sustainability

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Review

The Intersection of Fashion, Immersive Technology, and Sustainability: A Literature Review

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Abstract: Fashion industry emissions, resource use, and waste are attracting increasing consumer and government attention, with broad agreement that a new approach is required along the supply chain. Following the COVID-19 pandemic, a move to digitalisation facilitated an accelerating interest in digital applications, including immersive technologies such as augmented and virtual reality. This systematic literature review explores the intersecting topics of fashion, immersive technologies, and sustainability to determine the trends, examine the solutions offered, and discuss the implications of immersive technologies for sustainability. Four resources were consulted (Scholar, SCOPUS, WOS, and ProQuest), resulting in 74 articles for the review. Grey literature was included due to the currency of the topic and gaps in the available academic literature. The findings highlight immersive technology uses in the fashion industry, which are part of a move towards sustainability. These technologies are used to reduce online returns, educate consumers, reduce waste in design and manufacture, and remove the need for physical items. However, issues include high energy costs, consumer reluctance, and skill shortages. Results suggest future research and industry discussions should focus on empirical studies to measure the sustainability impact of immersive technologies, monitor technology diffusion and uptake, and measure the industry skills gap.

Keywords: sustainable fashion; fashion industry; immersive technology; virtual reality; augmented reality

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1. Introduction and Background

The concept of 'sustainability' can be defined and operationalised in several ways. In the fashion industry, a precise definition of sustainability has been elusive, given tensions between organisational cultures and actors within the fashion chain [1], particularly between the sustainability of business operations [2,3] and sustainability achieved through design [4,5] or materials used [6]. Additionally, sustainability can incorporate social issues such as worker conditions and environmental aspects such as water pollution and greenhouse gas emissions [7] and is linked to the concept of corporate social responsibility and transparency [8].

As such, sustainability in the fashion industry context can refer to not being wasteful of resources at various stages of fashion design, production, and consumption, i.e., the use of natural products and energy in a way that reduces harm to the environment and people, or sustainability in terms of continuation of business or supply chain, i.e., the ability to continue or be continued for a long time.

For the fashion industry, whose emissions, resource use, and waste have attracted increasing attention in recent years, these two approaches to sustainability generally go together. Sustainable clothing is 'an umbrella term for clothes that are created and consumed in a way that can be, quite literally, sustained, while protecting both the environment and those producing garments' [9].

Current fashion consumption patterns are considered unsustainable [7,10,11], and change and transparency about sustainability efforts [12,13] are required along the entire

fashion supply chain to address the sustainability challenges within the industry and meet nationally and internationally recognised sustainability goals [14,15]. Slow fashion is promoted as a potential solution [16,17] given the focus on long-lasting items of clothing made with sustainability in mind, in contrast with the fast fashion approach, which aims to quickly bring trends to consumers and involves the 'mass production of clothes that represent the latest trends at high speeds and low cost to maximise profits' [18,19]. The fashion industry is described as the 'world's second largest polluter' [20], and the short lifecycle of the products produced within the industry, particularly in fast fashion, promotes excessive consumption behaviour in consumers [18,21].

The fashion industry is estimated to account for 8–10% of global carbon emissions, 20% of wastewater, and more energy consumption than aviation and shipping combined [22]. Sustainability projects aimed at tackling this industry's image problem and solving the underlying inefficiencies exist, and there are recognised differences between the impacts of fast fashion and slow fashion, but the fashion industry appears to be unsustainable in its current form. Efforts at sustainable changes require careful marketing to prevent accusations of 'greenwashing', a practice which involves only highlighting good practice while obscuring negative impacts on the environment [12]. The main issues with fast fashion, in particular, are: high carbon emissions; poor labour conditions; excessive water consumption and wastage; extensive land use; water pollution and microfibre contamination; and pre and post-consumer waste [19]. Addressing these issues requires a range of solutions, approaches, and innovations.

In the wake of the COVID-19 pandemic, a move to digitalisation facilitated an already accelerating interest in digital solutions, which enable the fashion industry to operate competitively and achieve sustainability aims. The term 'immersive' describes an experience which is seeming to surround the audience, player, or user so that they feel completely involved in something and researchers and the fashion industry seem to be most often referring to 3D virtual technologies such as: AR (Augmented Reality); VR (Virtual Reality), and XR (Extended Reality, usually an overarching term encompassing AR and VR) as 'immersive technology'. These technologies can be represented as existing along a 'virtuality continuum' [23], which places real environments at one end and virtual environments at the other end of the continuum. Augmented Reality is placed nearer to the real environment end, as AR overlays digital content onto the real environment, applied in mobile apps and video games. VR affords access to a completely virtual world through the use of a specialised headset, or one where the 'participant-observer' is totally immersed in and able to interact with a completely synthetic world' [23].

This review includes 3D simulation and visualisation, Computer-Aided Design (CAD), and, subsequently, 3D printing and additive manufacturing within the immersive technology portfolio as these offer user manipulation within virtual environments, which creates a somewhat more 'immersed' experience compared with 2D renderings. While total immersion and complete synthesis are often the hallmarks of VR, these 3D and virtual technologies may be considered to belong on the virtuality continuum [23]. However, it must be noted that VR/AR use in CAD is sometimes limited to viewing the models rather than manipulation due to a time-consuming and highly technical process in adapting the 3D models for VR/AR [24].

The adoption of immersive technologies by the general population is embryonic, but the industry is growing at a fast pace, with the VR market size predicted to increase from 12 billion USD in 2022 to more than 22 billion USD by 2025 [25]. The fashion industry is responding to this rise in interest in new immersive technologies in a myriad of ways which are explored further in this review. The fashion industry is manoeuvering towards a future where people live more of their lives in digital environments, with some examples being: gamification and connecting with gaming platforms [26]; digital fashion for virtual platforms and the metaverse [27]; and using these technologies to provide better customer experience when shopping virtually [28].

However, there are challenges associated with the uptake and diffusion of new technology. The leading obstacles to the adoption of immersive technology are said to be poor user experience, lack of content offered, and cost of investing in equipment [29]. This literature review is part of a larger AHRC-funded project, which also conducted consumer research into the effects of VR on brand image and perception in young millennials. For almost all the participants other than those who are computing students, the study was the first time they had used a VR device or accessed a VR world, further indicating that adoption of and access to VR is not yet widespread outside of the computing community. AR is perhaps the more accessible of the two technologies. Some examples of this would be apps which make use of AR technology to create social media frames to overlay brand imagery onto user-generated content [30] or to run virtual try-on (VTO) services.

As such, this review seeks to examine the role emerging immersive technologies have in the fashion industry as they transition towards greener production and consumption, working towards aligning with the United Nations Sustainable Development Goal 12 [15].

Extant studies have proposed a model for wider technological innovation in the fashion industry in conjunction with sustainability goals [31] or reviewed the challenges and opportunities afforded by the suite of Industry 4.0 technologies for the fashion industry [32], but a literature review or study specifically focused on immersive technologies and their potential impact on sustainability in the fashion industry has not yet been conducted.

Studies do exist which sought to uncover the connections between immersive technology and sustainability in a variety of other sectors and areas of industry. These include immersive technology as a tool for sustainable architecture [33] and as a sustainable approach in marketing [34]. Extant studies have also examined sustainability in the fashion industry, for example, in design [10], the supply chain [35], and retail [36]. However, there lacks an investigation into, and discussion of, the three concepts together: sustainability, immersive technology, and the fashion industry. Systematic literature reviews of immersive technology applications in other sectors, such as in the tourism industry [37], show the scale of interest in technology and highlight the benefits and challenges of new technology adoption, providing insight into trends and gaps which are of interest to researchers and industry practitioners. Therefore, a systematic literature review approach has been adopted here to uncover the intersections between the three topics.

The authors have previously investigated how immersive technology is being used in the fashion industry [30], and while some reference was made to potential gains in sustainability, this concept was not fully explored. Therefore, the next step is to examine the extent to which these technologies may offer solutions for the fashion industry's sustainability issues. Thus, the aim of this review is to address the identified research gap by examining critically existing research that discusses the intersection of fashion, sustainability, and immersive technologies specifically, to provide an overview of how they are being represented in both academic and grey literature, and to identify gaps and future directions. Both sustainability and immersive technologies are buzzwords in the fashion industry [38,39], and this review is intended to contribute to the academic and industry discussion around the current situation and future possibilities. As such, only works which specifically mentioned immersive technologies as a tool for achieving sustainability in the fashion industry are included.

2. Methodology and Scope

2.1. Methods

The literature review was conducted following the two-stage approach applied to other recent systematic literature reviews [40] and which conforms to the PRISMA guidelines for reporting systematic reviews [41]. The process involves identifying relevant articles with a keyword search, followed by a more rigorous inclusion and exclusion process (referred to as screening in PRISMA) in the selection of articles in the second stage. Citations were imported into Excel, and duplicates were removed. Coding was conducted manually. Four resources were consulted: Web of Science, Scopus, Google Scholar, and ProQuest. Web

of Science and Scopus were chosen as they present a curated collection of articles, which are gathered using a strict set of source selection criteria devised by expert editors [42]. However, these two databases are sensitive to biases in their selection criteria and are limited in their coverage. Google Scholar, which is a more inclusive and automated search engine, can maximise coverage of a topic, but is subject to errors and the inclusion of non-scholarly material [42]. Finally, ProQuest was included as it archives many of the important publications pertinent to the topic of this review, including the Vogue Archive, the Women's Wear Daily archive, and the International NewsStream database, which provides recent news content. Each resource was chosen to complement the topic and help alleviate any drawbacks resulting from consulting the others.

For PRISMA compliance, a flow diagram is presented in Figure 1, which outlines the process from identification to inclusion.

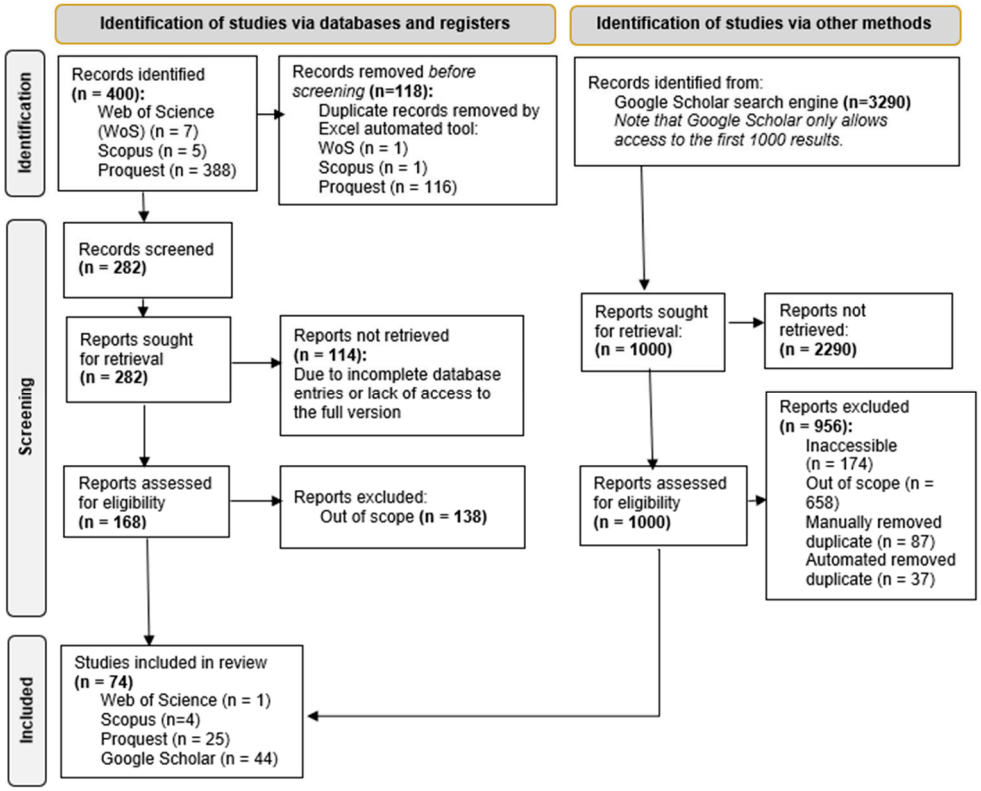

Figure 1. PRISMA 2020 flow diagram for selection of sources.

A total of 74 pieces of literature were included in the final list of articles. The initial number of results returned, and the final inclusion totals from each resource are listed in Figure 1.

Results were analysed using Excel's 'Analyze' tool for an overview of geographic location, date of publication, and topic area and to compare other bibliometric data. The articles were then critically analysed, particularly focusing on identifying trends, gaps, challenges, and opportunities amongst the intersecting topics.

2.2. Scope

The focus is on academic pieces and research directions, but grey literature and non-peer-reviewed work such as newspaper and trade articles are also included as they are an important insight into the industry and the discussions around trends and innovative technologies at a time of rapid change. Many systematic reviews exclude grey literature, as the review is intended to be the identification of current and past research status on a topic. However, other reviews do include non-peer-reviewed works for several reasons. Firstly, the inclusion of such material can bridge the research and practice gap on a topic in a variety

of disciplines by representing the industry perspective [43] or experience-based views [44] of a topic. The two previous examples come from the management discipline [43] and the computing and technology field [44] and can be considered relevant given the fashion management and technology focus of this review.

Incorporating a wider range of insight into a topic than peer-reviewed materials only is termed a 'multi-vocal' literature review in some disciplines [44]. Grey literature inclusion can also be valuable where the topics are 'trendy or industry driven' and 'academic literature is generally scarce' [45], or particularly where technology application and use are involved. As mentioned, there is little peer-reviewed literature about the intersection of the three main topics of this review, and therefore grey literature adds value and currency.

Grey literature is a large category incorporating a range of source types; therefore, Adams' [43] concept of 'shades of grey literature', which separates the grey category into three tiers based on credibility and retrievability, was utilised. The grey literature included in this review is 2nd tier grey literature according to Adams' definition, which includes news articles and company materials, and has moderate retrievability and credibility [43]. Nevertheless, as grey literature is subject to a wide variety of editorial standards, it is presented separately in much of the analysis and results.

The search string used for all resources was: ("fashion industry" OR "fashion brand" OR "fashion retail" OR "fashion marketing") AND ("immersive technology" OR "virtual reality" OR "augmented reality") AND ("sustainable" OR "sustainability"). Other search strings were considered, but they returned few results (or returned a large proportion of irrelevant results). The resulting articles were then manually coded into categories to give an overview of the key themes and trends. The coding and categorising of the articles included in this review are shown in Table 1.

Table 1. Categories and coding.

Topic area	Industry digital transformation Circular economy/business Consumer acceptance/perceptions Design, development and production Design education Literature review
Type of fashion	Digital fashion Fashion Retail Fashion/Textile Industry Luxury Mass customisation Second-hand/refashioning/rental/owned Small brands
Sustainability challenge	Consumer choice/consumption (including returns) Smarter design and production Whole chain
Technology	3D printing/additive manufacturing 3D simulation/visualisation AR/VR/Immersive Gamification Haptics Metaverse Various VDR/VFR/VTO

The categories were identified based on terminology employed by the authors of each piece, and such groupings were used to gather similar papers together for discussion and comparison purposes. There was considerable overlap between topics, and therefore these groupings are a general guide only.

Bibliometric data were also gathered and analysed, particularly: year of publication (no time limitations were set on the queries); source type (i.e., Scholarly journal, newspaper article, etc.) and geographic affiliation of lead author.

3. Overview of Reviewed Articles

3.1. Bibliometric Data and Descriptive Analysis

As can be seen in Table 2, the majority of included articles were from the UK, with USA, China, Italy, Australia, and India also featuring amongst the top geographical origin for papers included in this review. Given the English language focus of the review and the resources consulted, this distribution is expected. Of the final selection, 52 were scholarly journals or texts, 13 were newspaper articles, 5 were magazine articles, 3 were from wire feeds, and 1 from blogs, podcasts, or websites.

Table 2. Geographical origin and types of articles.

Geographical Origin (All *n* = 74)	Scholarly Research Articles (*n* = 52)	Grey (Newspapers, Magazines, etc.) (*n* = 22)
UK (*n* = 17)	UK (*n* = 11)	UK (*n* = 6)
USA (*n* = 10)	USA (*n* = 6)	USA (*n* = 4)
China (*n* = 5)	Italy (*n* = 5)	India (*n* = 2)
Italy (*n* = 5)	China (*n* = 4)	Australia (*n* = 2)
India (*n* = 4)	South Korea (*n* = 3)	China (*n* = 1)
Australia (*n* = 4)	Australia (*n* = 2)	Egypt (*n* = 1)
South Korea (*n* = 4)	Canada (*n* = 2)	Israel (*n* = 1)
UAE (*n* = 3)	Greece (*n* = 2)	Malaysia (*n* = 1)
Canada (*n* = 2)	India (*n* = 2)	ROI (*n* = 1)
Greece (*n* = 2)	Sri Lanka (*n* = 2)	Singapore (*n* = 1)
Sri Lanka (*n* = 2)	UAE (*n* = 2)	Thailand (*n* = 1)
Albania (*n* = 1)	Albania (*n* = 1)	UAE (*n* = 1)
Brazil (*n* = 1)	Brazil (*n* = 1)	
Bulgaria (*n* = 1)	Bulgaria (*n* = 1)	
Egypt (*n* = 1)	Germany (*n* = 1)	
Germany (*n* = 1)	Hong Kong (*n* = 1)	
Hong Kong (*n* = 1)	Indonesia (*n* = 1)	
Indonesia (*n* = 1)	Latvia (*n* = 1)	
Israel (*n* = 1)	Morocco (*n* = 1)	
Latvia (*n* = 1)	Portugal (*n* = 1)	
Malaysia (*n* = 1)	Romania (*n* = 1)	
Morocco (*n* = 1)	Spain (*n* = 1)	
Portugal (*n* = 1)	Egypt (*n* = 0)	
ROI (*n* = 1)	Israel (*n* = 0)	
Romania (*n* = 1)	Malaysia (*n* = 0)	
Singapore (*n* = 1)	ROI (*n* = 0)	
Spain (*n* = 1)	Singapore (*n* = 0)	
Thailand (*n* = 1)	Thailand (*n* = 0)	

Thirteen included articles were published from 2010 to 2019, while 61 were published between 2020 and 2022 out of the total list of 74. This may be indicative of a post-COVID boom in the discussion of these topics using the terminology employed in the search string. Given that many industries and organisations sought digital solutions to keep their business running during the lockdowns and other pandemic restrictions, this is unsurprising. However, this may be a result of the consulted resources prioritising more recent results. Figure 2 shows included articles by year of publication, separating scholarly content and grey literature.

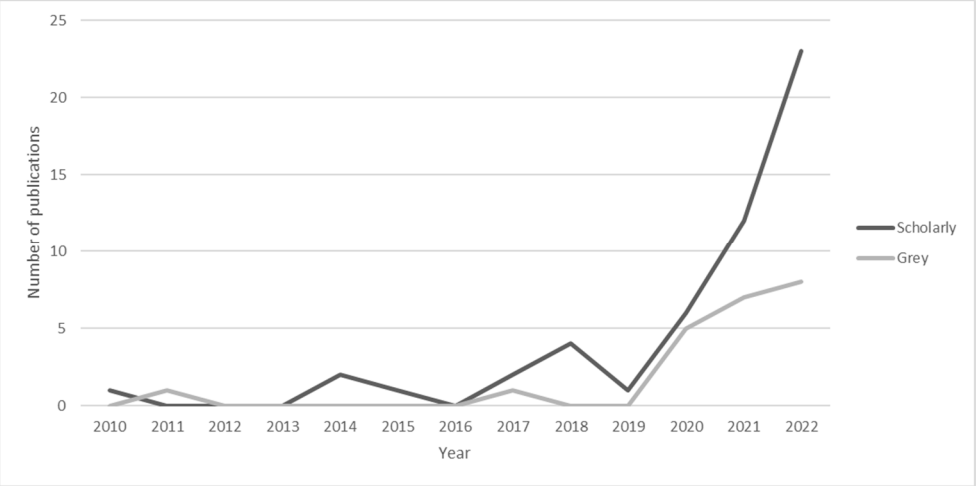

Figure 2. Date of publication.

3.2. Thematic Overview

The following sections are a result of the thematic analysis. An initial broad overview of all the included articles, their dates of publication, and their types alongside indicated topics, technologies, and sustainability challenges are given in Tables 3 and 4, with a further discussion of individual topics, technologies, and challenges in subsequent sections.

Table 3. Scholarly works included in the review.

Year	Thematic Coding	Article Reference Number
2010–2019 (n = 11)	**Lead topic**	
	Design, development, and production	[46–51]
	Industry digital transformation	[52–55]
	Consumer acceptance	[56]
	Main technology	
	3D simulation and visualisation	[46–49,53,54]
	VDR/VFR/VTO	[52,56]
	AR/VR/Immersive	[51]
	Various	[55]
	Haptic	[50]
	Sustainability challenge	
	Smarter design and production	[46–51,53,55]
	Consumer choice/consumption	[52,56]
	Whole chain	[54]
2020 (n = 6)	**Lead topic**	
	Industry digital transformation	[57,58]
	Consumer acceptance	[59,60]
	Design, development and production	[61]
	Circular economy/business	[62]
	Main technology	
	3D simulation and visualisation	[57,61,62]
	AR/VR/Immersive	[59,60]
	Various	[58]
	Sustainability challenge	
	Consumer choice/consumption	[58–60,62]
	Smarter design and production	[61]
	Whole chain	[57]

Table 3. *Cont.*

Year	Thematic Coding	Article Reference Number
2021 (n = 12)	**Lead topic**	
	Industry digital transformation	[26,30,63–66]
	Design, development and production	[67,68]
	Consumer acceptance	[69,70]
	Circular economy/business	[71]
	Design education	[72]
	Main technology	
	AR/VR/Immersive	[30,66,69,70]
	Various	[63,64,72]
	3D simulation and visualisation	[68,71]
	3D printing/additive manufacturing	[67]
	Gamification	[26]
	VDR/VFR/VTO	[65]
	Sustainability challenge	
	Smarter design and production	[64,67,68,71,72]
	Consumer choice/consumption	[26,30,65,69,70]
	Whole chain	[63,66]
2022 (n = 23)	**Lead topic**	
	Industry digital transformation	[27,31,32,73–78]
	Consumer acceptance	[79–85]
	Design, development and production	[86–89]
	Design education	[28,90]
	Circular economy/business	[91]
	Main technology	
	Various	[27,31,32,75–77,89,90]
	AR/VR/Immersive	[28,73,80,84,85]
	3D simulation and visualisation	[79,86–88]
	VDR/VFR/VTO	[78,82,83,91]
	Metaverse	[74]
	Gamification	[81]
	Sustainability challenge	
	Whole chain	[27,28,31,32,73,74,76–78,86,90]
	Consumer choice/consumption	[80–85,91]
	Smarter design and production	[76,79,87–89]

Table 4. Grey literature included in the review.

Year	Thematic Coding	Article Reference Number
2010–2019 (n = 2)	**Lead Topic**	
	Industry digital transformation	[92]
	Consumer acceptance	[93]
	Main technology	
	3D simulation and visualisation	[92]
	AR/VR/Immersive	[93]
	Sustainability challenge	
	Smarter design and production	[92]
	Whole chain	[93]

Table 4. *Cont.*

Year	Thematic Coding	Article Reference Number
2020 (n = 5)	**Lead topic**	
	Industry digital transformation	[94–97]
	Consumer acceptance	[98]
	Main technology	
	Various	[95,96,98]
	Gamification	[94]
	AR/VR/Immersive	[97]
	Sustainability challenge	
	Consumer choice/consumption	[94,98]
	Whole chain	[95,96]
	Smarter design and production	[97]
2021 (n = 7)	**Lead topic**	
	Industry digital transformation	[99–105]
	Main technology	
	Metaverse	[99–102]
	Various	[103,104]
	AR/VR/Immersive	[105]
	Sustainability challenge	
	Consumer choice/consumption	[99,101–103]
	Whole chain	[100,104,105]
2022 (n = 8)	**Lead topic**	
	Industry digital transformation	[106–111]
	Consumer acceptance	[112]
	Circular economy/business	[113]
	Main technology	
	Various	[107–111]
	Metaverse	[106,113]
	AR/VR/Immersive	[112]
	Sustainability challenge	
	Whole chain	[108,109,111]
	Smarter design and production	[106,107,110]
	Consumer choice/consumption	[112,113]

While the list of included articles is not large enough to draw definitive generalisations, some trends can be observed over the period. Firstly, the earliest articles in the review (both academic content and grey literature) explored: 3D simulation and visualisation for mass customisation, better satisfying customer individual needs and reducing costs [46,56,77], and for design production efficiencies and cutting sample costs [47,92]; and also examined how VTO technology could aid customers in choosing better fitting clothes and offer a more personalised experience [52,56].

Furthermore, prior to the pandemic, articles discussed: VR's capacity to educate consumers about the lifespan of garment production, consumption, and disposal, to raise awareness of climate effects [93]; customisation and 3D simulation technology to enable efficiencies and decrease wastage [48,49,51,53–55]; and tackling the issue of the lack of tactile feedback in virtual products, which has implications for both designers and customers [50].

By 2020, the discussion had moved to gamification [94]; the impact of consumers spending more time online and at home for retail [58,59]; living more of life virtually and dematerialisation of fashion [57,98]; the move to virtual fashion shows [95–97]; 3D virtual technologies for refashioning or re-using materials or garments [61,62].

One notable popular topic in the articles from 2021 was the metaverse and the impact digital clothing could have on lessening the need for a physical item [99–102]. However, the term was only featured in one of the scholarly articles, with the bulk of the interest in the metaverse coming from the grey literature included in the review.

By 2022, the metaverse continued to be highly discussed [27,74,106,107,113], and the immersive technologies had broadened out from a focus on 3D visualisation and simulation to a variety of technologies suggested as potential solutions to a variety of sustainability challenges, as discussed in the following sections.

3.3. Topic Area

3.3.1. Industry Digital Transformation

Papers coded under this topic often focused on a move towards virtual solutions, not only digitisation (making existing data digital) but also the transformation of the industry to embrace the virtual world (digitalisation). As the use of developing technologies (including immersive) is discussed in relation to how they may improve the current paradigm in the fashion industry, it is perhaps no surprise that industry digital transformation was a strongly represented theme in the gathered literature.

The texts coded under this topic fell into three main categories, largely tied to a particular stage of the fashion chain, while others looked at innovations along the entire chain. The three main areas were digital innovations in design, prototyping, and manufacture; digital innovations in consumer interactions; and digital innovations through dematerialisation of the industry. Industrial digital transformation featured in a large proportion of the reviewed literature and is explored in more detail in subsequent sections.

3.3.2. Consumer Acceptance and Perceptions

The second most popular topic area was around consumer acceptance and perceptions. Many of these pieces of work examined technology acceptance and adoption [56–58,69,79,80,83] or purchase intentions [81]. However, some explored how immersive technologies may directly influence more sustainable consumer behaviour through virtual marketing [84], with some discussing the capacity of the technology to educate consumers about the lifespan of garment production [93] or the impact of the technology on social responsibility, fair-trade purchases [60], and green consumerism [70].

3.3.3. Design, Development, and Production

The third most populated topic in the review was the domain of design development and production. As discussed elsewhere in this review, earlier immersive technology solutions tended to be 3D visualisations or simulations and CAD, but that should not designate those topics as historical concerns. The technology for the 3D design of garments, particularly the fit and flow of material on a moving human body with multiple body sizes, is evolving and remains a challenging technological endeavour [48,50,61,68,86,87,89]. Some of the papers reviewed focused on mass customisation as a new offering enabled by 3D visualisation technologies [46,49,88], and one examined the potential for haptics to replicate the real-world design process [50].

3.3.4. Design Education and Skills

While many of the papers briefly mentioned the important role of education and training in facilitating the use of new technologies in the fashion industry, one particularly explored curriculum design, the educational model, and the skills needed to support industry transformation [72]. The digitalisation skills gap is not unique to the fashion sector; many industries are grappling with the need to retrain the existing workforce to use new digital tools, and considering the skills needed for a future workforce and ensuring those needs are prioritised by education and training providers. Using immersive technologies at any stage of the fashion supply chain requires digital competence, and buying into this expertise can be expensive; as such, questions are raised about the capacity of smaller brands to go green if the talent pool is small [107].

VR and AR could contribute to sustainability goals by reducing environmental impact in the design and fitting process and allowing fashion shows to go digital, for example, yet major suppliers of fashion industry talent, such as China, have not been quick to

incorporate new technologies or approaches into the curriculum. Chinese universities that have majors in fashion and textiles do not yet offer courses related to sustainable fashion [107]. Additionally, alongside the transformation in the fashion industry, a variety of skill sets are required—design (using digital tools), technical (including working with new engineered materials), and business-related skills (new digital ways of marketing, promotion and service delivery) [72]. These skill-related challenges pose a threat to the capacity for new technologies (including immersive) to address sustainability challenges in the sector.

3.4. Area of the Industry

The selected articles could be sorted into seven areas of fashion: fashion/textile industry (n = 39); digital fashion (n = 20); second-hand/refashioning/rental/owned/recycled (n = 6); mass customisation (n = 5); fashion retail (n = 5); luxury (n = 3); small brands (n = 1). Of particular note for this review, and not covered in other sections, were the papers in the second-hand/refashioning/rental/owned/recycled category and those discussing digital fashion.

3.4.1. Second-Hand, Refashioning, Rental, Owned and Recycled Fashion

The use of 3D CAD (computer-aided design) to prototype refashioned apparel made from second-hand garments, i.e., to upcycle or rejuvenate old clothing and materials, was discussed [61,62,64,71]. The use of 3D technology in this way has interesting implications for the sustainability of the fashion industry and the adoption of circular economy principles, especially given that post-consumer waste is a sustainability concern [19].

This is also discussed in relation to the use of digital technologies to increase consumer acceptance of circular business models and second-hand fashion [71]. While much of the focus is on other fashion 4.0 technologies, such as blockchain (a digital ledger of records which cannot be altered and can be used to confirm authenticity), AR is considered, in the form of try-on apps, as one of the digital tools used to increase consumer acceptance of second-hand items. However, there is a great deal of effort required to make the product attractive to buyers in a digital environment, and it is a challenge to replicate customer interaction in a digital or virtual environment [71]. AR and try-on technologies are emergent in the field of second-hand clothing, with the potential to impact the second-hand industry, but which are not currently established as a working solution.

Exploring the topic of immersive technologies to support the second-hand fashion industry from a different perspective, another study [85] found that features involving high technology, such as VR, had the least impact on users' usage of fashion resale platforms, but other digital technologies which were not immersive were more successful.

Continuing with the topic of consumer acceptance of used clothing, one study examined the use of virtual wardrobes to enable consumers to have a better sense of their owned items, and to prevent over-consumption [83]. The study found that consumers' responsible consumption behaviour and 'personal innovativeness in information technology' positively affected attitudes to virtual wardrobes, suggesting that the technology would be most effective at contributing to sustainability efforts for consumers with a higher level of digital proficiency and willingness to seek a sustainable lifestyle.

3.4.2. Digital Fashion

The second area of the industry particularly interesting to the scope of this review, is digital fashion. There were 19 papers discussing digital fashion included, and several discussed digital fashion, particularly in the context of the metaverse, more prevalent in the newspapers and magazines included in this review [99–102,106,109,113].

A report [106] on H&M's sustainability efforts included a discussion of a 'metaverse inspired' collection which has both virtual and physical garments, some of which are made from recycled materials and enhanced by AR 'lenses'—which are social media VTO filters or frames—bringing together the physical and virtual aspects of the campaign.

An editorial for a special digital fashion issue [74] discussed the evolution in the fashion industry and fashion industry research ranging from digitalisation for efficiency in the real world to the emergence of a new era of digital with the development of the metaverse and digital-only fashion was discussed. Others [56,65] examined the VTO of digital clothing, the latter focusing on brands pivoting to digital collections and the former on how virtual fashion could be used to educate consumers (and designers) about the fashion industry's sustainability issues and solutions.

Gamification was also discussed [26,94], both the insertion of fashion brands into existing gaming environments and fashion brands gamifying their interactions with consumers. Finally, this subsection explores the rapid acceleration of immersive technology (alongside other digital technology) applications in the fashion industry post-pandemic [65] and features a news article on what is reportedly the first fully digital fashion brand launching a collection at London Fashion Week 2021 [105].

3.5. Sustainability Challenge

Three main areas emerged under this coding: consumer choice/consumption (n = 28), smarter design and production (n = 27), and whole chain (n = 24).

3.5.1. Consumer Choice or Consumption

The consumer choice or consumption coding was used for articles describing immersive technology applications which had the capacity or intention to influence consumer behaviour in several ways, for example:

- VTO applications, which may reduce online returns as a better fit is achieved, or which allow consumers to virtually experience their own wardrobe to discourage buying unnecessary additions [52,56,58,64,65,80,82,83];
- Immersive technology employed to highlight the sustainability issues of the industry and encourage more sustainable consumption [60,70,84,93];
- Acceptance of circular business models and recycled products [61,71,83,85,113];
- Dematerialisation through digital fashion offerings allows consumers to have multiple new outfits for their digital channels, which reduces the need for physical items [27,65,74,98–104,106,108,109,113];
- Gamification, where brands are entering existing virtual gaming worlds to encourage digital fashion purchases, or they are taking a gamification approach to their interactions with consumers [26,81,94].

These applications of immersive technology have in common an attempt to influence consumer consumption behaviour. It remains to be seen how impactful these technology solutions could be, as most studies and articles reported on the acceptance (or not) of the technology, but often did not give evidence or measure any improved sustainable consumption by using the technology.

3.5.2. Smarter Design and Production

Three-dimensional printing, also known as additive manufacturing, was discussed briefly in only a few papers in this review [57,59,77,80]. The articles excluded did not strongly connect immersive technologies or sustainability with additive manufacturing; however, there is potential for additive manufacturing to achieve more sustainability through better customisation and greener, cleaner production, as new materials are developed and the digitalisation of the industry continues to connect and streamline the fashion chain. Additive manufacturing in the fashion industry involves designing clothing virtually and then printing them using 3D printer machinery. Applications include complex 3D knitwear or seamless pieces of clothing, with future potential for innovative new materials that could be produced more sustainably than traditional materials [67].

Virtual fashion shows were briefly mentioned earlier, but immersive technology has more applications in the fashion industry than just virtual shows, especially at the design stage. The prototyping or sampling system can be wasteful if the product needs multiple

amendments, and immersive technologies in the form of 3D simulations or visualisations can help to reduce the need for a physical sample [48,53,54,79,87,112]. There are also efficiencies in reducing the amount of travel for fashion buyers, who can enter a virtual showroom rather than visiting suppliers on site [65,95–97].

3.5.3. Whole Chain

Several papers highlighted how immersive technologies would be applied to assist with sustainability goals at multiple points of the fashion chain (for example, [67,73]). These papers and articles tended to give a broad overview of innovative technology applications in the industry and include two literature reviews: definitions of digital fashion [90] and AR and VR in the apparel industry [28].

Others focused on the bigger topic of 'Fashion Industry 4.0′ [31,32,63,64,76], which is the next step in industry technological advancement, moving beyond the automation and digitisation stages into a smart, networked system with heavier reliance on data and the virtual, and less reliance on the physical and manual labour. Immersive technologies are part of the Industry 4.0 suite of technologies, which include: Blockchain (digital ledgers, which enable NFTs (non-fungible tokens) digital assets), AI (artificial intelligence), IIOT (Industrial Internet of Things), smart systems and factories (which use sensors and other technologies to provide real-time data), big data and analytics, cloud computing, digital twins (virtual replicas of real-life systems), and autonomous robots. The immersive technologies generally considered within the Fashion Industry 4.0 umbrella include AR, VR, metaverse potential, additive manufacturing, 3D printing, and 3D visualisation software.

3.5.4. Challenges and Opportunities

Many of the articles in the review highlighted the opportunities for moving towards sustainability afforded by the adoption of immersive technologies, however, some identified drawbacks and potential pitfalls.

One significant potential challenge is the high energy cost of digital innovations [103] and what that means for sustainability if there is a rise in digital fashion items. NFTs, which enable fashion designers and brands to create exclusive digital goods, had, until recently, an energy dilemma. The average NFT digital collectible was estimated to 'consume the same amount of energy as a month's worth of electricity for a person living in the EU', with one of the most popular platforms for cryptocurrency, Ethereum, estimated to have had 'a carbon footprint comparable to that of Lebanon' [103]. The energy issue for NFTs involves the electricity used by the server farms to host the digital information, although efforts to improve this situation by streamlining the model (which proves the authenticity of the currency) have already been successful, now with a 99% reduction in carbon emissions [114]. Given that digital innovations can be energy intensive, more research is needed to identify the true benefits and costs to the fashion industry and how it could impact sustainability ambitions. Emerging technologies may be energy intensive in the early stages, and therefore early adoption may not afford progress towards sustainability goals.

Another challenge is the emergent and niche nature of immersive technologies. There are innovative sustainable practices, which could be aided by immersive technologies or other digital solutions, in almost every step of the fashion value chain, yet there is a lack of a platform or effective organisation to integrate them together. This results in a piecemeal approach with software and processes varying from brand to brand and lacks the capacity for larger systemic changes in the industry [107]. This is a common challenge for Industry 4.0, as radically changing systems, processes, and culture takes many years.

Previous sections have already highlighted other challenges associated with the adoption of new technologies, such as: consumer reluctance or lack of technical know-how when using new technologies such as VTO; lack of technical skills in the industry in order to develop and maintain these applications; the high cost of contracting professionals to implement immersive solutions; and the limited impact of immersive technologies on consumer behaviour compared with impacts already afforded by other, non-immersive, solutions.

3.6. Technology

Most often, articles discussed several immersive technologies (n = 25), but some were focused on a specific technology: 3D simulation/visualisation (n = 17); VR (n = 8); metaverse (n = 7); VDR/VTO/VFR (n = 7); AR/VR (n = 5); AR (n = 3); gamification (n = 3); 3D printing/additive manufacturing (n = 2); immersive (n = 1); and haptics (n = 1). Technology (and the terminology used to define it) is evolving, and inevitably there will be content that fits the scope of the review which was not picked up by the search due to the varied use of terminologies. An example of this is the term 'immersive technolog[y/ies]', which was not a common phrase in any of the resources consulted. Rather, authors described a specific technology (AR, for example), a specific application of that technology (VTO), or talked more generally about digitalisation, which has implications for future literature searches in this topic area.

It is also important to remember that technology is only helpful if it is used, and many of the articles, while discussing various technologies, did not discuss technical limitations; rather, they explored the capacity for users (usually consumers) to accept and benefit positively from the technology. Studies of this type often employed the TAM (Technology Acceptance Model) to gauge reactions to and potential uptake, especially given immersive technologies are emergent and require new equipment (in the case of VR headsets, however, some AR is available through mobile phones). The TAM asserts that a digital tool will only be accepted by users if it is perceived to be useful and perceived to be easy to use [59,80,83]. Furthermore, it would appear that some consumers do not feel AR and VR are useful or easy to use.

3.7. Summary of Results

Key trends and themes from the review are shown in Table 5.

Table 5. Key results.

Key Results		
Bibliometric and descriptive	Most articles were from the UK and USA	
	52 scholarly articles; 22 grey literature; 74 in total	
	13 published between 2010 and 2019 61 published between 2020 and 2022	
Thematic analysis	Potential sustainability benefits from use of immersive technologies in the fashion industry	Reducing online returns
		Educating consumers
		Enabling more efficient design and production
		Enabling re-use or refashioning of existing clothing
		Lessening the need for industry travel and physical samples through digital showrooms
		Dematerialisation and replacement of physical items with digital for consumers who wish to keep up with fashion trends

Table 5. *Cont.*

Key Results		
Thematic analysis	The technology applications (used or proposed)	3D simulation/visualisation alongside AR/VR for design and customisation
		VTO for reducing customer returns
		Metaverse and digital fashion for dematerialisation while keeping up with new trends
		3D printing/additive manufacturing for efficiency, customisation, potential for cleaner material production
		Virtual showrooms and fashion shows for reduced need for physical samples and travel
		Immersive experiences to convey the sustainability challenges (and efforts) of the industry
	Challenges	Technology reluctance
		Skills gap in industry
		Cost and energy demand of highly technological solutions
		Limited impact on consumer behaviour compared with other non-immersive technologies
		Early stage of technology diffusion and adoption

4. Discussion and Implications

A summary of recommendations for future research and industry can be found in Table 6, followed by an elaboration on these points.

Table 6. Recommendations and future discussion summary.

Recommendations for Future Research	Recommendations for Industry
Empirical studies measuring sustainability impact of immersive solutions	Assess whether current skills of the industry will meet future demand
Monitor evolution, diffusion, and use of immersive technology within the sector	Gather consumer feedback following use of immersive technologies
Empirical studies measuring energy demand of new immersive technologies	
Quantify the technology skills gap in the fashion industry	
Continue to examine effects of dematerialisation, digitalisation, and the metaverse on marketing and consumer theory	

In terms of future direction for research, empirical studies are critical to prove (or indeed, disprove) sustainability progress when employing immersive technologies. If immersive technologies become more commonplace in the fashion industry, the effects on sustainable consumption should be closely studied. Extant studies show how swayed consumers are by green or sustainable messaging through immersive digital experiences, but those studying VTO, for example, mostly focus on consumer attitudes and perceptions towards the technology rather than whether it reduced returns or changed behaviour in a measurable way. Similarly, when and if digital fashion becomes more prevalent, studies which show a real-term reduction in consumption of physical products would evidence the sustainability claims made by the digital fashion industry.

Given that these are emerging technologies, it is unsurprising that the field lacks empirical studies that measure or quantify how effective these immersive technologies could be for meeting sustainability goals. While there are several examples of immersive technology use in the industry, use remains limited, and niche and often appears as an extension of existing digital tools and processes rather than a radically new way of doing business. Once the technology becomes more diffuse, the empirical research gap should be addressed.

In addition, despite the subject of the metaverse being a trending topic, the metaverse in the true sense of the word (a common, global, shared, immersive, 3D virtual space where life takes place in ways not easily replicated in the physical world) is not yet here. There is some debate about when the metaverse will happen (with estimates ranging from soon to a few decades) and whether the scale of impact on people's daily lives will be as large as previously predicted [115]. Given the uncertainty about the digital future, it remains to be seen how much digital fashion can influence the sustainability dilemma in fashion—if consumers are not spending as much time in their digital lives as predicted, the opportunities for digital fashion and a move towards dematerialisation to significantly reduce clothing consumption will be reduced. Measurement of digital fashion adoption at scale (and any reduced need for physical clothing or reduced consumption) can only take place once the metaverse is more widely realised and populated. It should be noted that only one of the scholarly papers in this review discussed the metaverse, and this is a research gap in terms of the fashion industry's future sustainability.

COVID-19 saw a scramble to interact with consumers (and the entire supply chain) virtually. Despite the subsequent interest in immersive technology, many of the articles discussed reluctance (from consumers and/or industry) to embrace such technology. In fact, a large proportion of the papers in this review cite consumer behaviour as the main sustainability challenge. Some used immersive technology to educate consumers about the sustainability issues of overconsumption and fast, unsustainable fashion; some encouraged greater thought about purchasing by allowing personalisation or ensuring a good fit with VTO in the hope that it will reduce dissatisfaction and return of the product. This research and discussion should continue as the technology becomes more diffuse and more widely accepted by consumers. As mentioned, technologically, XR has limitations and is in a reasonably early stage of diffusion. AR is more commonplace through mobile phone apps, but VR headsets are still niche, and this may explain some of the barriers to adoption. Alternatively, reluctance to engage with immersive technology may simply be an issue with the technology itself (ease of use), and this should be further explored.

The TAM and theories concerning consumer behaviour were well-discussed in the included literature, and this work should continue as the technology becomes more commonplace. In addition, evolution of the next stage of digitalisation (namely, emergence of the metaverse) will challenge existing marketing and consumer theory, and as such, researchers should investigate how these developments will affect existing theories and models.

Sustainably producing clothing would appear to be an expensive endeavour. The challenge for the industry is to afford the same opportunities for sustainable production to all, including smaller brands, but digital technologies such as immersive applications can be expensive and technologically intensive to run. Exploring ways of reducing the costs of such new technologies would enable the wider industry to participate in potentially increasing sustainability and innovation using these newer digital tools.

Additionally, the skills gap is a much-discussed topic across many industries and sectors moving towards Industry 4.0 processes. It is a global challenge to ensure industry has the workforce it needs to continue and adapt. Papers in this review suggest that education and training providers have some curriculum adjustments to make to meet the needs of the future fashion industry. It is suggested that more work is done to determine the future skill needs of the fashion industry and to map the curriculum to the skills gap.

5. Conclusions

The previous sections have reviewed the literature, which sits at the intersection of three topics: sustainability, fashion, and immersive technologies. There are several applications of immersive technologies in the fashion industry, which may potentially impact sustainability despite the emergent nature of the technology, and the discussion of these topics and technologies appears to be rising in popularity. However, there are challenges associated with the use of immersive technologies in this sector and scant evidence of the extent to which these technologies are successful solutions to fashion's sustainability issues. Future research directions and discussion points for industry are supplied.

A review is usually limited by its search terms, and using more specific search terms for the applications of technology (such as 'virtual try-on') may have uncovered new relevant works. It was found that the catch-all term 'immersive technolog[y/ies]' was not often used; however, there are limits to search strings, and the most pertinent and descriptive terminology available to the authors was used at the time of data collection.

Searching this topic in the literature often yields a large proportion of papers that focus on the technology, how it works, and how it can be improved, rather than the real-world applications and implications of the technology. Entries in this review were examined for relevance to the topic areas to ensure they explored applications and implications of the technology in the industry in some capacity.

Given the focus on sustainability in this search, the results were focused on a narrower range of issues in the fashion industry, such as customer returns and circular economy, than the other applications of XR in the industry, such as engaging with customers and presenting products in new ways virtually to reach new audiences. In a similar vein, there are several emerging technologies which have the potential to impact the sustainability of the fashion industry, but only immersive technologies were considered here.

Additionally, VR/AR use in 3D modelling, such as CAD, is sometimes limited to viewing the models rather than manipulation due to a time-consuming and highly technical process in adapting the 3D models for the VR/AR environment. Therefore, the inclusion of such technologies within this review may be premature until the technology advances to allow the 3D modelling for design to be a more immersive experience. CAD and similar are included, however, given their potential immersive nature and potential for reducing sampling resources, costs, and timescales.

There was considerable overlap between topics grouped for analysis, and therefore, these groupings are a general guide only. Some topics, categories, or years of publication have only a few examples in the list of included articles and therefore, further research in the coming years tracking these trends is required to establish patterns.

Finally, the inclusion of grey literature is contentious but, as mentioned, permitted where trends that extend beyond the bounds of academia are the topic of discussion, particularly where practice and industry are key concerns. It is hoped that the inclusion of such material has added value to this review.

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