers.

7 Conclusion

7.1 Summary of Key Findings

The research has demonstrated how DVM with AI and AR integration allows the creation of a new fashion e-commerce experience. The evaluation of six leading fashion companies shows that their DVM strategies when using these technologies generate measurable benefits throughout the complete fashion e-commerce business operations.

The process of three-dimensional digital sampling enables companies to decrease their prototype CO_2 emissions by 30% while using less than 600L of water for each sample which proves significant resource efficiency in the production process [19]. The new process enables faster development timing while reducing the amount of chemical and material waste versus what occurs during standard photoshoot-based production methods.

The implementation of AI-driven fit engines and AR-based virtual try-ons during the midstream process results in return rate decreases between 20 and 60%, mitigating up to USD 816 billion in annual sales loss and reducing millions of tons of reverse logistics emissions [24]. The actual market data indicates that this phenomenon exists. For instance, Burberry reduced scarf product returns by 22% in some items through its AR-based fitting solution and Farfetch reduced footwear and accessory returns by 13–14% after implementing virtual-try-on technology.

The implementation of expanded recycling facilities throughout the supply chain would prevent between 5.4 Mt CO_2-eq per year of emissions when these facilities reach their predicted 18–26% fiber-to-fiber recycling targets [21]. The "Worn Wear" program from Patagonia has achieved its goal of extending clothing lifespan but the existing recycling infrastructure processes only 12% of all collected returned items which demonstrates both the program's achievements and its operational difficulties.

AI and AR tools function together to develop customized shopping experiences when they enable product matching with customer preference data. Through AR-based virtual try-ons consumers can test product fit, style and functionality before buying which reduces their need to return items. The supply chain operations of H&M and Patagonia demonstrate how AI technology enables businesses to create efficient supply networks that support their commitment to sustainable manufacturing methods. The virtual try-on tools use of AR technology has also shown success in decreasing the number of customer returns. This impact has been particularly relevant for the luxury sector, with brands like Burberry and Farfetch reporting reductions on returns due to the use of virtual try-ons.

In addition to improving the shopping experience, these technologies simultaneously support sustainable association development. Stella McCartney and Patagonia, for example, implemented AI and AR technology to build circular business systems that enhance their sustainable fashion initiatives.

Together, the research findings show that AI and AR-enhanced DVM create sustainable results that last throughout production as they reduce prototype waste,

returns and enable circular economy operations. Despite these results stem from corporate data and pilot testing projects, they establish a definitive path for fashion e-retailers to use digital tools to achieve environmental sustainability and business stability.

7.2 Limitations and Future Research Directions

Although this article develops a lifecycle-aligned framework to study DVM in fashion e-commerce, several limitations must be acknowledged. First, the case-study analysis depends on corporate disclosures and earnings releases which may present positive results while leaving out any negative information. For example, H&M Group has been investigated for suspected deceptive statements about their environmental sustainability claims [35], Adidas faces criticism for illusive climate promise advertising [36] and Burberry face criticism for its practice of burning unsold products which challenges their circular business model [37]. These controversies reinforce the fact that self-declared metrics, despite useful to quantify efficiency of AI and AR technologies, only represents the corporate sustainability performance facet.

Second, primary consumer insights have not yet been completed, and they will be included in Phase 2. Its absence here limits the comprehension on how users experience the technology and how often they use it. Third, the focus on six major fashion brands (none of them SMEs) leaves an important empirical gap for smaller operators, despite Table 1 suggest that cloud-hosted CGI and pay-per-use AI sizing tools could down-scale and generate proportional benefits. Last, this chapter examines technological sustainability elements, but it does not address any sociotechnical risks which include data privacy concerns, digital access barriers and negative feedback loops. Regarding those limitations, future research should develop the following issues:

- Longitudinal studies on return reductions: future research needs to study AI and AR technology effects on return rates by conducting extensive investigations that analyze diverse consumer segments. While conducting longitudinal studies, researchers will be able to better understand how these technologies affect consumer experiences and sustainable results.
- Impact of consumer experience on circular fashion: it's necessary to deepen exploration on how consumer attitudes and experiences influence the success of circular fashion models. Future research needs to investigate why consumers join resale, repair and recycling initiatives through studies of digital platforms that support these activities.
- Technological barriers for SMEs: future research must identify the technological obstacles that prevent small fashion companies from implementing AI and AR solutions. The identification of financial, technical and operational obstacles will enable designers and developers to create solutions that can welcome all retail businesses regardless of their size.

- Sustainability report and metrics: additional research activities will be needed to establish standardized environmental impact measurement criteria for DVM technologies that could generate sustainability metrics and reporting systems.

In conclusion, DVM technology system offers promising opportunities for both user experience design and sustainability claim in the fashion e-commerce realm. However, continued research is essential to fully understand their long-term impact and scalability, particularly as the fashion industry continues to evolve.

References

1. Goworek H, Oxborrow L, Claxton S, McLaren A, Cooper T, Hill H (2020) Managing sustainability in the fashion business: challenges in product development for clothing longevity in the UK. J Bus Res 66(10):1839–1851. https://doi.org/10.1016/j.jbusres.2018.07.021
2. Bertram RF, Chi T (2017) A study of companies' business responses to fashion e-commerce's environmental impact. Int J Fashion Design Technol Educ 9(1):2–13. https://doi.org/10.1080/17543266.2017.1406541
3. Niinimäki K, Peters G, Dahlbo H, Perry P, Rissanen T, Gwilt A (2020) The environmental price of fast fashion. Nat Rev Earth Environ 1(4):189–200. https://doi.org/10.1038/s43017-020-0039-9
4. Lu S, Yang L, Liu W, Jia L (2020) User preference for electronic commerce overpackaging solutions: implications for cleaner production. J Clean Prod 258:120936. https://doi.org/10.1016/j.jclepro.2020.120936
5. Ellen MacArthur Foundation (2017) A new textiles economy: redesigning fashion's future. Ellen MacArthur Foundation. Accessed from https://www.ellenmacarthurfoundation.org/a-new-textiles-economy. Accessed 6 Oct 2024
6. Cant MC, Wiid JA (2020) Visual merchandising elements: drivers of retail strategies? J Appl Bus Res 36(5):197–204. https://doi.org/10.19030/jabr.v36i5.9316
7. Xue L, Parker CJ, Hart CA (2023) How augmented reality can enhance fashion retail: a UX design perspective. Int J Retail Distrib Manag 51(2):158–175. https://doi.org/10.1108/IJRDM-09-2021-0435
8. Bozzi C, Neves M, Mont'Alvão C (2022) UX, design, sustainable development, and online selling and buying of women's clothes. In: Handbook of usability and user experience, pp 191–217. https://doi.org/10.1201/9780429343513-15
9. Khan MKR (2021) Online visual merchandising for apparel and fashion industry. Kohan Textile J 20(11):37–52
10. Sampaio JP, Zonatti WF, Mendizabal-Alvarez FJS, Rossi GB, Baruque-Ramos J (2017) New technologies applied to the fashion visual merchandising. Mod Econ 8(3):412–429. https://doi.org/10.4236/me.2017.83031
11. Kim HY, Lee Y, Cho E, Jung YJ (2020) Digital atmosphere of fashion retail stores. Fashion Textiles 7(30):1–17. https://doi.org/10.1186/s40691-020-00217-6
12. Yan T, Wu J, Meng H (2023) The effect of digital fashion visual symbol perception on consumer repurchase intention: a moderated chain mediation model. J Fash Mark Manag 27(3):1–17. https://doi.org/10.1108/JFMM-08-2023-0202
13. Nestler A, Karessli N, Hajjar K, Weffer R, Shirvany R (2021) SizeFlags: reducing size and fit related returns in fashion e-commerce. In: Proceedings of the 27th ACM SIGKDD conference on knowledge discovery and data mining (KDD 2021), August 14–18, 2021, Virtual Event, Singapore. ACM, Singapore, p 9. https://doi.org/10.1145/3447548.3467160
14. Kong D, Seock Y-K, Marschner S, Park HT (2024) Leveraging 4D golf apparel wear simulation in online shopping: a promising approach to minimizing the carbon footprint. Sustainability 15:11444. https://doi.org/10.3390/su151411444

15. Kim J, Ha J (2021) User experience in VR fashion product shopping: focusing on tangible interactions. Appl Sci 11(13):6170. https://doi.org/10.3390/app11136170
16. Siregar Y, Kent A (2019) Consumer experience of interactive technology in fashion stores. Int J Retail Distrib Manag 47(12):1269–1287. https://doi.org/10.1108/IJRDM-09-2018-0189
17. McKinsey and Company, and The Business of Fashion (2024) The state of fashion 2024. McKinsey and Company. Accessed from https://www.mckinsey.com/. Accessed 6 Oct 2024
18. Global Brands Magazine (2024) AI's fashion revolution: Transforming the industry in 2024. Global Brands Magazine. Accessed from https://www.globalbrandsmagazine.com/ais-impact-on-fashion-industry-2024/. Accessed 6 Oct 2024
19. Ellen MacArthur Foundation (2021) Clothing doesn't need to be physical to exist: the Fabricant. Accessed from https://www.ellenmacarthurfoundation.org/circular-examples/the-fabricant/. Accessed 30 June 2025
20. European Commission, Joint Research Centre (2021) Textiles and the environment. Accessed from https://publications.jrc.ec.europa.eu/repository/handle/JRC139405_EN/. Accessed 30 June 2025
21. European Commission, Joint Research Centre (2024) Feasibility study of measures to incentivise improved textile waste management. Accessed from https://publications.jrc.ec.europa.eu/repository/handle/JRC139566/. Accessed 30 June 2025
22. European Environment Agency (2022) Management of used and waste textiles in Europe's circular economy. Accessed from https://www.eea.europa.eu/publications/management-of-used-and-waste-textiles/. Accessed 30 June 2025
23. Interreg North-West Europe (2022) Scaling textile recycling in Europe—turning waste into value. Accessed from https://vb.nweurope.eu/media/19019/2207-scaling-textile-recycling-in-europe-turning-waste-into-value.pdf/. Accessed 30 June 2025
24. Weinswig D, Bhatia M (2023) Digital merchandising strategies: the power of automation and 3D product imagery in retail. Coresight Research. Accessed from https://coresight.com/research/digital-merchandising-strategies-the-power-of-automation-and-3d-product-imagery-in-retail/. Accessed 30 June 2025
25. Business of Fashion and McKinsey and Company (2025) The State of Fashion 2025. Accessed from https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion/. Accessed 30 June 2025
26. Shoham Y, Knight B, Hendrikson K (2025) 2025 AI Index Report. Human-Centered AI Initiative at Stanford University. Accessed from https://hai.stanford.edu/ai-index/2025-ai-index-report/. Accessed 30 June 2025
27. Adidas (2023) Annual Report 2023. Accessed from https://www.adidas-group.com, Accessed 10 Oct 2024
28. McKinsey and Company, and Global Fashion Agenda (2020) Fashion on climate: How the fashion industry can urgently act to reduce its greenhouse gas emissions. Global Fashion Agenda. Accessed from https://www.mckinsey.com/. Accessed 6 Oct 2024
29. Burberry (2023) Responsibility data appendix 2023/2024. Burberry Group plc. Accessed from https://www.burberryplc.com/. Accessed 6 Oct 2024
30. Farfetch (2023) Third annual Conscious Luxury Trends Report. Farfetch Limited. Accessed from https://aboutfarfetch.com/. Accessed 6 Oct 2024
31. Sustainability Magazine (2023) Top 10 brands embracing the circular economy. Sustainability Magazine. Accessed from https://sustainabilitymag.com/top10/top-10-brands-embracing-the-circular-economy-in-2023. Accessed 6 Oct 2024
32. Patagonia (2023) Patagonia Group Sales Fall 2023 Report. Patagonia, Inc. Accessed from https://www.patagonia.com/. Accessed 6 Oct 2024
33. Stella McCartney (2023) Impact Report 2023. Stella McCartney Ltd. Accessed from https://www.stellamccartney.com/. Accessed 6 Oct 2024
34. H&M Group (2024) H&M Group Annual and Sustainability Report 2023. H&M Group. Accessed from https://hmgroup.com/wp-content/uploads/2024/03/HM-Group-Annual-and-Sustainability-Report-2023.pdf/. Accessed 30 June 2025

35. The Sustainable Fashion Forum (2024) H&M is being sued for “misleading” sustainability marketing. What does this mean for the future of greenwashing? Accessed from https://www.thesustainablefashionforum.org/hm-greenwashing-lawsuit/. Accessed 30 June 2025
36. Modaes (2024) Adidas acusada de greenwashing: Una sentencia le obliga a retirar sus claims climáticos. Accessed from https://www.modaes.com/empresas/adidas-acusada-de-greenwashing-una-sentencia-le-obliga-a-retirar-sus-claims-climaticos/. Accessed 30 June 2025
37. Economic Times Brand Equity (2024) Why Burberry burns millions of dollars of clothes each year. Accessed 30 June–4 July 2025, from https://brandequity.economictimes.indiatimes.com/news/business-of-brands/why-burberry-burns-millions-of-dollars-of-clothes-each-year/115241715. Accessed 30 June 2025