

Dematerializing fashion. Improving design-led sustainable and hybrid retail experiences via digital twins

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Abstract

Digitization has changed the way individuals build relationships, work, and consume. Such changes have affected the fashion industry in significant ways, revealing a whole series of new practices, not only regarding the design and manufacturing processes but also modifying how products are displayed, distributed, and consumed.

In the age of connectivity and technological innovation, a dematerialized economy is being shaped based on rethought consumption patterns and solutions to reduce energy demand. New concepts come together aiming at the possibility of economic development supported by sustainable social and environmental practices. Regarding this, the fashion industry has relatively recently embraced the dematerialization of fashion products, exploring different paths and opportunities that multiply the possibilities of relationships with the consumer and on the other promotes more sustainable and valuable processes.

Since the outbreak of the covid-19 pandemic, luxury brands and large retailers invested in the incorporation of new technologies, especially regarding the digitization of clothing, where multi-million partnerships between fashion brands and the games industry in the development of skins for electronic games proved to be a promising investment. In addition, for many companies, the adoption of 3D design and computer graphics software for the creation, modelling and prototyping processes represents an optimization in the workflow, increasing productivity, efficiency and reducing the environmental impact. The boundaries between the physical and the digital seem to be progressively being blurred, offering new experiences to users. In these circumstances, the Digital Twins technology, already adopted by other industries, is now starting to find its place in the fashion system, showing a potentially disruptive impact on traditional retail and communication channels that pass from omnichannel to phygital up to a new hybrid reality.

Considering the range of applications and usability opened by the digitalization of fashion, the emergence of new technologies (AI, VR, MX, Digital Twins) and the complexity of new challenges and impositions faced by the design field, the present paper aims to define innovative trajectories within the fashion retail sector, impacting both business models (in order

to make it more sustainable and valuable) and consumer experiences. In addition, this paper intends to discuss how design could contribute to creating new sustainable experiences, supporting the transition between physical and digital spaces, as well as adapting operational practices to make the phygital process positive and viable.

Author keywords

Fashion Dematerialization; Retail; Digital Twins; User Experience; Design for Sustainability.

Introduction

The entrance of new players - mostly from Information and Communications Technology areas - into the fashion competitive landscapes, the pandemic crisis that has further required a quick digital transformation (Bertola, 2021), and the emergence of contemporary technologies, such as metaverse, 3D printing, the Internet of Things, VR, AR, AI and Digital Twins, made the fashion industry recognize the importance of integrating digital fashion into its operation portfolio (Baek et al., 2022). Such digitalization process relates to the concept of dematerialization of fashion, which allows the unfolding of new trends into the contemporary design scene, aimed at the development of digital products using advanced technologies (Azambuja et al., 2021). Even if recent, the process of digitalization of fashion may expand the field of action of fashion design by bringing new ways of relating to fashion processes itself, beyond the challenge of bringing together the physical and digital worlds (Giuriatti & Pinheiro, 2022). Furthermore, one of the opportunities created by the digitalization of fashion regards the dematerialization of the supply chain, capable of "improve resource efficiency and compressing, eliminating, and shortening various business activities, as well as reorganizing the operating model toward a more collaborative approach in different stages of the process" (Casciani et al., p.790, 2022).

Within this context, this paper presents a conceptual framework (regarding the impact of advanced technologies on fashion consumer experience and how Digital Twins are reshaping the fashion value chain), followed by an interpretative framework, composed by three different operation models (Digital Twin-empowered hyper-real visual campaigns; Digital



Twin-empowered tailored and sustainable buying and retail dynamics and Digital Twin-empowered phygital and immersive retail experiences), intending to investigate the impacts of Digital Twins technology within the fashion value chain, focusing on distribution and communication processes.

Conceptual framework

The impact of advanced technologies on fashion consumer experience

Since the Covid-19 pandemic outbreak, the global fashion industry faces exceptionally challenging conditions, and due to the various restrictions imposed - mainly during 2020 and 2021 - digitalization processes have been accelerated. However, to date, few brands or retailers have embraced technology with a truly competitive mindset to fuel positive and valuable innovations (Bertola, 2021). Now, fashion and technology work together to enable companies to expand into new markets, win deeper levels of customer loyalty, and establish data driven strategies and decision making (Bof & McKinsey, 2022).

Emerging technologies such as blockchain and non-fungible tokens (NFTs) along with impactful technologies such as Digital Twins (DT), artificial intelligence (AI), machine learning (ML), and virtual reality (VR) (Joy et al., 2022), are placing the fashion industry under a historic transformation, entering the new global competition market by augmenting those phases in which design, creativity, sustainability, and technological transformation are the principal axes while simultaneously re-inventing its business models (Iannilli & Linfante, 2022).

Besides the high investments from fashion brands into the Metaverse (Burberry - B Bounce Game, 2019; Gucci - Tennis Clash game, 2020; Balenciaga -Fortnite game, 2021; Ralph Lauren - Zapeto, 2021; Zara - Lime Glam Meta collection, 2022; Adidas - Digital Ozworld Experience, 2022), the use of other technologies are also arising, such as IoT (Burberry, 2012; LDN Adidas, 2019); Mixed Reality (Hipanda, 2019; Lego & Snapchat, 2019; Gucci, 2022); AI (Chanel+Farfetch, 2019; Burberry, 2018) and Digital Twins (Yooxmirror, 2018; Bacon's version, 2021). Apart from increasing process efficiency and quality in the production process, reduce costs and improve logistics, these technologies can strategically create a unique relationship with consumers, especially those belonging to generation Z. In fact, such technological commitment coming from fashion companies is somehow directly linked to the demands of this new generation of consumers, which will define the future of consumption with \$4.4 trillion in estimated discretionary spending power (Snap Inc., 2022). In addition to being considered digital natives, along with Millennials, Gen-z generation base their relationships with companies by evaluation how they treat the environment, protect personal data, and position themselves on social and political issues (Deloitte, 2022).

How Digital Twins are reshaping the fashion value chain

Digital Twins are expected to become a business imperative, covering the entire life cycle of an asset or process, and forming the foundation for connected products and services (Hartmann & Auweraer, 2020). Coined in 2010 by John Vickers of NASA (Hazrathosseini & Afrapoli, 2023) the term "Digital Twin" stands for an encapsulated software object or model that mirrors a unique physical object, process, organi-

zation, person, or other abstraction (Gartner Glossary, 2023), and according to Kamble et al (2022, p.1) "it is a method of developing sustainable, intelligent manufacturing systems for attaining robust quality, reducing time, and customized products using real-time information throughout the product life cycle".

Listed as one of the top 10 strategic technology trends in 2018 and expected to cross the chasm in 2026 to reach \$183 billion in revenue by 2031 (Gartner, 2018/2022), Digital Twins are being explored in multiple fields (Guo & Lv, 2021), where the most successful ones, according to IBM, are those of engineering (systems), automobile manufacturing, aircraft production, railcar design and building construction manufacturing. The fashion field, however, found itself forced to accelerate its digital processes due to the pandemic (BoF & McKinsey, 2020/2021), and now recognizes Digital Twin technology as a possible valuable and sustainable addition into the field.

A first and rather extensive literature review (Nobile et al., 2021; Noris et al., 2021) has shown a growing interest of the scientific community in the topic, which the proliferation of experiences and explorations of leading fashion brands and emerging digital companies has accompanied. In particular, the authors investigated the field of Digital Fashion (within which Digital Twins represent a particular typology with peculiar features and potentialities) according to three categories: Communication & Marketing - also related to the transformation of the Customer Experience in the retail environment; Design & Production; and Culture & Society. Not surprisingly, the area of Communication & Marketing includes the most studies and applications.

Fashion brands have been experimenting the application of Digital Twins from buying campaigns (SUNNEI) and visual campaigns (Puma Flash Retail Film; Chase the light - Timberland; Kendall for the TB Summer Monogram campaign by Burberry) to animated fashion shows (Bacon's Version by Bacon; GCDS Out of this world SS 2021) and retail distribution (I.T Hong Kong x The Fabricant). Within the gaming industry, widely explored by fashion companies over the last few years, the specific use of Digital Twins is still diffident (Ralph Lauren redesign of polo logo for first time in new digital collection with Fortnite; Moncler limited-run of physical apparel inspired by the fashion house's far-reaching archives with Fortnite; Balenciaga and Fortnite on a series of in-game outfits and a limited-run physical apparel collection). From the creative and production processes to the retail and communication operations, Digital Twins, according to Riedelsheimer et al (2020, p.664) "could be used as an information basis on environmental, social and economic aspects along the whole lifecycle and provide assistance by optimizing the product's environmental and social impact."

Interpretative framework

Reframed fashion retail & communication operating models through Digital Twins implementation

Within a context of progressive and pervasive dematerialization of fashion, large and small fashion companies have recognized the great potential of digitization both to make their omnichannel distribution system smoother and more efficient (Jocovski, 2020; Palmié et al., 2022) and to improve and enhance the consumer experience (Alexander & Kent, 2020; Bonetti et al., 2019). According to this critical scenario, this paper proposes an interpretative framework to understand

and analyze the impacts of the adoption of Digital Twins within the fashion value chain, with a specific focus on those distribution and communication processes that typically result downstream of the design and product development phases. Starting from the analysis of exemplary case studies, this research proposes three different operating models that, in one hand, shows the most recent strategies and operational paradigms in the fashion field and on the other hand, identify potential and significant trajectories of development and innovation in the sector.

The three different operating models reflects the many transformations of the "traditional" supply chain (Figure 1) with impacts acting at the level of: business models, user experience, and sustainable processes.

The first operating model refers to the adoption of Digital Twins in a complementary approach to the traditional design and prototyping process of the physical garment, with significant impacts on the collections' display and communication formats and, consequently, on the experiential models proposed to the consumer. The second operating model regards the adoption of Digital Twins by transforming the traditional supply chain from the early stages of fashion product design, opening the possibility of experimenting and redefining key and particularly "unsustainable" processes such as sales campaigns and online distribution channels' management. Finally, the third operating model proposes a still partially unexplored and highly alternative model to the traditional supply chain translating into a properly phygital solution the relationship with the consumer and integrating in a valuable way the digital and physical dimensions of the purchasing experience.



Figure 1. Illustrative diagram of the traditional Fashion Supply-Chain (simplified elaboration from the Miroglio Group Supply-Chain diagram presented at the company visit, July 2022).

Digital Twin-empowered hyper-real visual campaigns

The rise of digital transformation, and its acceleration due to the COVID-19 pandemic, has significantly impacted the fashion industry. One of the most visible and impressive consequences was how visual content and fashion shows are produced. Many fashion events and fashion weeks have been postponed or cancelled due to the pandemic, and those that have taken place have often been held virtually or with strict safety measures. One of the significant impacts of the pandemic on fashion shows has been the shift towards virtual events (de Carvalho Godim & Cunha, 2023; Linfante & Pompa, 2021). Many fashion brands and designers have turned to digital platforms to showcase their collections through live streams, pre-recorded videos, or interactive digital experiences. These strategies have allowed them to continue to present their works while reaching a global audience, thus experimenting with new visual formats and narrative codes and simultaneously introducing changes and new operational settings to the traditional fashion design process (Figure 2). In fact, creative and technical back-end design processes - trend and color choice; fabric and raw material research and choice;

sketching; colors approval and technical files development - were directly impacted, as shown in the following cases.

A couple of examples can particularly illustrate the potential and impact of the dematerialization of fashion in communication, from fashion shows to visual and marketing campaigns. "Out of This World SS2021" was the first virtual and appropriately "multi-format" fashion show proposed by the young brand GCDS, realized in collaboration with the international AR, VR and MR production studio Emblematic Group. It represents one of the first cases that used digital avatars not only for the presentation of the collection, but also for the realization of an immersive and narratively complete experience offered to an active and involved community. The virtualization of the garments took place starting from the sketches of the creative director Giuliano Calza, thus disrupting the conventional process of prototyping and product development (GCDS Had the Most Surreal Front Row, 2020). In this way, the creation of the digital fashion show and the entire collection production process followed parallel, non-sequential processes, allowing the former to be released well in advance of the latter and expanding the opportunities for interaction between the brand and its community (Moore, 2020). The fashion show was part of a more comprehensive communication and exhibition format that, based on an interactive digital platform, enabled augmented reality community socialization through playable video games, interaction with avatar-like front-row guests, and behind-the-scenes content.

Another example of a digital pipeline being used to produce a fashion show, and more generally, to promote a new and more sustainable model of visual content production and marketing, is 'Bacon's Version Show', presented at Milan Fashion Week 2021 by Bacon Clothing and developed in collaboration with TwinOne (Essere sostenibili nella moda usando la realtà virtuale, 2022). TwinOne recreated the 3D digital collection, starting with sketches and paper patterns and then, using the 3D game tool Unreal Engine technology, developing a potentially unlimited number of fabric-colour-pattern variations. This new digital pipeline impacted both the traditionally long prototyping phase and the equally costly production phase of visual communication content (Goodine, 2021) by promoting a new sustainable framework that reduces waste, accelerates timelines, and eliminates redundant investments.

Digital Twin-empowered tailored and sustainable buying and retail dynamics

As discussed previously, Digital Twins have been introduced and implemented within distribution processes for various purposes, ranging from supply-chain optimization to improving the user experience, to promoting new and more sustainable operating procedures. From the point of view of sustainable supply-chain optimization, for example, they can help retailers to manage inventory more efficiently, reduce waste, and improve responsiveness to changing demand (dos Santos et al., 2021). Similarly, from the point of view of improving the user experience, Digital Twins allow customers to make more informed purchasing decisions by creating virtual try-on experiences (Riedelsheimer et al., 2020), with a positive impact, particularly for online retailers or by offering garments' ID cards thus improving transparency and traceability. In the following described cases, the back-end processes affected concerns mainly campaigns and online distribution

channels' management, such as market analysis, merchandising strategy and assortment planning.

In this context, SUNNEI Canvas - a project developed from 2020 onwards by the streetwear brand SUNNEI with the support of the 3D production agency Pezzo di Studio - represents an interesting example of connecting and hybridizing the digital dimension of fashion with its physical connection to the retail channel, implementing new services and forms of interaction between the brand and its audience, from buyers to end customers (Iannilli & Linfante, 2022) (Figure 3).

SUNNEI Canvas is an ongoing project launched with the SS21 collection of the brand's signature pieces delivered in all white and designed to be customized and developed with selected stores worldwide: the clothing and accessories could be modified to meet the specific preferences and needs of each store. To facilitate this customization process, SUNNEI created an online platform - only accessible with a password - that utilizes 3D engineering and customization technology to allow buyers to modify shapes, fits, and fabrics digitally. In order to enhance the virtual experience, SUNNEI developed male and female avatars with human-like features and a 100% SUNNEI aesthetic. These avatars can be used to showcase the clothing and accessories in the SUNNEI Canvas collection and allow buyers to see how they would look on a virtual model. The customization process, therefore, will result in different collections resulting in "Made for..." tags for different retailers (Leitch, 2020). The SUNNEI Canvas collection was launched as part of Milan Digital Fashion Week, with the buyers' platform also going online on that day. A second part of the collection was released in September, focusing on end customers' experience. The second part of the project focuses on community involvement by proposing an "endless video game" without objectives or levels to overcome. The avatars in the game are dressed in outfits and look chosen by game players, who are part of the SUNNEI community. The whole project is a reflection on the potential of the venture between fashion and the game industry to generate and test new ways of consumer engagement and involvement (Salibian, 2021).

Digital Twin-empowered phygital and immersive retail experiences

The third operating model refers to a complete integration of a digital pipeline assuming, different from the previous cases, a complete consumer and retail-oriented perspective. In the exemplary case considered, the adoption of Digital Twin has the main objective of experimenting and taking opportunities with new emotional and highly interactive models in the final client relationship. The opportunity for collaboration between the retailer I.T Honk Kong and The Fabricant, a pioneering agency in the fashion dematerialization field, arises on the retailer's 30th anniversary. For the occasion, a travelling pop-up exhibition is planned to showcase a unique collection of global exclusives created in collaboration with leading fashion designers (The Fabricant, 2022). The adoption of Digital Twins, together with other technologies that "activate" and "augment" the physical space of the exhibition/retail space, represents one of the first and most interesting experiments of phygital reality (Iannilli & Spagnoli, 2021). This approach connects the tangibility of the physical experience with the interactivity and smoothness so typical of the digital dimension (Figure 4).

The travelling pop-up exhibition was held at various locations, including Hong Kong, Shanghai, and Beijing, in the winter

of 2018 and in Europe at the beginning of 2019. Designed to showcase a unique mix of physical and digital garments featuring interactive displays, the exhibition was intended to provide a unique and immersive shopping experience that showcased the capabilities of digital fashion and the potential for omnichannel retail. The exhibition included a digital collection of garments from brands such as Marques Almeida, Helmut Lang, and Alexander McQueen, only available for pre-purchase viewing in digital form at the pop-up locations. Customers could purchase these garments by scanning QR codes using a specially developed app. The retailer's goal was to attract various consumers with this unusual presentation and shift the perception of what a fashion retailer could deliver (Morris, 2019). Moreover, the interactive digital displays included a surreal maze of humanoid figures rendered in real-time 3D and buyable garments. The humanoids were programmed to respond to shoppers' movements, which were tracked using object detection cameras mounted above the screens. The 3D models were rendered using the three.js library and were synchronized with videos of the digital garments, which were displayed across 16 LED displays ('I.T Hong Kong', 2019).

This third operating model focuses on the experimentation of new codes and forms of emotional, immersive, and interactive connection traditionally about the exhibition sphere, which is reframed and performed in a hybrid space between the pop-up store and the travelling exhibition. This implicates the back-end processes from the design phase to distribution, logistics and retailing, until delivering the experience to the consumer. In addition, the perspective shift reflected the potential of the dematerialization of fashion from a communication and retail point of view and made it possible to renew and revolutionize the traditional supply chain and, therefore, the connected business model, starting from the innovation of the consumer experience, with promising and positive future implications.

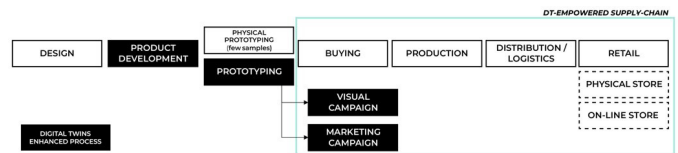


Figure 2. Digital Twin-empowered fashion supply-chain with impacts on visual and marketing campaigns' phases.

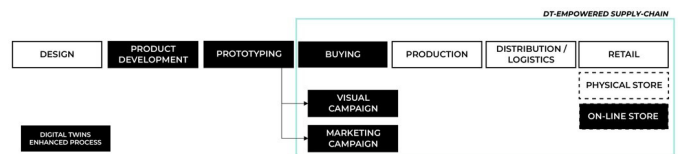


Figure 3. Digital Twin-empowered fashion supply-chain with impacts on B2B and B2C buying and selling phases.

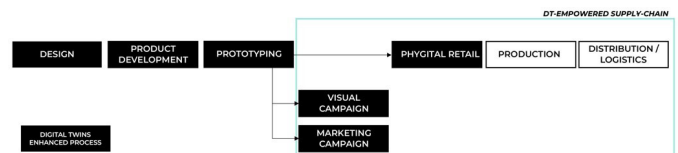


Figure 4. Digital Twin-empowered fashion supply-chain with impacts on phygital products and services offerings.

Improve Design-led Sustainable Innovation in Fashion Retail

Increasing sustainable actions in creation, production and consumption processes has become an urgent issue and challenge involving the fashion industry along with the whole stakeholder ecosystem. Awareness about sustainable fashion is growing, even though most operating models and applied experiences are exclusively focused on the fashion product development phase (Kozłowski et al., 2018), going from waste reduction design strategies to raw material control to product lifecycle management. More recently, new agendas are emerging, acting on different levels and contributing to bridging a gap both in terms of operational practices and strategic conceptualization in the field of sustainable fashion: on one hand, the growing interest in the retail sector (Ruiz-Real et al., 2019) that, together with the communication domain, represents the interface between fashion product and consumer and which, by adopting sustainable approaches, has the potential to affect both the consumer experience and business models (Dodds et al., 2022); and on the other hand, the need to integrate the concept of sustainability into the fashion design processes (Kozłowski et al., 2018) with a systemic approach to generating long-term and viable sustainable innovation in the fashion system.

Concerning specifically the fashion retail design field, technological and digital acceleration very quickly increased the implementation of advanced technologies (among others AI, VR/AR, MX and, not least, Digital Twins) in all back end and front-end distributive processes (Bulović & Čović, 2020; Casciani et al., 2022). In addition, as big data is increasingly being used in trend forecasting research/consumer behavior analysis and data centers and data transmission networks are responsible for nearly 1% of energy related GHG emissions (Iea, 2022), the use of data also integrates debate regarding sustainability. These technological applications have often been used to improve specific retail chain knots. However, a systemic reflection on the potential of technology to sustainably rethinks the fashion value chain, shaping a virtuous integration of retail design, marketing, management, and ICT disciplines is still in its infancy (Dodds et al., 2022; Iannilli & Spagnoli, 2021).

Similarly, a reflection on the peculiarities, practices, and tools of "Design for Sustainability" has been pursued. Taxonomic definitions (Arnette et al., 2014) and analytical frameworks (Rocha et al., 2019) are flanked by evolutionary readings of the Design for Sustainability domain. Design for Sustainability has seen a progressive broadening from a predominantly technical and product-centric level of innovation to a broad socio-technical and systemic innovation scale (Ceschin & Gaziulusoy, 2016). In a context in which "the current understanding suggests that sustainability is a system property and not a property of individual elements of systems (...) achieving sustainability requires a process-based, multi-scale and systemic approach to planning for sustainability guided by a target/vision instead of traditional goal-based optimization approaches" (Ceschin & Gaziulusoy, 2016, p.119).

Starting therefore from the previously investigated operating models - which highlighted both the potential of the Digital Twins in the distribution, promotion and valorization processes of the fashion product and the consequent transformation of the value chain - a first and tentative critical interpretation of design-led innovation for fashion retail is proposed (Figure 5).

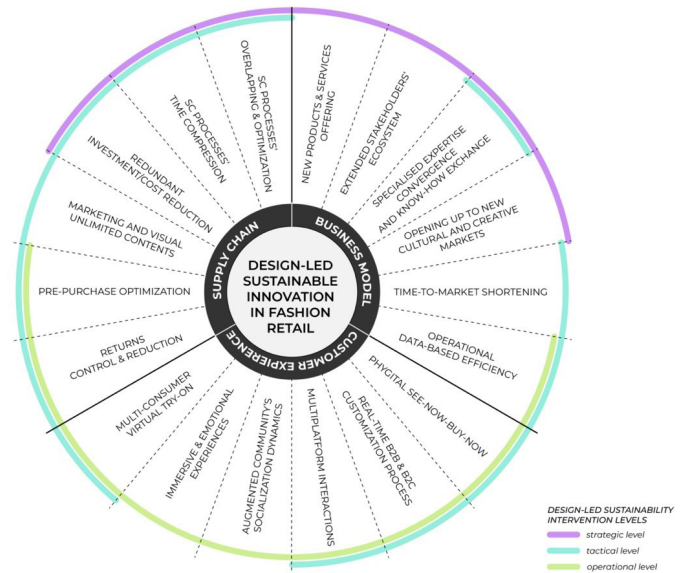


Figure 5. Design-led Sustainable Innovation in Fashion Retail enhanced by adopting advanced technologies (with a focus on Digital Twins implementation).

Design-led innovation oriented to promote sustainable solutions through the exploitation of advanced technologies operates on several interdependent levels: on business models' innovation, the supply chain and, finally, the customer experience innovation. The valuable impacts that adopting Digital Twins can bring in these three domains range from the improvement of customer service (e.g. Real Time B2B and B2C customization as in the case of SUNNEI Canvas) to performance efficiency (e.g. time reduction in marketing and visual contents' production as in the case of Bacon's Version), to the creation of new hybrid and phygital consumption formats (e.g. offering new products and/or services as in the case of the I.T Honk Kong exhibition/pop-up). Within this framework, it is also important to highlight how design-led innovation for sustainability can act at different levels: strategic, tactical, and operational. These levels, systematized by Rocha, Antunes and Partidário (Rocha et al., 2019) and used as an analytical framework to explore different Design for Sustainability models, here similarly return the different dimensions that a systemic approach to sustainability for fashion retail should take charge of. In particular, the strategic level refers to the highest layer of corporate policies and macro-strategies; this level acts mainly at the business model scale and systemic supply-chain transformations. The tactical level refers to the operating processes and the system of relationships that regulate specific business units; for this reason, the tactical level has impacts that predominantly involve the supply chain and the customer experience when its transformation entails changes in processes, services, and distribution channels. Finally, the operational level acts within the micro-level of project management approaching primarily incremental sustainable innovation and focusing on streamlining traditional processes or flanking them.

Concurrently, addressing these different levels becomes mandatory to drive and implement sustainable innovations in the areas of fashion retail and communication. Within this context, design is required to encompass the system's complexity once again and embrace technological innovation (together with other contemporary drivers) by embedding it within positive and long-term signifying frameworks.

Conclusion

In the light of the dematerialized economy that is being shaped in the attempt to fulfill new sustainable demands through advanced technologies (AI, VR, MX, Digital Twins), fashion embraced digitization as a facilitator in the process of rethinking smart solutions for its value chain. In this context and aiming to study the impact of Digital Twins technology within the fashion system and how it can be used throughout the supply chain as a mean of feasible practices, this paper analyzed three different operational models. The first model "Digital Twin-empowered hyper-real visual campaigns", mostly regarding visual and marketing campaigns; the sec-

ond model "Digital Twin-empowered tailored and sustainable buying and retail dynamics", inclined to the traditional supply chain transformation from the early stages of product design; and the third model "Digital Twin-empowered phygital and immersive retail experiences", drawing up phygital solutions. The research then, based on the analyses of the three operational models, presents a critical interpretation of design-led innovation for fashion retail, showing that the application of advanced technologies (in particular Digital Twins) can, from a sustainable point of view, improve customer service, increase efficiency and create new phygital consumption formats.

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