Digital Fashion

A Qualitative Assessment of the Digital Fashion Innovation System and its relation to Sustainability

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ABSTRACT

The fashion practice is currently undergoing a 4th industrial revolution. Fashion 4.0 "operates in cyber-physical space and develops toward smart products, production and networks, automation, optimization, flexibility, as well as sustainability-oriented, datafied and customer driven processes" (Särmäkari, 2023, p. 88). This revolution came to public attention after the Dutch fashion startup *The Fabricant* auctioned a digital-only dress for $9500 (Renwick, 2019). Emerging technologies such as AI, blockchain, NFTs (non-fungible tokens), as well as virtual and augmented reality, is expected to bring drastic change to the fashion industry (Joy et al., 2022). These innovations are not infrequently associated with a sustainable transformation of the fashion industry. In a world characterized by overconsumption, virtual clothing supposedly offers a solution; consumption without real consequences? A literature review on digital fashion shows that while innovation and innovative technologies are mentioned in the literature, a systematic analysis of the innovation processes behind digital fashion is still under researched. Within the theoretical framework, systematic approaches to research innovation systems are presented and discussed. In addition, concepts of sustainability are proposed to contextualize digital innovation within the fashion industry in the ongoing sustainability movement. Using a qualitative research approach, interviews were conducted with the digital fashion community within Europe about their understanding of innovation, digital fashion, and sustainability. Results from the interviews were analyzed based on existing concepts and theories to enable a mapping of digital fashion as an innovation system. In addition, the results are embedded in the context of sustainability efforts. The findings suggest that digital fashion may be understood as an umbrella term that lacks a "one-fits-all" definition across differing perspectives. While the innovation system seems to have dispersed over the past years, its divers actors and institutions provide a foundation for radical and incremental innovation. Digital fashion's relation to sustainability, however, is characterized by numerous tensions resulting in a susceptibility to greenwashing.

KEYWORDS: *Digital Fashion; Innovation; Systems of Innovation; Sustainability; Ecosystem*
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Introduction

The global economy is changing. Driven by digital technologies and their implementation in manufacturing, scientists refer to this change as the Fourth Industrial Revolution (Kagermann et al., 2013). This revolution can be understood as a model "where new modes of production and consumption will dramatically transform all major industrial systems" (Bertola & Teunissen, 2018, p. 353). As the third largest manufacturing industry, this change is also affecting garment production and thus the fashion industry. The age of digital fashion has been ushered in. This is the result of groundbreaking innovation that made headlines around the world in 2019 with the auction of a purely digital fashion item created by the Dutch label The Fabricant. Digital fashion may not just be a new type of end product, but a rethinking of the fashion industry as a whole. It goes hand in hand with a transformation of the ecosystem. Schwab (2017) describes the Industry 4.0 model as a new creation of the entire entrepreneurial ecosystem, in which data and information are collected and exchanged at all organizational levels and across the entire value chain. In the case of the fashion industry, the ongoing question of greater sustainability plays a major role here. Digital process and manufacturing optimization is accompanied by the hope that smart factories will have a significant impact on the efficiency and sustainability of textile production (Bertola & Teunissen, 2018). However, this link between digital transformation and sustainability has also been met with criticism. Hohn and Durach (2021) paint a bleak picture of the future, in which digital change exacerbates or at least further entrenches existing inequalities and negative environmental and social impacts.

The objectives behind this scientific work are threefold. Within academic literature, digital fashion is also an emerging field of research. Based on academic research, several literature reviews have attempted to define digital fashion. One of the goals of this work is to look at digital fashion from a practical perspective and thus offer a practice-based dimension to the theoretical definition. The second component of this research work is the investigation of digital fashion based on an innovation system understanding. Since digital fashion can possibly be understood not only as an end product, but also as an ecosystem of the digitalization of the fashion industry, digital fashion lends itself as a new object of innovation research. The combination of the technological orientation and creative nature of the fashion industry in particular creates a field of tension between conventional, STEM-based, and creative-oriented understandings of innovation. The final component of this thesis focuses on the connection between digital fashion and questions of sustainability. Scientists have been exploring the possibilities and opportunities for moving

one of the biggest polluters and causes of social injustice toward more sustainable paths for quite some time. This scientific work aims to contribute to this by investigating the extent to which digital fashion contributes or can potentially contribute to a sustainable transformation of the fashion industry. The underlying scientific question addressed in this thesis is derived from these contexts. To what extent can digital fashion be understood as an innovation system, and what implications does this relatively new ecosystem have for the sustainability movement in the fashion industry?

In addition to its scientific relevance, this research question also has social relevance. Research on sustainability can obviously be linked quite directly to social relevance. A possible transformation of the fashion industry away from excessive resource consumption and consumption toward circular models, degrowth, and sufficiency would be a major step forward for society in overcoming current and future human and ecological crises. Embedding digital fashion in a systemic understanding would ensure that it is understood less as a digital gimmick and more as a potential driver of innovation. Integrating digital fashion into an innovation system paves the way for the fashion industry and policymakers to recognize the innovative potential of this system, manage it in a future-oriented manner, and leverage it.

In order to address the research question, this paper is structured as follows. Within a theoretical framework, the concept of digital fashion is first analyzed with the help of a literature review. This not only highlights possible definitions and practical applications of digital fashion, but also draws attention to gaps in the academic literature. Subsequently, theories of innovation are discussed, and the processes of an innovation system are examined. As the third component of the theoretical framework, two sustainability approaches are presented. Finally, the sustainability issue within the fashion industry is contextualized and possible solutions are discussed. The methodological part of this thesis explicitly describes the research methodology and design. It discusses the sampling of study participants, operationalization, data collection, and analysis. A qualitative approach was chosen, which uses semi-structured interviews to collect data from experts in the field of digital fashion. The results section presents the findings and classifies them in relation to the research questions and the theoretical framework established above. Finally, the results are discussed with regard to possible social and scientific implications as well as the limitations of this research.

Theoretical Framework

1 Digital Fashion

Since digital fashion is the central point of reference for this research project, this concept will first be defined more precisely below. Various definitions of digital fashion can be found in the literature. At the beginning of the 21st century, the term referred to e-commerce platforms that sold items of clothing (FashionNetwork, 2011). Howarth (2013), on the other hand, describes digital fashion as any fashion concept that integrates experimental technologies, such as 3D printing, body scanning, and virtual design. This definition is an extension of the preliminary definition of digital fashion as a wearable computer (Park & Lee, 2001). The constant development and integration of new technologies poses a challenge to formulate a uniform definition that is not based on the technologies currently in use. Nobile et al (2021), on the other hand, provide a more comprehensive definition. According to them, digital fashion encompasses "all the processes that include (i) marketing and communicating tangible and intangible products; (ii) the development and implementation of processes that support the advancement of the industry; (iii) the effects of digital advances on society." (p. 297).

Systematic literature reviews serve to better define the field of study. Noris et al. (2021), for example, focused on the keywords "digital" and "fashion" to develop a framework for digital fashion from the perspective of marketing and communication. This includes three main topics: (i) *Communication and Marketing (C&M)*; (ii) *Design and Production (D&P)*; and (iii) *Culture and Society (C&S).* However, this framework is not without criticism. Baek et al. (2022) criticize that the keywords used do not take into account a large number of possible studies, since, for example, studies on the implementation of algorithms for demand prediction do not include the word "digital," but are no less relevant for an all-encompassing definition of digital fashion. Based on a previous discourse analysis on digital fashion, Baek et al. (2022) used a variety of keywords in their literature research and analyzed emerging topics and trends within digital fashion literature. The topics that emerged from their analysis were design, virtual, body, consumers, printing, and supply. The most dominant topic, *design,* is increasingly concerned with advanced technologies used in the fashion design process. *Virtual* refers to the juxtaposition of fashion innovation in the virtual world versus the physical world. The *body* topic area can be described as an aspect that deals with the capture, modeling and use of the human body in various digital processes in the fashion industry. It includes the ergonomic fit of garments, the creation of digital body models and their application in

design, production and consumption. The *consumption* topic deals with the question of how digital transformation in fashion retailing is changing the consumption experience. The topic of *printing* deals with innovative clothing production processes, with a strong focus on 3D printing. Finally, studies on digital progress within the fashion supply chain are collected under the topic of *supply* (p. 5). Based on these six topics, the researchers define digital fashion as follows: “Digital fashion is the virtual creation, production, and representation of one's identity via computer-generated design” (Baek et al., 2022, p. 8).

Based in this definition and the aforementioned thematic fields, a literature review was conducted. An overview on the literature reviewed sorted by themes is provided within the Appendix A. As some of the research papers cannot be categorized within one single thematic field, they may appear more than once within the summary. In the following sections research within the thematic fields will be discussed, emphasizing key findings.

1.1 Design

Under the topic of *design*, digital fashion is considered as an optimization factor for design and production processes through technologies such as body scanning and digital patterns. These tools can lower entry barriers for designers and reduce the number pf physical samples, thus contributing to more sustainable workflows (Baek et al., 2022). Precision and personalization are central themes. Parker et al. (2022) show how the Gryphon algorithm significantly enhances the accuracy of 3D body scans, enabling scalable solutions for better-fitting garments. Oh and Suh (2021) highlight the potential of these technologies for mass customization, including customized mannequins for retail and tailoring. Complementing this, Peng et al. (2012) investigate the user acceptance of home scanning systems, emphasizing the need to balance accuracy with usability and minimal setup effort.

Accessibility and democratization of design tools also play a crucial role. Kang and Kim (2019) introduce a computer-aided system that translates 3D models into 2D patterns, allowing users without advanced technical knowledge to design complex garments. This facilitates faster prototyping and broadens participation in design innovation.

From a sustainability angle, McQuillan (2020) explores the integration of 3D digital design into zero-waste fashion. She argues that CLO and similar software enable simultaneous development of textile and form, fostering interdisciplinary workflows. However, the often linear and siloed nature of the traditional fashion industry must be

critically noted, as it may complicate the implementation of holistic processes such as zero-waste. Even if 3D software enables a deeper understanding of the relationship between design and waste, these advances can be undone if conventional, waste-intensive design processes are applied again in later production steps. The need to consider waste as early as the design process may require a fundamental restructuring of established ways of working in the fashion industry.

1.2 Consumer

The consumer experience is conceptually distinct from digitized design or production processes yet closely tied to the digital transformation of fashion retail (Baek et al., 2022). Wang et al. (2021) and Sarkis et al. (2025) demonstrate that augmented reality (AR) can enhance purchase intent by increasing interactivity, vividness, and perceived aesthetics, while also fostering brand loyalty and more informed decision-making. However, successful implementation depends on user-specific communication strategies, as Masuda (2012) argues.

Virtual interfaces offer new opportunities but also raise challenges. While consumers show general willingness to engaging with digital humans (Silva & Bonetti, 2021), interactions with avatars can alter self- and body-perception, particularly among young women (Park & Olge, 2021). Herz and Rauschnabel (2019) further emphasize that wearability, comfort, and fashionability influence acceptance of virtual reality glasses, whereas perceived risks around health and privacy pose as barriers.

Altogether, these studies highlight the multifaceted nature of consumer behavior in digital fashion contexts. Acceptance of AR, VR, and digital embodiments cannot be reduced to technological features alone; psychological, cultural, and social dimensions are equally decisive.

1.3 Body

This thematic area explores the ergonomic and functional performance of clothing, increasingly realized through 3D printing and virtual representation. While early research focuses on the physical body in design processes, the scope has expanded to include virtual bodies and avatars (Baek et al., 2022). Liu et al. (2017) presents a method for creating digital human models (DHMs), essential for virtual try-ons, digital design, and fashion

shows. Brownridge and Twigg (2014) emphasize that digital fashion involves not only garments but also the representation of the body itself.

The psychological and social dimensions of avatars play a significant role in how digital fashion is perceived. Vasalou and Joinson (2009) demonstrate that self-presentation through avatars varies by context: attractiveness is prioritized in dating, intellect in gaming, and authenticity in blogging. These insights align with Park and Olge (2021), who discuss how digital embodiment can influence self-perception.

In terms of sustainability, Peng and Al-Sayegh (2014) introduced the ShapeMate app (providing human body shape estimation for online fashion applications) and found that personalized virtual fitting improve satisfaction and reduce return rates, offering clear environmental and economic benefits.

1.4 Virtual

The theme of the *virtual* is considered from a business-centered and a consumer-centered perspective. From a business angle, technologies like 3D body scanning, virtual fit verification, co-design, and style advice enhance the online shopping experience and help digital retailing keep pace with physical stores (Miell et al., 2018; Ross, 2012). These tools not only reduce size uncertainty and return rates but also increase supply chain efficiency through shorter lead times, lower development costs, and customization potential (Greder et al., 2020; Gustafsson et al., 2021). Case studies further highlight improved creativity and supplier communication through 3D integration across the value chain (Arribas & Alfro, 2018)

From the consumer perspective, technologies such as AR mirrors, apps, and fitting rooms positively impact brand interaction and decision-making (Cuomo et al., 2020), though they must be applied carefully to avoid overwhelming users. VR also enhances perceived store attractiveness (Jin et al., 2021). Beyond retail, AR proves promising in fashion education. Elfeky (2021) shows how immersive AR environments can foster skill development and garment visualization, complementing traditional learning approaches.

1.5 Printing

In addition to the computer-aided 3D design methods already mentioned (see Gerder et al., 2020), this topic mainly deals with 3D printing within digital fashion. Kim et al. (2019)

found in their study that 3D printing in the fashion industry is progressing slowly compared to other industries. This could be due, for example, to the high procurement costs of the technology, the fact that production time is extended due to necessary post-processing, and the fact that the printed garments are usually heavier than conventional garments, which limits wearing comfort. Looking at 3D-printed products through the lens of the technology acceptance model (see Rrauschnabel & Ro, 2016), there is room for improvement in terms of perceived user-friendliness. Sun and Zhao (2018) also point to the need for further development of 3D printing in the fashion industry. With the development and application of new technologies such as 3D printing, the role of the designer is becoming more complex and increasingly includes technical data. However, this will require new skills, knowledge of materials and processes, the integration of technical knowledge into education, the overcoming of challenges such as balancing technical and creative skills, and software limitations. The social implications of 3D printing and additive manufacturing in global apparel supply chains should also be critically examined (Hohn & Durach, 2021). Increased efficiency through additive manufacturing could lead to faster fashion cycles, as well as a reduction in jobs and a deterioration in working conditions. Hohn and Durach (2021) also point out that social sustainability in established supply chains could deteriorate or that these issues could be carried over into new supply chains.

1.6 Supply

The last theme, *supply*, highlights the importance of data quality and how it can be improved using blockchain technologies. In general, the integration of new technologies allows for the implementation of new business models that are aligned with a circular economy and thus support economic, social, and environmental sustainability. Choi and Luo (2019) examine the conditions under which blockchain can improve social welfare but at the same time impair the profitability of the supply chain, since implementation is associated with high fixed and variable operating costs. There are mutual benefits for both the manufacturer and the consumer, as well as social well-being, through blockchain technology supported platforms. To reduce the costs of blockchain, Choi and Luo (2019) suggest government funding or an environmental tax. The latter would indirectly impose sanctions on surplus production, which could be reduced through improved data quality and thus better demand forecasting. A second noteworthy study on the topic of supply is

that of Huynh (2021). This study examined how digital innovation can be considered an enabler for circular business models in the fashion industry. Huynh (2021) identifies three main types of digital circular business models:

- (i) **The blockchain-based supply chain model** aims to improve traceability in the fashion industry's value chain and optimize automated sorting for recycling. In this context, blockchain serves as a central technology, alongside real-time data and the Internet of Things (IoT), to enable a transparent, verifiable and immutable flow of information throughout the entire product life cycle. This would enable consumers to obtain sustainability data on their products, and increase the efficiency of recycling or reuse.
- (ii) **The service-based model** is facilitated by digital platforms and mobile apps that enhance user interaction and product management. This model includes clothing rental/subscription-based models, as well as repair and second-hand sales models. Blockchain can improve the efficiency of sorting garments for rental and resale.
- (iii) **The pull demand-driven model** represents a more radical transformation. It aims to make the business model no longer dependent on highly volatile demand and inaccurate demand forecasts, but to enable demand-driven production in order to reduce overproduction. 3D printing technology plays a central role here in producing customized products on demand.

The literature review covers a wide range of topics within digital fashion, from technological innovations in design and production, to the impact on consumers and changes in the supply chain. However, a systematic approach to innovation in digital fashion seems to be missing within academic research. This research, therefore, may contribute to bridging this gap. Furthermore, positive impacts of digital solutions on sustainability efforts were discussed in a theoretical context only. Whether digital fashion is actively implemented to facilitate a sustainable future of the industry has yet to be examined.

2 Innovation

In order to examine the research component of digital fashion in relation to innovation and innovation processes, the following section describes the concept of innovation from various perspectives.

The term innovation has its historical roots in research on technological development and economics (Wijngaarden et al., 2016). Joseph Schumpeter defines innovation as the introduction of a new product, a new production method, the opening up of new markets, new sources of raw materials, and the creation of new forms of organization (1934). He distinguishes between innovation and invention. Inventions, in his understanding, build the basis for innovation to happen. It may be understood as the new product or production method. Innovation, however, describes the process of new, innovative combinations of existing production methods, more precisely implementing the inventions within existing structures (1939).

Entrepreneurs play a central role in this process. According to Schumpeter (also see Baumol, 2004) entrepreneurs are the central function of innovation. Instead of established firms, the 'outsiders' or entrepreneurs introduce innovations (Fritsch, 2017). Subsequent research has focused increasingly on research and development (R&D) in sectors such as agriculture, manufacturing, and mining. Technological product and process innovation is defined as "technologically new products and processes implemented and significant technological improvements in products and processes" (OECD – EUROSTAT 1997, 31).

This definition is clearly unsuitable for the creative sector. The creative sector or creative industries are described as those that produce products and services resulting from creative work (Rutten et al., 2004). Creative products or services, furthermore, have cultural, artistic, or entertainment value (Caves, 2000). Innovation within the creative sector hence takes a different form from the technological product and process innovation described above. Eltham (2013) criticizes the dominant understanding of innovation as being strongly focused on economic success, which only partially applies to the creative sector. He cites literary works, for instance, which only achieved economic success posthumously but had little market value during the author's lifetime and are nevertheless considered innovations within their own right. Jaaniste (2009) describes innovation policies from a STEM (science, technology, engineering, and medicine) bias. He argues that "innovation policy has been based around scientific knowledge and manufactured technologies" (p. 217). Even with the inclusion of other policies, such as education and culture, science and technology remain the central component of innovation policies.

Stoneman and Bakhshi (2009) also argue that innovation in the creative sector takes a different form than in the STEM sector, namely through smaller or inconspicuous changes in the aesthetics of a product design or within the production process. In addition to soft innovation; e.g., innovation in production that is aesthetic rather than functional in nature, as proposed by Stoneman & Bakhshi (2009); there are several other conceptualizations of innovation in the creative sector. Miles and Green (2008) describe hidden innovation, a form of innovation that is hidden from traditional measurements and has no scientific or technological basis. Stylistic innovation, a concept developed by Capetta et al. (2006), describes innovation as a change in the meaning of existing products or changes in aesthetics. Castañer and Campos (2002) understand innovation as the introduction of something new within an organizational field.

Caves (2000), on the other hand, describes innovation in the creative sector as process innovation, a new combination of existing components, whereas traditional innovation is based on costly and goal-oriented intentions to advance or develop technological or scientific innovations. With regard to innovation processes, Pratt and Gornstaeva (2009) distinguish cultural product and process (CPP) innovation from conventional innovation in that it emerges from a more organic development regulated by market structures and institutions, rather than being equivalent to a technological big bang. Within production, CCP innovation is fueled by creative inspiration, whereas on the consumer side, innovation depends on consumer taste (Jaaniste, 2009). After examining the understanding of innovation within the creative sector, Wijngaarden et al. (2016) conclude that innovation is a process and by-product of creative work. Spillover effects on the wider economy does not play a central role. Rather, the focus is on artistic or social goals that allow artists to continue working on their practice. When considering innovation in the creative sector, it is important to "consider it a field-specific process that has value in specific contexts and locations and takes different shapes in different settings" (Wijngaarden, 2016, p. 401). This means that what is perceived as novelty, which stands for innovation, is strongly dependent on the environment and the specific characteristics of the creative field.

2.1 In- and Outputs of Innovation

Robert Lorenz (2010) proposes an Input-Dimensions-Impact framework to encompass different perspectives on innovation. On the input side "innovation starts with an idea, combined with creativity and needs to be backed by an innovation culture, and further

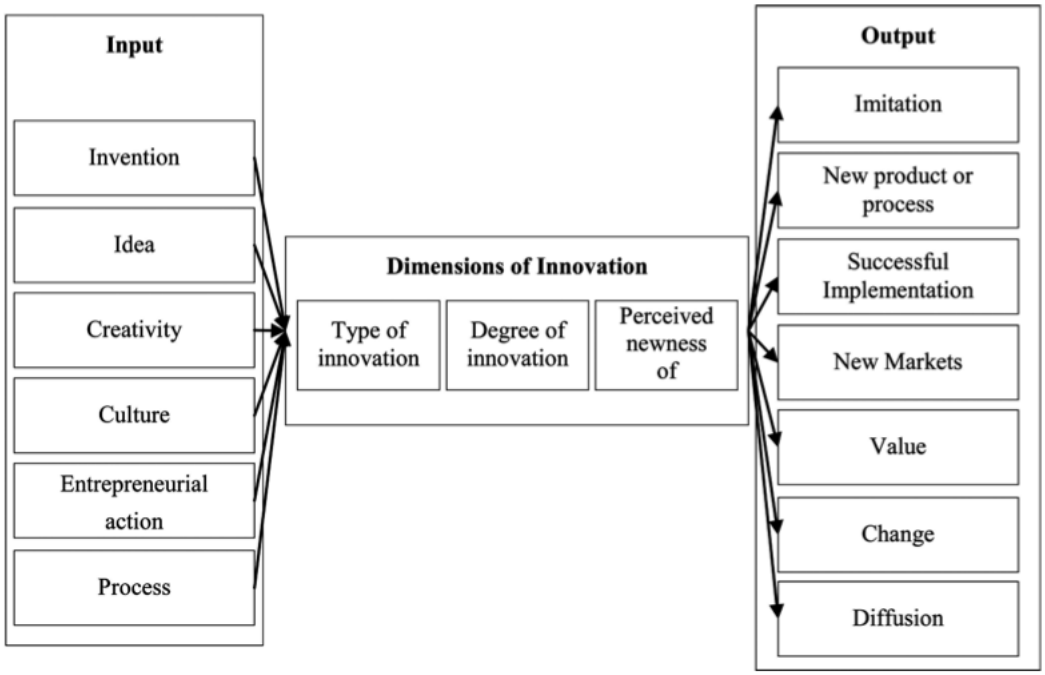
processed with the vigor of entrepreneurial thought from an invention to an innovation" (p. 65). As depicted in Figure 1 innovation consists of the type of innovation, the degree of innovation, and the perceived newness of innovation. Besides the types mentioned in the previous section on defining innovation, seven common types shall be named: (i) product innovation – an improved or new product; (ii) process innovation – an improved or new process or production method; (iii) organizational innovation – implementing a new organizational structure; (iv) business model innovation – developing a new way business is done; (v) social innovation – applying new social patterns of human interaction; (vi) service innovation – in line with product innovation yet focusing on the intangible nature of services; (vii) marketing innovation – developing new methods for marketing products.

The degree of innovation is often described in terms of incremental or radical innovation. While the first refers to improving existing products or services continuously, creating incremental change, the latter refers to "path-breaking changes" that bring transformational change to a whole sector, industry, or market (Green et al., 2015, p. 147). The degree of innovation is further characterized by the familiarity with the used technologies and the potential markets in regard to the innovative output (Lorenz, 2010). The newness of an innovation refers to the subjective perception of the adopting or innovative unit on the innovation (e.g. the consumer or innovator). Hence, the innovation can be new to an individual, and industry, etc. regardless of it being implemented by other units before (Lorenz, 2010).

According to Lorenz's (2010) framework the output can be new products or processes that have been successfully implemented. While innovations can be based on imitation to conquer new markets and create value, they require change and are spread by diffusion. Rogers (2014) describes the steps of diffusion alongside a customer acceptance model. After knowing about an innovation, the potential consumers need to be persuaded by the characteristics of the innovative good. This is followed by a decision on adoption or rejection, the implementation and finally the confirmation of the innovation.

Figure 1

Input-Dimensions-Impact Framework



Note. (Lorenz, 2010, p. 65)

A further dimension that has not been mentioned within the framework of Lorenz (2010) are contextual factors. Wijngaarden (2019) suggests that local networks also need to be taken into account when accessing the source of innovation. Especially in the creative industries, where R&D is not considered the main source of innovation, collaborations, interactions and networks may also spark innovation. The transferal of knowledge is fostered through project-based working (Caves, 2000) as well as interactions alongside the supply chain between buyers and sellers (Roy et al., 2004). Further, proximity is thought to stimulate innovation. By creating an information and communication ecology through face-to-face interactions between different actors a firm's innovativeness may be fostered (Capone & Lazzeretti, 2018). Feldman and Florida (1994) emphasize the role of clusters as a source of innovation. They suggest that clusters mitigate the costs and risks of innovation as they promote information transfer and spillovers. Porter (2000) likewise argues that face-to-face interactions within clusters facilitates the spread of information as well as creates motivation to innovate through perceived pressures by nearby rivals. Information transferal or spillovers are further fostered through the low barriers to entry and surplus of labor within the creative sector, specifically within the design field. "Applying skills

outside the design field is on the rise as design becomes more and more intertwined with different industries" (Lavanga et al., 2021, p. 333)

The type of innovation may also have an impact on the contextual factors, emphasizing the reciprocate relation between innovation and the surrounding system. According to Lorenz and Frederiksen (2008) the type of innovation, produced by the cultural sector is dependent on economic externalities (e.g. localization and urbanization). Which in turn foster the clustering of cultural industries, commonly in global cities. Localization economies refer to positive externalities induced due to proximity to other institutions offering similar products or knowledge. Urbanization economies, on the other hand, are positive externalities that are based upon variety of products and knowledge within a location. Lorenz and Frederikson (2008) differentiate between three types of innovations commonly produced by the cultural sector: variety, novelty, and radical innovation. Through incremental, smaller changes, variety is produced by cultural institutions. These processes profit from localization economies, specifically shared knowledge between different actors of the cluster. Novelty (e.g., innovations that differ from common aesthetics or norms) also happen incrementally yet require knowledge exchange that predominantly happens between actors of a cluster with different specializations or products. Hence, they require urbanization economies and a variety of different industries with spillover effects across the different actors. Products with completely new functions, e.g., radical innovations, rarely emerge. These require both localization and urbanization economies as they combine specialized as well as diverse knowledge into new products and new markets.

Economies of urbanization and localization fall in line with the concept of cultural districts. Santagata (2011) defines a cultural district as "a social and economic experience at the confluence of two phenomena: that of localization […], and that of the idiosyncratic (peculiar, unique) nature of culture and cultural goods" (p. 147). They can be characterized by a geographical agglomeration of cultural firms that benefit from positive externalities through proximity to each other. Proximity, in turn, fosters interaction which enhances innovation and knowledge creation (Lavanga, 2020). This might be applicable to the digital fashion ecosystem. The case of The Fabricant, and its market breakthrough in 2019 may be understood as a radical innovation, which was made possible by context-specific factors such as the existence of a cultural cluster or economies of localization and urbanization.

As mentioned in the introduction, the fashion industry, like other industries, is undergoing a fourth industrial revolution. The introduction of digital technologies in production, in the products or services themselves, and in communication between actors may have far-reaching changes on the role of local proximity in relation to the ecosystem. Busch et al. (2021) investigate the characteristics of digital urban production. With regard to the role of proximity, the study highlights three propositions: (i) Despite digital communication options, proximity to consumers is essential for establishing feedback loops. (ii) Local proximity to skilled workers who are concentrated in urban areas is important for digital urban production, e.g., IT specialists in particular. (iii) In order to offer tailor-made solutions, local proximity to urban knowledge institutions is essential and cannot be replaced by digital alternatives. Although these propositions also depend on which digital products are produced (Bausch et al., 2021), they could potentially be transferred to the digital fashion sector. This is particularly true if digital fashion is understood in a broader sense as an optimization tool, as was partly interpreted in the literature review (see section 1.1 Design).

2.2 Diffusion of Innovation

Another crucial aspect regarding the diffusion of a good or service is the network effect. Generally, network effects describe the change in utility of a good depending on a change in number of users. Liebowitz and Margolis (1998) differentiate here between the autarky value, generated by the product itself independently from its user, and the synchronization value. The latter is dependent on the possibility to interact with other users of the same product. One further differentiates between direct and indirect network effects. Direct effects come into play when the number of users of a specific product increase. An example from the digital fashion would be the use of virtual fashion platforms, like DressX. The more users consume virtual fashion through their platform the bigger the utility of showcasing or wearing virtual fashion. Indirect effects, on the other hand, are mediated by the market and occur when complementary goods grant new possibilities to consume or use the product. Here the development of VR-tech such as VR-glasses can have a positive effect on the utility of virtual fashion as it complements and makes the use of virtual fashion more appealing and accessible to others. Both examples refer to technological network effects. Arthur (1996) describes these as operating on the consumer as well as the supplier side. The more users use a given product, the more suppliers can offer applications for it, creating a positive feedback loop. Focusing more on the consumer

side, socio-psychological network effects come into question. Kretschmer et al. (1999) explain these, on the one hand, through human behavior, basing their purchase decision on information passed down by previous users of a product (e.g. information cascades) and on the other hand, through the general benefits from being able to share social experiences by using a common good. These socio-psychological effects in turn accelerate the demand for, specifically cultural goods as their utility is context dependent making them an experience good, and spread through social contagion.

Specifically in digital fashion, diffusion of innovation may be accelerated through eWOM (electronic Word of Mouth). Social media influencers can be considered as fashion opinion leaders (Zhou et al., 2019). Through virtual garments they gain the opportunity to present themselves in various identities by using digital products within cyberspace instead of physical representations in the real world. Fashion opinion leaders play a central role in the adoption and diffusion process. They contribute to faster and broader spread of fashion trends, help legitimize new styles, and serve as key sources of information (Workman & Johnson, 1993).

A different perspective on the diffusion of innovation is taken on when observing the strategic diffusion of transformational change. Von Wirth et al. (2019) argue that there are three ideal diffusion processes to be observed. Firstly, embedding refers to the integration of a design, approach or idea in already existing structures. This, for instance, involves the adaptation of a new technology or combination with existing institutions to give context and meaning to said technology. Secondly, translation or horizontal diffusion describes the strategy of replicating or reproducing an existing concept, design or idea, in a different context. For instance, replicating an innovative business model for on demand production in a new location. Lastly, scaling refers to scaling up an original idea or concept that was produced on one scale (e.g., providing virtual fashion to regular fashion consumers) to another (e.g., providing a virtual fashion design tool, to incorporate fashion designers).

2.3 Three theoretical frameworks

Just as within cluster theory there are different actors that are commonly linked through a network of knowledge transferal, different actors fostering innovation can be understood as part of an innovation system. Within innovation research, there are three different theoretical frameworks that are frequently used. To guide the analysis and map out the innovation system surrounding digital fashion, these approaches are an important

component for better understanding their dynamics, and how they function. Based on a systematic literature review by Coenen and Díaz López (2010), the three approaches will be briefly described below.

The three conceptual approaches established within innovation research that systematically examines innovation and takes on different perspectives on actors, structures, and dynamics are: sectoral innovation systems (SSI), technological innovation systems (TIS), and socio-technical systems (ST systems). All three analyze innovation as a network phenomenon, yet differ in their thematic focus, the system boundaries they consider, and their objectives.

SSI focuses on product groups within specific sectors and emphasizes the role of companies as central actors. Transformation is understood here as an incremental, evolutionary process that is strongly linked to existing market structures and institutional frameworks. TIS, on the other hand, situates specific technologies at the center of its analysis. It also sees companies as key players, but attaches greater importance to the dynamics of innovation functions such as knowledge diffusion, market development, and legitimacy building. Both approaches view knowledge as a tradable resource and evaluate innovation according to economic criteria.

In contrast, ST-systems broaden the view to include social functions such as mobility or energy supply. They analyze technological transitions, for example, and consider not only economic but also social and cultural aspects of innovation. In doing so, they focus more on the diversity of actors, social learning processes, and institutional change. Innovation is understood here as the result of co-evolution between technology and society, in which not only companies but also user groups, social movements, and political actors play a role.

While SSI and early TIS primarily target competitiveness and industrial development, newer TIS approaches and ST systems increasingly address sustainability issues and green transformations. Despite their different focuses, all three approaches show that innovation processes are shaped by complex interactions between actors, knowledge, institutions, and networks. According to Coenen and Díaz López (2010), an integrated view of these perspectives can help to understand innovation systems more comprehensively and design them more effectively. A system approach to researching innovation systems further dictates the type of sampling necessary to fully grasp the system's complexity. Hence, diverse actors within that system need to be considered. This also falls in line with cluster theory within creative industries. As CI rely on urbanization

and localization economies, actors with specialized as well as diverse knowledge surrounding the system's core need to be taken into account.

3 Sustainability

This section focuses on the concept of sustainability and presents a few definitions. While the buzzword "sustainability" is used in many places, it is in danger of losing its meaning (Throsby, 2019). On one hand, the term offers a lot of room for interpretation. On the other hand, the processes necessary to stimulate sustainable development are usually formulated in somewhat vague terms. After introducing the concept of sustainability, this section will take a closer look at sustainability within the fashion industry. As the fashion industry ranks second among the most environmentally damaging industries (Pugh et al., 2024), sustainability plays an essential role in transforming the industry for the future. Concepts such as the circular economy and the well-being wardrobe, which set the tone for the industry, will be presented here. This will be followed by a discussion of the drivers and barriers to sustainable development and, finally, the potential role of digital fashion will be presented.

3.1 Defining Sustainability

As early as 1995, cultural economist David Throsby argued that economic systems and cultural systems should be understood as a unified system. This consolidation stems from the understanding of cultural assets as cultural capital. The tangible and intangible assets created by artists contribute to cultural value that can also generate economic value. This cultural capital gives rise to the need to administer or manage the capital, comparable to other natural resources available to a community or nation. It is precisely in this management function that Throsby (2016) sees the possibility of applying a sustainability framework. With growing awareness of the environmentally damaging effects of economic growth, the concept of sustainable development initially focused on a future-oriented approach that would "meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 43). From this aspiration, the term ecologically sustainable development (ESD) was coined, which combines biological, social, and economic components into a holistic system and takes their interdependencies into account. Derived from this framework, Throsby (2019) conceptualizes culturally sustainable development (CSD). This concept is based on five

principles that describe the important components that sustainable development should demonstrate in the cultural sector:

- (i) **intergenerational equity:** a long-term perspective that takes into account both present and future generations and their interests
- (ii) intragenerational equity: within a community, access to cultural capital must be provided equally to all members of that community
- (iii) **importance of diversity:** cultural diversity plays just as important a role in sustainability development as biodiversity does in environmentally sustainable development
- (iv) **precautionary principle:** a risk-averse position must be taken when decisions about the destruction of cultural capital, such as cultural heritage, have to be made
- (v) **interconnectedness:** economic, social, cultural, and environmental systems must be understood as a single entity that is interdependent. Cultural and economic development are particularly closely linked in this regard.

These five principles can be used to assess whether cultural capital is being managed sustainably. The last principal in particular underpins the fundamental necessity to perceive sustainability not in isolation within a single system (e.g., the economic or ecological system) but as intertwined within all the aforementioned systems.

Similar to Throsby's holistic approach to sustainability, Guattari's (2000) model of the three ecologies lays out a framework under which sustainable development can be dissected and evaluated. In this framework the three dimensions (e.g., ecologies) of environment, human relations, and human subjectivity are transversely related. The environmental ecology refers to natural resources, our planet, and the environment. The social ecology encompasses the human and social relations, society, and hierarchies. Finally, the mental ecology reflects upon the human desires, subjectivity, self-esteem, and inner capabilities. Guattari (1990) coins the currently unsustainable way of life as the Integrated World Capitalism (IWC). It is characterized by competitive individualism, medialization, and consumption. Furthermore, lifestyle industries driven by norms around health, well-being, meaning, and productivity are closely tied to individuals' self-esteem. According to this reasoning, the IWC is responsible for unconscious desires that propel consumer capitalism and a continuous demand for ever more consumption. To address this problematic behavioral pattern, it is crucial to address all of the ecologies simultaneously and not in isolation. Linking this framework with the fashion industry and its attempts to

become more sustainable emphasizes that sustainable initiatives must be distributed equally across the three ecologies (Von Busch, 2022). Hence,

> Industry change and circularity, must be linked with mitigation of social conflict in the dimension of human relations, decolonial practices, and affect-based perspectives on fashion. These initiatives, in turn, could align with the remodeling of fashion in the dimension of subjectivity, by the promotion of user agency, self-esteem, and 'fashion-abilities' (von Busch, 2022, p. 408)

Since Throsby's (2019) concept of CSD has established itself as the dominant one in sustainability research, this approach is also used in this study to analyze digital fashion in terms of sustainability. Guattari's (2000) three ecologies are not excluded but can also be found in the CSD model.

3.2 Sustainability & the Fashion Industry

The fashion industry, or also referred to as the fashion system, is a complex system that encompasses "diverse activities that allow for the creation, production, distribution, and consumption of fashion" (Buchel et al., 2022, p. 231). It is furthermore characterized by its linear model of take, make, and waste (e.g., the harvesting of materials, the production of garments, and the wearing and disposal of garments) (Brydges, 2021). The industry, however, has faced increasingly backlash for limited social, and environmental considerations. Hileman et al. (2020), for instance, highlight the asymmetric distribution of power within the industry's value chains just as Peters et al. (2021) emphasize that the fashion industry is one of the largest polluters in the world. While the fashion industry has undergone drastic changes through "innovation in global supply chains, lean retailing, and […] digitization" (Brydges, 2021, p. 1), and through efforts to facilitate more sustainable practices within the industry, a transformative change towards sustainability is remaining a pie in the sky (Buchel et al., 2022). One reason for the industry's resilience to sustainable change may lie in the complexity and fragmented nature of the fashion value chain (Beard, 2008).

The concept of circularity, a framework for a closed-loop economy, has become increasingly prominent. The Circular Economy (CE) aims to transform the aforementioned linear model of production processes into a circular or closed-loop model (Brydges, 2021). Research on CE has shown that it might provide opportunities to decouple environmental

threats from economic growth (Elia et al., 2017). Examples for CE approaches within the fashion industry are clothing swaps, second-hand shopping, repair services or material recycling. However, these initiatives are prominent within the last stages of the production model, namely waste. While waste-reduction is crucial, an overemphasis on just one stage cannot make up for the impact created at the remaining stages. Additionally, actions taken at one specific stage of the supply chain, have an impact on other stages as well due to their interconnectedness (Bick et al., 2018). Initiatives at the other two stages are for instance sourcing biodegradable fibers within the take stage or applying a design-oriented approach to increase value and longevity of the garments during the make stage (Brydges, 2021).

Another tool to promote a just transition of the fashion industry towards sustainability is the Wellbeing Wardrobe. While the current fashion industry is based on high-volume and low-cost production (Pugh et al., 2024) redirecting its pursuit towards a wellbeing economy could tackle social, environmental, but also economic hazards. A wellbeing economy's aim is to foster "fairness and equality, good social relationships as well as human mental and physical health, and a thriving environment" (Pugh et al., 2024, p. 229). Andreoni & Galmarini (2014) further characterize it as centered around principles of community, conviviality and reciprocity. Pugh et al. (2024) identified five key aspects that play an essential role in establishing a wellbeing economy. (i) establishing limits, (ii) establishing new indicators to incorporate wellbeing, (iii) promoting fairness on a global and intergenerational plane, (iv) establishing just governance, and (v) establishing new exchange systems that go beyond profit margins and sales growth. Through these five key elements, a just transition can take place that balances out the unequally distributed burden of future costs and benefits that come with transitioning a truly global fashion system. For instance, reducing carbon emissions within the production stages will disproportionally affect parts of the supply chain that is associated with textile manufacturing which is commonly situated in the Global South (Dominish & Sharpe, 2021).

In addition to the obstacles and opportunities for making the fashion system sustainable already mentioned, further factors that can influence sustainable development will be discussed in the following. One external factor that can support the implementation of circularity is, for example, spatial and non-spatial proximity (Kim, 2024). Non-spatial proximity refers to cognitive, organizational, social, or institutional links that can exist independently of physical proximity. Both types of proximity influence the exchange of knowledge between various stakeholders and actors within a system, which is essential for

promoting sustainable innovation. Spatially organized proximity in particular seems to be an effective way to exchange implicit knowledge, build relational trust, and reduce uncertainties in the production, distribution, and consumption of cultural products such as fashion (Kim, 2024).

As the current fashion industry is stuck in unsustainability, a collaborative approach is important to drive systemic change and scale innovation (Buchel et al., 2022). This is mainly due to the fact that, alongside the dominant fashion regime, there are niches that only exist under certain conditions. According to Buchel et al. (2022), these niches have the potential to change the existing regime or to be co-opted by it. Within the current fashion system, agility in the value chain plays a central role. The fashion market is typically defined by short product life cycles, high volatility, low predictability, and high impulse purchasing (Christopher et al., 2004). In order to meet this highly volatile and rapidly changing demand, value chains must move away from forecast-driven supply and instead focus on market sensitivity, virtual integration through, for example, co-managed inventory through cooperation between various actors in the supply chain, networked logistical systems, and process alignment.

Of course, external factors such as a changing economic situation, political interference, or global crises such as pandemics or the climate crisis also play a significant role (Buchel et al., 2022). In addition to the factors already mentioned, such as linear take-make-waste models or the focus on individual stages of the product life cycle when implementing sustainable approaches, consumer behavior must also be taken into account. For instance, a lack of environmental awareness can limit demand for sustainable fashion, which is then determined solely by moral values (Blas Riesgo et al., 2023). Even if these moral values can be used as an instrument for change, it should be noted that the sustainability movement should not be disproportionately ceded to socially disadvantaged groups. Von Busch (2022) argues that the rhetoric surrounding sustainability is often accompanied by moral finger-pointing at poorer classes of society. Not only does this fail to recognize the systematic problem, it also perpetuates systemic inequalities.

3.3 Digital Fashion & Sustainability[1]

As environmental and social concerns around the fashion industry grow, fashion consumption is undergoing transformation. Schauman et al. (2023) identify a shift toward

[1] This section is partially based upon an essay written by myself for the course on Econ. Of Fashion and Sustainability (CC4119) taught by Dr. M. Lavanga at Erasmus University. Graded: 8.4

sufficiency, modeled along the dimensions of excitement, utility, relatability, and circularity. Consumers increasingly practice mindful consumption, seek pragmatic value, desire guilt-free pleasure, and recognize their systemic embeddedness, aligning individual choices with broader environmental goals. In this context, digital fashion can be perceived as a potential enabler of sustainable consumption. However, the hype around digital fashion, NFTs, and the metaverse has declined post-pandemic. As Mason Rothschild remarks, "digital fashion doesn't have much intrinsic value. […] Nobody's going to spend money on digital clothes if they don't have the physical version" (Kotsoni, 2024, para. 12). Wagner and Kabalska (2022) further question whether digital fashion creates equivalent value for consumers, given its immaterial nature, even though it allows fashion firms to save on material costs and reduce emissions.

Beyond digital garments, digitization has an impact on the supply chain as discussed in the previous section on digital fashion. While Huynh (2021) has outlined three circular business models, enabled through blockchain technology, limitations persist. Recycling remains problematic due to toxic emissions in textile processes (Huynh, 2021). On-demand production may reduce waste, but degrowth requires mutual commitment from consumers and suppliers (Pugh et al., 2024). De Koning et al. (2024) also caution that merely increasing sustainable alternatives may fall short without systemic change. Additionally, the complexity and rigidity of global supply chains may hinder the benefits of agility through automation (Christopher et al., 2004). From a social sustainability angle, digital solutions often overlook accessibility issues linked to digital literacy, challenging the notion of intergenerational equity (Throsby in Pugh et al., 2024). Without a just transition, digital transparency may risk reducing complex issues to mere data, reinforcing surveillance and shifting blame rather than addressing structural injustices (Von Busch, 2022).

4 Summary of the Theoretical Framework

Before outlining the methodology, this section summarizes the theoretical framework. The first part defined digital fashion as a multifaceted concept, involving not only the marketing and communication of both tangible and intangible fashion products, but also the implementation of digital processes that drive industry innovation an influence societal behavior. The literature review mapped the academic landscape and pointed to significant gaps. Particularly, the need to understand digital fashion as an innovation system and to examine its real-world relationship to sustainability beyond theoretical promise.

The second section focused on innovation. Traditional innovation theories; often rooted in STEM fields; fail to fully capture the dynamics of the cultural and creative industries, where value creation is nonlinear and context specific. To address this, tailored definitions for the cultural sector were presented and discussed. Lorenz's (2010) input-dimension-impact model served as a starting point, later expanded through concepts such as spatial proximity, local networks, knowledge exchange, and cluster theory. The diffusion of innovation was explored via network effects, opinion leaders in fashion, and strategic diffusion models. Finally, three frameworks; SIS, TIS, and socio-technical systems; were introduced to better understand innovation ecosystems. The flexibility of the latter two approaches, especially ST systems, supports a broader interpretation of actors and innovation dynamics relevant to this research.

The final section addressed sustainability. Drawing on Throsby's (2019) cultural sustainable development and Guattari's (2000) three ecologies, sustainability was framed holistically; economically, ecologically, culturally, and socially. The fashion industry was then analyzed through this lens, with circular economy strategies and the wellbeing wardrobe concept presented as practical entry points. Digital fashion was critically examines in this context. While it holds potential for more sustainable practices, it also risks reinforcing existing unsustainable systems through mere optimization. Moreover, digital fashion is not inherently sustainable. Issues like energy-intensive technologies and digital exclusion pose ongoing challenges.

Methodology

After providing a theoretical background on the field of digital fashion, presenting frameworks for analyzing the innovation system as well as processes of innovation, and addressing crucial concepts of sustainability regarding the fashion industry, this section will provide an overview on the methodology of this thesis. The research method, and design will be outlined, followed by an outline of the units of analysis, and finalized by insights onto the operationalization as well as on the data analysis.

1 Research and Method Design

The main objective of this research is threefold. First, it aims to provide an understanding of how digital fashion is articulated and applied in practice by individuals working with digital fashion (RQ 1-2). Second, the digital fashion system shall be mapped out through investigating key stakeholders, institutions, drivers and barriers to innovation, as well as dissecting innovation processes that take place within the system (RQ 3-5). Finally, the concept of sustainability in regard to digital fashion is under investigation, as it is often presented as inherently linked to digital fashion. The nature of this relation shall be observed and analyzed (RQ 6-7).

These main objectives can be summarized through the following research questions:

- RQ1: How do practitioners / experts within the field define digital fashion?
- RQ2: How do practitioners / experts understand innovation within digital fashion?
- RQ3: How can we map out the system of digital fashion?
- RQ4: What are the dynamics as well as processes of innovation within the system of digital fashion?
- RQ5: What are drivers and barriers to innovation in digital fashion?
- RQ6: What is the relation between sustainability and digital fashion?
- RQ7: To what extent is digital fashion providing sustainable solutions for the broader fashion industry?

The research was mainly contextualized within the Netherlands. Since the newer TIS-approaches and the socio-technological system approach however does not limit an innovation system to national or regional borders, the context was broadened to neighboring countries, such as Germany, the UK and Belgium.

As this research aims to understand nuanced motives of experts on innovation, their understanding of digital fashion and its relation to sustainability, a qualitative research method was selected as the most appropriate to execute research on this matter. A quantitative approach to gaining in-depth answers to the previously mentioned research questions would present a limitation. Bryman (2012) underlines the importance of the research design being in line with the objective of the research. Hence, a qualitative method which encompasses deductive as well as inductive reasoning can be deemed suitable. This research is based on and embedded within existing research on digital fashion, innovation systems, and sustainability. While it provides the opportunity to test the accuracy of pre-existing theories in the context of digital fashion, its main objective is to develop an understanding of the developing field of research on digital fashion.

2 Units of Analysis and Sampling

The digital fashion system is at the center of this research project. The Netherlands provide an excellent starting point for this research as The Fabricant, and Amsterdam-based formerly digital only fashion label, was perceived as a pioneer in developing the market for digital fashion. After its initial great success, the environment surrounding digital fashion changed, as did the company and the system behind it. It is therefore reasonable not to limit the scope of this study to the Netherlands alone. Initial research also quickly revealed that the digital fashion community is internationally networked and does not seem to adhere to national or regional boundaries. Geographically, however, the study was ultimately limited to Central Europe, with a focus on key figures from the Netherlands and other players from Germany, Belgium, and the United Kingdom. This is due to limited access to international key actors as well as a deliberate decision to narrow the scope of the research to provide evidence for or against an existence of regional/national borders within the innovation system. Purposive sampling and snowball sampling were used to reach experts in digital fashion and recruit them to participate in the study. Initially, potential participants were contacted through research on portals such as LinkedIn. In addition, research institutes such as the Willem de Kooning Academy Rotterdam, Amsterdam Fashion Institute (AMFI), and the Design Academy Eindhoven were also points of contact for initial inquiries. Furthermore, Dr. M. Lavanga's network was utilized, which provided contacts to experts within the digital fashion system. Overall, 38 emails were sent resulting

in 11 participants. An overview of the participants is provided within the following section on data collection.

Participants were selected based on their involvement in digital fashion. Their involvement can range from practicing digital artistry as a 3D or digital designer, technology provider for digital fashion, researchers of the field of fashion tech and digital innovation as well as individuals that provide insights into the market for digital fashion through innovation consultancy for fashion brands. As investigating the practiced understanding and application of digital fashion is one of the main objectives of this thesis, a range of perspectives from different actors within the system was crucial here.

3 Data collection

Between April and June of 2025, semi-structured interviews were conducted to gather data. The majority of the interviews were conducted online, ranging between 1h to 1.5h in duration. Some of the interviews were complemented by further answers via mail. One participant was not able to participate in a face-to-face interview and provided answers via email. Their interview duration is hence based upon an estimation. In total, a little more than 12h of interview footage was collected.

Five of the interviewees had a background in design, whether that be graphic or fashion design. The other interviewees showed a variety of educational backgrounds, from pharmacology, physics, to economics and media communications. Table 1 provides an overview of the participants, their sex, occupation or current role, as well as information on interview form, duration and date. Further information about the country in which they are currently active is also listed. Except for one interviewee, all participants were actively involved or connected to digital fashion in some shape or form. Interviewee 2 was the only participant who considered themselves as no longer active in digital fashion. Interviewee 2 was formerly involved in digital fashion through research on AR and its possibilities in digital fashion, which made them an insightful participant regardless of their current occupation outside the world of digital fashion.

Table 1

Overview of Interviewees

	Sex	Education	Occupation/ Role	Country	Interview form	Interview Duration	Date
Interviewee 1	F	Graphic design	Digital Fashion artist	United Kingdom	Written	10min	22.04.25
Interviewee 2	M	IT/computer science, interaction design in the media sector	Pioner in AR Implementation	Netherlands	Online	1h13min	15.04.25
Interviewee 3	M	Pharmacology	Head of Content and Editor for Consultancy in innovation, technology, and fashion	Netherlands	Online	1h29min	09.05.25
Interviewee 4	M	Computer science and marketing, digital innovation with a specialization in IT security	Project Manager at Innovation fashion Hub	Germany	Online	1h	14.05.25
Interviewee 5	M	Fashion design	Consultant for digital innovation in fashion	Belgium / United Kingdom	Online & Written	1h33min	05.05.25
Interviewee 6	D	Graphic design	Freelance 3D artist and Art Director	Germany	Online	1h07min	23.04.25
Interviewee 7	M	Graphic design and design research	Research in Digital Communication of arts and culture	Netherlands	Online	1h26min	25.04.25
Interviewee 8	F	Tailoring apprenticeship and fashion studies	Freelance digital fashion designer & Lecturer at AMFI	Netherlands	Online & Written	1h06min	26.04.25
Interviewee 9	F	Cultural Economics	Project Developer working on digital solutions for luxury fashion brands	Netherlands	Online	1h	27.05.25

Interviewee 10	M	Chemistry and Physics	Entrepreneur in Fashion-Tech Startup	Netherlands	Online	1h12min	30.05.25
Interviewee 11	F	Media Communications and Commerce	Digital Product Developer & Consultant	Netherlands	Online	1h	06.06.25

As is customary for semi-structured interviews, most questions were open-ended. Follow-up questions were often asked to deepen understanding of the interviews. These helped to examine motives and personal perspectives in greater detail. The interview questions are conceptualized in more detail in the following section on operationalization. However, it should be noted that the interviews were structured around four topics. The interviews began with questions about the interviewees themselves, their educational and professional backgrounds. This led to questions about their understanding of digital fashion, their personal experience with it, and a description of the system behind it. The third component consisted of questions about innovation, which transitioned into the topic of sustainability. This division helped to maintain an overview during the interviews and gave the interviewees the opportunity to respond to questions in detail without having to constantly switch between topics.

4 Operationalization

Based on the literature reviewed in the previous sections, an interview guide was created that aims to explore individual definitions, approaches and practices regarding the three main topics of this research. The interview guide is provided within the Appendix B. Further questions were added during the interviews, depending on the individual's unique perspective on the matter. The interview was structured around four main sections which will be discussed in the following part.

Background

The interview started off with questions regarding the interviewees background. It served as a gateway into the conversation and allowed for gathering data on the interviewees educational background, their motives behind choosing a career that is related to digital fashion or fashion innovation, and finally how they ended up in their current position. This information is important to differentiate potentially differing perspectives on the main

subjects of this research but also help to better define the relatively young sector of digital fashion.

Digital Fashion

The second section is characterized by questions that primarily gather data on the interviewees' understanding, definition of, and involvement in digital fashion. Since the interviewees were selected on the requirement of being involved in digital fashion, their understanding, definition, and also their nature of involvement differed drastically. As observed through the literature review on digital fashion, technological applications play a key role in defining digital fashion. Hence, questions about what types of applications the interviewees use or are aware of were added. A second set of questions was directed towards describing the system behind digital fashion. After asking on the general characteristics of the digital fashion system, questions on key actors, groups, institutions, technology providers, intermediaries followed. These were then supplemented by questions that aim to understand the dynamics within the system and between the previously mentioned key actors. As innovation systems can be understood as a social system these insights grant access to a better understanding of the environment that the digital fashion system is situated in. Furthermore, inferences can be drawn from the dynamics within the system regarding information diffusion and how the sector is developing. For instance, whether network events like art fairs play a role for digital fashion practitioners or if the nature of their information exchange is happening through different platforms than for traditional fashion practitioners. After the first couple of interviews, questions concerning the development of the digital fashion system were added. It became apparent that the system was changing drastically through external factors such as the Covid-19 pandemic, the introduction of NFTs and the later plummet of interest thereof, as well as the development of Artificial Intelligence (AI). This section was then closed with questioning the motives behind the development of digital fashion. Whether it is driven by technological change, creativity, representation, accessibility, sustainability or a combination of several of them.

Innovation

This set of questions was again introduced with a personal definition or understanding of innovation. It stands in relation to the research by Wijngaarden et al. (2016) who were interested in finding commonalities as well as differences of defining innovation between

actors within the cultural and creative sector and the prominent STEM-sector. After agreeing on the interviewees' definition of innovation further questions followed on the different types of innovations that emerged, whether they were product or process innovations, new business models, social or organizational innovations. Referring to the inputs and outputs of innovation the interview guide provided a question to investigate what is driving innovation in digital fashion, as well as what may constitute as a barrier to it. Before delving into the processes of innovation, the interviewees were asked which innovations they were personally involved in or contributed to. This question mainly helped to keep focus on the following questions on different processes and the innovations that were mentioned here were intended to serve as examples. The questions ranged from dissecting the developing stages of new ideas, the implementation and trial of new products, ideas, or processes, up to the diffusion of innovations. Again, a focus was set on the dynamics and possible obstacles along the way. Not every interviewee was able to answer the sub-questions on processes of innovation as they were active within different steps along the development, implementation, or diffusion of innovation. Hence the results may have led to a fragmented representation of these processes.

Sustainability

The final segment of the interview was focused on sustainability. As within then previous segments, the initial question asked about the individuals' personal understanding of sustainability, and what sustainability means in the context of digital fashion. The interviewees' initial answer often gave away whether they understand sustainability regarding the environment only, or whether they had a broader definition of the concept. The second half of the initial question was often followed by examples of sustainable processes that come with digital fashion. In order to understand the relation between sustainability and digital fashion, the interviewees were asked to what extend digital fashion can contribute to a more sustainable fashion industry. The aim was to understand whether digital fashion holds the capacity to bring systemic change or provide incremental solutions. To give space to potential criticism, the interviewees were also asked about possible tensions they might perceive when combining digital fashion and sustainability. Since there might be differing definitions of digital fashion, the second half of this segment was then focused on innovations and sustainability. The interviewees were asked about specific innovations in the field of fashion and digital fashion, that already contributed to greater sustainability and what they perceive as the most important contribution to

sustainability efforts so far. In addition to that, the interviewees were asked to give their personal future outlook on sustainability within the fashion industry and what innovation and/or digital fashion could contribute to achieve that ideal. Lastly, specific barriers and enablers to sustainable innovations were examined. These could encompass external factors such as awareness, change in policy, economic change and specific institutions equally.

As briefly mentioned before, not every interviewee was able to answer all the questions, or some questions had to be tweaked in order to better align to their specific role or perspective on digital fashion, innovation, and sustainability. An overview of the questions can be found in the Appendix B.

5 Data analysis

The data analysis was conducted during the last stages of gathering further data through interviews. Thematic analysis was selected as the method of analysis. This method allows for a deductive and inductive coding approach. Hence, a multi-stage process of coding and categorizing was applied. The recorded interviews were automatically transcribed, aided by the transcription tool provided by Microsoft Teams. The transcripts were subsequently checked and edited manually. Afterwards, interview transcripts were processed through open coding supported by Atlas.ti and ultimately analyzed. After initially reading through the transcripts important themes were highlighted in accordance with the theories discussed within the theoretical background, laying out the groundwork for the codes used in the following steps. Thereafter, words and quotes were assigned codes. These were thereafter reviewed again and presented as findings. The multi-stage process of developing categories, highlighting themes and expanding them is crucial to mitigate concerns on reliability as thematic analysis poses the risk of overlooking key pieces of data (Braun & Clarke, 2006). An overview of selected codes, as well as their relations between categories can be found in Appendix C. In order to report on the findings of this research, representative quotes were selected to highlight important arguments and visualize patterns within and between interviewees. The findings of this analysis are presented in the chapter below and further include topics that were deemed important by the interviewees.

6 Reliability and Validity

While reliability and validity of qualitative research has often been criticized for its lack of generalizability (see Babbi, 2008; Bryman, 2012) the design of this study was chosen carefully in order to restrain limitations. This study employed a qualitative case study approach. Case studies are particularly well-suited to exploring emerging or insufficiently studied topics, as they provide a nuanced and in-depth understanding of complex phenomena (Denzin & Lincoln, 2012, p. 1455). In order to map digital fashion onto an innovation system and dissect their innovative efforts, also in terms of sustainability, it is crucial to explore underlying reasons and processes by which individuals and organizations adopt specific principles and practices. Engaging directly with those who navigate these challenges on a daily basis provides valuable insights into their experiences and decision-making (Brydges, 2021, p. 3). Furthermore, reporting on sampling, data collection, operationalization, and data analysis provides groundwork to increase the reliability of this research.

Findings & Analysis

The reporting of the findings and analysis from the data gathered through interviews will follow the same structure as the theoretical framework. Each section: (1) digital fashion, (2) innovation, (3) sustainability, will be initiated with a descriptive outline of the findings. Subsequently, these findings will be interpreted and analyzed based upon the theories formerly introduced. Findings that may not align with theories previously mentioned will also be added here as they provide valuable insights into potential gaps within the academic literature.

1 Digital Fashion

The first component of this research is to examine which definition of digital fashion prevails within the system surrounding digital fashion. As already indicated in the methodology section, this study did not only include people who work directly with digital fashion, but also those who conduct research in this field or specialize in education or innovation promotion specifically related to digital fashion. It is therefore not surprising that there is no uniform definition of digital fashion among the interviewees. Interviewee 8 explains digital fashion as a concept that challenges the existing understanding of fashion. “Digital fashion is more than just clothes on a screen, it's a completely different way of thinking about what fashion can be” (Interviewee 8). Interviewee 8 also points out that there is only a vague distinction between digital and physical fashion.

“What is actually the difference when I make a dress on my computer and show it digitally, or somebody that makes a dress physically and takes a photo of it [to] present it digitally” (Interviewee 8).

Since, from their perspective, digital fashion cannot be defined by a clear differentiation from physical fashion, the concept is understood as an “exploration of identity.” In a practical sense, digital fashion encompasses virtual skins, AR filters, the use of AI, production processes, and customization (Interviewee 8). While interviewee 7 agrees with this identity-forming definition in the broadest sense, he adds that digital fashion can also be seen as a medium used for communication and thus considered an artistic practice. Contrary to this, digital fashion was also defined as a pure tool. Interviewee 5 differentiated here between the fields of fashion design and digital art. In the

context of fashion design, digital fashion is exclusively considered a tool that changes work processes but also brings about systematic changes, such as a sustainable transformation of fashion design. Interviewee 3 clearly emphasizes the ambiguous definition of digital fashion.

"I think in the traditional sense of what I would think of when I read the term [digital fashion], I would assume that people were mainly talking about creating a digital-only piece of clothing. [...]. I would say the much bigger part is digital fashion in the sense of using digital technologies to digitize part of the product creation process within a physical brand with the end goal of still creating a physical garment" (Interviewee 3).

These different perceptions of digital fashion can be grouped into three perspectives which can be linked to the individual career and educational backgrounds of the interviewees.

Interviewees with a more traditional fashion background (e.g., Interviewees 5 and 8) saw digital fashion as a practical tool for improving and increasing the efficiency of the existing fashion industry. This optimization was interpreted either in terms of sustainability or process optimization. They focused on closing the gap between traditional and digital ways of working and adapting specialist training (e.g., fashion design) accordingly.

People with a digital or creative-technological background (Interviewees 1, 2, 6, 7), on the other hand, saw digital fashion as an independent, expressive medium for artistic development, identity exploration, and new experiences. It, therefore, offers the opportunity to break free from the conventions of physical fashion and the system that goes with it. Their focus was often on creating new digital tools or experimenting with existing technologies.

Interviewees from system-oriented, economic, or broader digital fields (Interviewees 3, 9, 10, 11) understood digital fashion from a strategic and commercial perspective. They emphasized its potential for efficiency, cost reduction, and market expansion, while often realistically assessing the challenges of mass adoption and profitability. Their focus was on the impact of digital tools on the entire fashion system and consumer behavior.

While everyone recognized the benefits of digital tools, the focus varied considerably, ranging from the optimization of traditional processes to the artistic redefinition of fashion and strategic market development.

1.1 Actors and Dynamics

Another dimension of this analysis is the exploration of key actors of digital fashion and the dynamics between them. This analysis goes hand in hand with the later investigation of the innovation system surrounding digital fashion. It shall be mentioned that digital fashion *community* and digital fashion *system* were used interchangeably. During the interviews, participants were asked about key actors or institutions within the digital fashion *community*. This wording was deliberately chosen so as not to influence the participants' answers. Questions about a *system* might have led to a greater focus on corporate and official actors, rather than also considering informal participants in digital fashion. Hence, the following description of the digital fashion community refers to the actors and dynamics of the digital fashion system.

"I would describe the digital fashion community in the Netherlands, [...] even worldwide, as a very tight-knit community. I would say that every time I go to an exhibition or an opening about digital fashion, it's usually kind of the same people" (Interviewee 7).

Currently, it is a small but diverse community. Active members of this community come from a variety of professional backgrounds.

"I would say most of them are young. Some of them come from a fashion background, some of them from a more product or visual effects background. [...] In the end, they're all kind of nerds, in a good way. And they're very different from the typical French couture fashion designer" (Interviewee 7).

This diverse nature of the community also brings with it different motivations or reasons for participants. Compared to traditional fashion designers, those involved in digital fashion are much more interested in experimentation.

"For others, it's more about the artistic value of [digital fashion], or for some it's more about blockchain technology and the kind of agency you have over objects" (Interviewee 7).

Despite the different perspectives, however, the community is characterized by good networking: “They know how to find each other” (Interviewee 7). This network is often based on chat groups or social networks such as WhatsApp, Telegram, Instagram, or Discord (Interviewees 6 & 7).

In addition to digital fashion designers, the players within the system include companies such as The Fabricant, BNV (Brand New Vision), DressX, SYKY, and the gaming industry in particular. Interviewee 11 emphasized the role of games such as Roblox and Fortnite, where digital fashion is already integrated within their business models.

“[Gaming] is like a huge opportunity and there's so many people that are naturally like in their creative being. Like Roblox, there's already ecosystems. There's already this understanding of value of digital assets. I feel like that's actually the biggest place that digital fashion will thrive in, the gaming world.” (Interviewee 11)

This group includes larger fashion brands that have already established digital solutions in their companies, e.g., Hugo Boss, Perry Ellis, Adidas, conglomerates such as PVH or LVMH. High-end brands such as Hermes and Margiela were described as magnets for a digitally native community and have partially implemented blockchain technologies.

Technology and software providers also play a central role. Key examples were 3D software platforms such as CLO, Blender, and Substance Painter. Some of these platforms provide open-source resources and are complemented by knowledge exchange via online forums. AR/filter tools such as Lens Studio and AI tools such as Midjourney, Craiyon, and Fabricant AI were mentioned. AI-supported programs in particular make it easier for consumers to get started in digital fashion (Interviewee 3). As in many creative industries, however, AI is not viewed without criticism. Concerns about sustainability due to high energy consumption by servers, as well as ethical considerations, were raised by several interviewees.

Educational institutions were further referred to in this context. Some interviewees were directly connected to these or were able to provide examples based on their network. Among others, the Amsterdam Fashion Institute (AMFI), the Willem de Kooning Academie (WdKA), but also international institutions such as Oklahoma State University, University of the Arts London (UAL) and Fashion Institute of Technology (FIT) were mentioned.

According to the interview analysis, organizations, hubs, and initiatives related to digital fashion include VORN (Berlin Fashion Hub), PI Apparel, 3DRC (e.g., an industry group that focuses on enabling retailers and brands to leverage 3D technology in the fashion industry) London Digital Fashion Week, Future Front Row (e.g., a fully digital fashion show) and, in one example, government funding from the Berlin Senate Department for Economic Affairs and Energy.

Besides the dynamics of networking in digital spaces, physical events were considered very valuable for exchanging ideas on the implementation of digital technologies (Interviewee 3). In general, collaboration and knowledge exchange play a central role within the digital community for all interviewees. Furthermore, experimentation and creativity are an important part of the community (Interviewee 7).

1.2 The Dutch Digital Fashion Ecosystem

Special attention should be paid to the Dutch ecosystem, its emergence and development. The Fabricant has been repeatedly cited as a key pioneer and market opener for digital fashion in the Netherlands. Interviewee 3 described the company as "the first player, or at least one of the best players in the space." The company played a central role in establishing digital fashion as a concept and connecting many of the early players in the industry.

"That's where The Fabricant played a very key role. I think The Fabricant was very critical in actually bringing out this question: What is digital fashion, how can it exist, what can it be, and actually connecting a whole bunch of very early people who were digital" (Interviewee 11).

In the meantime, the company and its environment have changed. The Fabricant has evolved from a service agency focused on creating digital fashion and NFTs to a platform with a strong focus on AI-based design tools. The beginnings of the ecosystem were largely determined by external factors. The Covid-19 pandemic created a "sweet spot for digital fashion" (Interviewee 8) by generating a great deal of interest in co-creation among stakeholders.

"Covid really pushed it. You know, it was the fact that we were suddenly pushed into an environment where we couldn't work in the same way. So it wasn't a proactive thing, it was a reactive thing" (interviewee 3).

Interviewee 5 also described the community's beginners as "wild [...] digital warriors" who wanted to "break down and rebuild" the prevailing system. This enthusiasm has since been lost because no stable business model could be established (Interviewee 5).

In addition to this external factor, the Amsterdam Fashion Institute (AMFI) should also be mentioned. Interviewee 5 noted that a course in digital fashion was initiated at AMFI back in the 1990s. Later, CLO3D was integrated for design students to align the curriculum with digital practices. He emphasized that AMFI was "very, very early" in terms of digitalization and strongly oriented towards industry and the future.

Interviewee 9 went on to discuss a culture of innovation within the Netherlands, specifically in Amsterdam. Her description of a culture that is open to novelty and innovation, organized by entrepreneurs, reflects well what Schumpeter considered to be the central characteristic of entrepreneurs.

"I think in Amsterdam there's like a lot of entrepreneurs and people that are looking for things that are a bit different. So I think it makes sense that it started here. It was because there's, like, an openness to innovation and to things being a bit. Yeah, I guess new and different to what already is." (Interviewee 9)

Interviewees 9 and 10 also cited the Dutch startup culture as crucial to the establishment of digital fashion. On one hand, this is due to good financial start-up assistance from the state (Interviewee 9) and, on the other hand, to a technological affinity and understanding that can be found in the Netherlands (Interviewee 10). Interviewee 10, a start-up founder whose company combines fashion with technology to design new measuring tools for the healthcare sector, benefits particularly from his location in the Netherlands. His company is based in Eindhoven and therefore benefits from knowledge exchange and local specialists from the fields of IT, healthcare, and fashion technology.

"So next to having employees, you have possibly reliable partners to work with to help you accelerate or to help you conquer certain elements of your product. [...] I mean, if you are geographically in the hub, that's always simplifying things because if you need an expert

who's two blocks away, you can always walk there, and that makes it much easier without even making appointments." (Interviewee 10)

After the initial euphoria surrounding NFTs and the metaverse, the focus of digital fashion has shifted. The hype has subsided, and there is a stronger shift toward functional applications as tools, e.g., AI for design and prototyping. The emergence of AI is seen both as a countercurrent to NFTs and as an opportunity to establish digital fashion in society.

"I think the Internet has slowly been taken over by generated content that is not even touched by humans. So it's these two counter waves that are going against each other. It's an interesting development to see, and I think now a lot of these fashion brands that came out with their unique selling points, being NFTs and digital value and scarcity online and stuff like that, are kind of rethinking their approach." (Interviewee 9)

AI also has the potential to democratize fashion and fashion design. Interviewee 11 emphasizes that AI could significantly lower the barriers to entry for fashion design, allowing anyone to design a piece of fashion. Interviewee 3 argued along the same lines, particularly with regard to social differences. AI tools could enable people to create designs on their cell phones and publish them on social media, even without the means for high-end computers. This has the potential to diversify the fashion design industry and not limit it to rich countries. A possible influence on consumer behavior in society is also suggested. With low barriers to entry into fashion design, people with no prior knowledge can use AI to learn in a playful way what it means to design a garment. This could potentially have the effect of making consumers perceive fashion as more valuable or turning away from fast trends in order to pursue their own individual needs.

"So if fashion becomes something that everyone can design and make, I think that's better than the [current] system. Now I think the more that people actually understand how to design fashion, what goes into it, what goes into the making would probably make them value it more or want them to design their own. And then that creates demand for actual on-demand manufacturing. Because right now the demand is not there." (Interviewee 11)

1.3 Challenges for Digital Fashion

However, the digital fashion community also faces several challenges. On the one hand, the precarious job market is mentioned. “They find it quite hard to find work in digital fashion [...] because they are quite dependent on the fashion industry [which] is not always very inviting” (Interviewee 7). Furthermore, a lack of mass acceptance for digital fashion in terms of digital tools or digital garments was mentioned. While the former is hampered by a lack of willingness to invest on the part of the fashion industry (Interviewee 3), the question arises with digital end products as to where the value of the product lies if it cannot be viewed or consumed in the physical world (Interviewee 2). While public funding rarely supports digital fashion (Interviewee 3), it often fails to translate the concept of digital fashion into functioning business models (Interviewee 5). Interviewee 5 & 8 emphasized the importance of education in digital fashion design. While some institutions offer courses on digital fashion, many fashion designers lack the knowledge and skills to implement fashion design in the digital age. This slows down the progress of digital fashion and at the same time represents a knowledge gap for future fashion designers (Interviewees 5 & 8). Profit orientation and commercialization, and for some also sustainability, are factors that drive digital fashion forward. The tension between these orientations is discussed further in the section on sustainability.

The insights from the interviewees’ definition of digital fashion does align with the initial definition of digital fashion by Baek et al. (2022) “Digital fashion is the virtual creation, production, and representation of one's identity via computer-generated design” (p. 8). However, they broaden the scope of applicability of digital fashion as a research field. Through the literature review, digital fashion was predominantly discussed as technological innovations in design and production, or its impact on consumers and changes across the supply chain. The findings suggest however that the role of education as well as the dynamics between community members, and external factors such as the Covid-19 pandemic and the emergence of AI should gain in consideration for future research. Furthermore, the interviews have emphasized the dual definition of digital fashion. In the traditional sense as a fully digital product, and in a broader sense as a tool that can be integrated at various stages along the fashion pipeline. Interviewee 3 stressed that the integration of both definitions into a single understanding of digital fashion might be what is hampering digital fashion today.

"And I think that the disconnect is how […] do you create a digital space where you can be doing both at the same time. You don't really need to be doing a huge amount of additional work, because if you're already creating the digital assets anyway, why not also be selling those?" (Interviewee 3)

Furthermore, the description of the Dutch digital fashion ecosystem can be categorized using Santagata's (2011) understanding of cultural districts. The Fabricant and its market breakthrough should be viewed in connection with a system that has been promoting digitization in the fashion world since the 1990s through appropriate educational offerings. A corresponding start-up culture and favorable conditions for SMEs in the Netherlands have been instrumental in establishing digital fashion. The agglomeration of creative people in close geographical proximity and the combination of specific knowledge from various fields (in this case IT, technology, and design) have provided a breeding ground for radical innovation. This is also in line with Lorenz and Frederikson's (2008) view that radical innovation within the cultural sector requires localization and urbanization economies. Despite the digital nature and the associated digital networks for knowledge exchange, geographical proximity still seems to play an important role. This is in line with Busch et al.'s (2021) propositions, which also perceive proximity as a core element for economic success in digital urban production companies. However, the extent to which digital networks and knowledge exchange compensate for this geographical proximity remains to be investigated. This is because the digital fashion system is described as widely dispersed but digitally closely networked, which could argue for a supplementation, if not a gradual replacement, of the need for geographical proximity.

2 Innovation

To analyze the innovation system surrounding digital fashion, this study uses a systems approach. This approach does not view innovation in isolation, but rather as the result of complex interactions between different actors, their knowledge, institutions, and networks. The previous section on digital fashion already identified the actors in this network. The following section elaborates on these actors, their dynamics, and the role they play in innovation. First, however, the concept of innovation will be examined in more detail from the perspective of the interviewees.

2.1 Innovation in digital fashion

Wijngaarden et al. (2016) demonstrated in their study on understanding innovation among creative workers that a narrow definition of innovation, which is often based on input (e.g., invention) and output (e.g., market success) models and associated metrics such as R&D expenditure and patents, can only be applied to service or creative industries to a limited extent. Interviews with several players in the digital fashion industry suggest that this assumption is correct. Several interviewees found it difficult to provide a general definition of innovation. Interviewee 7 described the term as overused and, in their practice, detached from technological innovation. Other interviewees' understandings of innovation included, for example, education in the sense of new curricula or research in general. Overall, the interviewees gave the impression that their understanding revolves less around radical innovation and much more around the adaptation of existing technologies or knowledge. When asked about their research and its innovative value, one interviewee specifically addressed this deviation from the STEM-based understanding of innovation:

"[The final product] can be something that you would never wear, it can be something even ugly. It can be something that you can't wear, or it wouldn't even fit your body. [...] And to me that's the innovation in there. There's no countable or measurable profit from that. [...] It's more just to change the idea of how we look at identity in fashion" (Interviewee 7).

Two interviewees whose work deals extensively with the application of technologies in the creation of digital fashion also indicate that their understanding of innovation is based on a focus on improving and applying existing tools and processes in the digital fashion context (Interviewees 2 & 6). Interviewee 2 also distinguishes between technological and conceptual innovation. While the former is quickly adopted by the masses, the true value of innovation lies in conceptual innovation, which exists independently of new technologies.

"I think conceptual innovation is independent from the tech stuff. I mean, the tech is improving, but you can still think of really weird ideas that don't need tech innovation, that you can also make with very basic fundamental tools or techniques. So it's nice that [technical innovation] happens, but it causes a lot of people to do the same thing. It's not

exactly pushing innovation so much. It's giving these waves where everybody is doing the same because something is new, to be quite boring" (Interviewee 2).

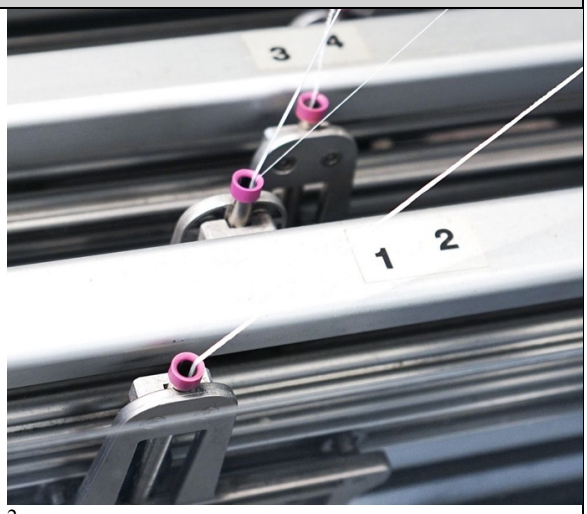
The strongly context-based definition of innovation is particularly clear in the statement by Interviewee 3, whose perspective on digital fashion is more market-oriented. He sees innovation as a tool for increasing efficiency and improving customer loyalty. This deviation based on the specific context is also consistent with the results of Wijngaarden et al.'s (2016) study.

The evaluation of the interviews revealed a wide variety of types of innovation. The main focus of most interviewees was on process innovations such as the automation of production processes, digital communication with customers or suppliers, and the use of 3D tools for virtual prototyping. Table 1 provides examples of respective types of innovation that were mentions in the interviews.

Despite the apparent distinction from the traditional understanding of innovation, it cannot be clearly assigned to other cultural definitions of innovation. The innovations described by the interviewees mostly had a functional level. Even if these were not necessarily measured in terms of optimization processes or economic externalities, this characteristic differs from definitions of soft innovation (Stineman & Bakhshi, 2009), hidden innovation (Miles & Green, 2008), and stylistic innovation (Capetta et al., 2006). The innovations within digital fashion, on the other hand, can be better classified according to Cave's (2000) understanding of innovation. They are characterized by a new combination of existing components, as described, for example, by Interviewee 7. In addition to process innovation, which was the focus of many of the interviewees, digital fashion is also associated with social innovation. This can be derived from the examples already mentioned by Interviewees 3 and 11, who described the democratization of fashion and the minimization of barriers to entry in the field of fashion design as potential effects of digital fashion innovation.

Table 1

Types of Innovation in Digital Fashion

Type of Innovation	Examples from the Interviews	Images for illustrative purposes
Process Innovation	Use of 3D tools for virtual prototyping to reduce physical samples, digital communication with factories, creation of customized digital workflows by combining existing tools, integration of digital tools into production processes (e.g., knitting machines, laser cutting), automation/robotics	 2
Product Innovation	Development of purely digital garments ("digital-only pieces of clothing"), AR filters/garments, avatars, phygital products (combining digital and physical), personalized/data-based fashion concepts, clothing for people with disabilities (adaptive fashion)	 3

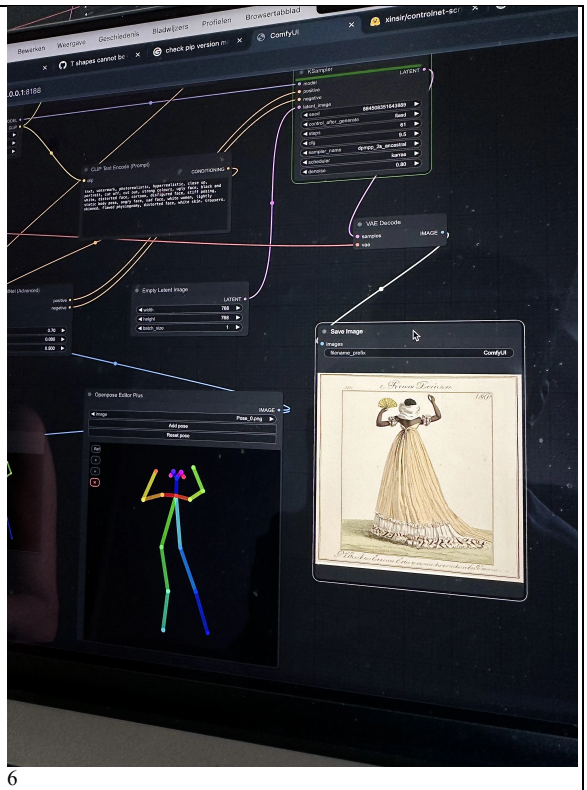
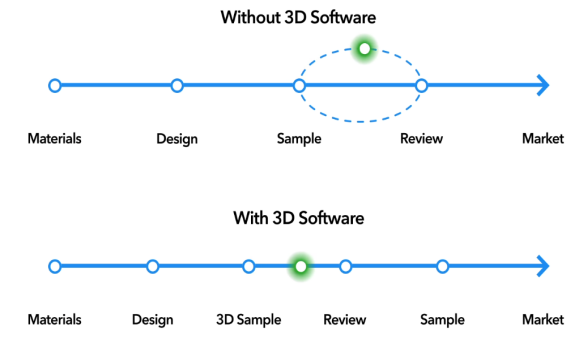
[2] 3D-Knitting - Knitwear Lab. (n.d.). Posts [LinkedIn page]. LinkedIn. https://www.linkedin.com/company/knitwear-lab/posts/?feedView=all

[3] Digital Garment - The Fabricant. (n.d.). RTFKT collaboration. https://www.thefabricant.com/rtfkt

Business model Innovation	Creation of new revenue streams through digital assets/NFTs, digital marketplaces (DressX, Dematerialised), provision of digitally-based design and production services (e.g. Carla/Unspun), possibly on-demand production based on digital designs (Micro Factory)	
Organizational Innovation	Changing design education, building digital communities and hubs (online & physical), new forms of internal and external collaboration.	 5

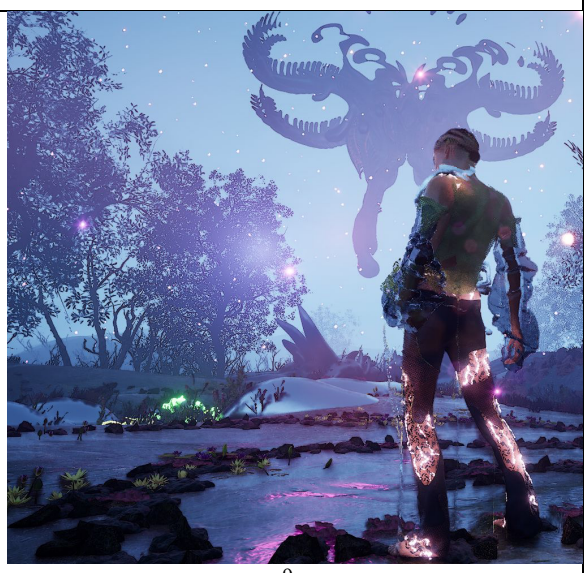
[4] On-Demand Business model - Unspun. (n.d.). About us. https://www.unspun.io/about

[5] Digital Fashion in Education - Amsterdam University of Applied Sciences. (n.d.). Master Digital Design: Digital Fashion Technology. https://www.amsterdamuas.com/programmes/master-digital-design-digital-fashion-technology

Social Innovation	Use of digital fashion for storytelling, activism or awareness raising, creation of platforms to promote user engagement and inclusion, formation of problem-focused online communities	 6
Service Innovation	Developing and providing digital design software and tools (CLO, Blender, AI tools, AR software), creating tutorials and educational platforms	 7

[6] Digital Fashion as a Communication tool - Cypherloom. (n.d.). Homepage. https://www.cypherloom.com/

[7] 3D-Softwear - CLO Virtual Fashion. (n.d.). CLO 3D. https://www.clo3d.com/en/

Marketing Innovation	Use of digital assets/AR for marketing purposes such as AR Mirrors, consumer-oriented	 8
Conceptual Innovation	New ideas and paradigms for fashion (fashion without physical boundaries, fashion as an expression of intangible data, questioning identity), creating something completely new or "weird," independent conceptual developments beyond technical trends	 9

Due to the close link between digital fashion and a technological basis and orientation towards the fashion industry, the general focus of innovation in digital fashion can be divided into two main areas. On one hand, there is a focus on efficiency and commercialization through process and business model innovations. Interviewee 3 emphasizes that, in his opinion, the real drivers for companies to implement digital

[8] AR-Mirror - Hirschmiller, S. (2023, May 19). How AR mirrors offer visual marketing meets user-generated content for fashion and beauty retail. Forbes. https://www.forbes.com/sites/stephaniehirschmiller/2023/05/19/how-ar-mirrors-offer-visual-marketing-meets-user-generated-content-for-fashion-and-beauty-retail/

[9] Conceptual Innovation at Berlin Fashion Week - Davey, H. (n.d.). Images [LinkedIn activity page]. LinkedIn. https://www.linkedin.com/in/harriet-davey-519822139/recent-activity/images/

innovation are “speed, efficiency, and money.” In addition, the reduction of physical samples through 3D design, i.e., innovation in prototyping and sampling, as well as in marketing and sales through AI-generated photo shoots, virtual fittings, and digital product passports were mentioned. On the other hand, innovation aims at artistic expression, identity, and accessibility through product and social innovation. Examples of this were the creative freedom provided by innovation in digital fashion, the democratization of fashion design, but also gaming and virtual worlds, which already provide an established ecosystem for self-expression through digital fashion. There is a fundamental tension between these two areas of innovation. The artistic and democratizing potential of digital fashion often collides with the commercial ambitions of the traditional industry, which mainly uses digital tools to maximize profits.

“If you had asked me five years ago, I would have said, ‘I'm going to change the world with digital fashion and we won't have to make samples or make any clothes because we can visualize anything before it's made’. [...] But at the same time, people also use innovation and technology to go even faster. [...] But isn't that missing the point?”
(Interviewee 8)

2.2 System of Innovation

Since the key players, institutions, and networks were already described in the previous section on digital fashion, the following section will now focus on their role within the innovation system.

Independent designers and creatives drive artistic expression and conceptual and creative innovation. Tech companies and software developers develop the basic tools, e.g., Blender, CLO, and open source tools, which are used by designers and creatives. Some of these technologies were not explicitly developed for the digital fashion context, but have been adapted by designers and creatives for their own purposes. Platforms such as CLO or Substance Painter and digital marketplaces such as DressX provide an infrastructure for artists and consumers alike. In addition, some of these providers create open source knowledge pools, thereby contributing to the diffusion of knowledge.

Large fashion houses, which primarily implement digital fashion tools for process optimization, create a sales market in which digital innovations can be applied on a larger scale.

Educational institutions not only conduct research in the field of digital fashion, but also pave the way for new generations of fashion and digital designers who have to find their way in an increasingly digital fashion industry. Fashion hubs and institutions with an advisory function that specialize in fashion innovation and digital fashion, such as VORN Hub or PI Apparel, offer physical platforms for designers and fashion brands to enable knowledge exchange between sometimes competing parties, thus playing an important role in the diffusion of innovation.

Consumer interests have played a relatively minor role to date. Apart from the gaming industry, no sustainably profitable market for digital fashion has yet emerged. Collaboration between these players, e.g., designers, coders, creatives from various fields, educational institutions, and brands, is described as common and is considered an important part of the innovation process.

Knowledge and knowledge diffusion are central components of an innovation system (see Coenen and Díaz López (2010)). Within the digital fashion system, new knowledge is created and processed through experimentation, the development of new workflows (e.g., process innovation), research projects, and the work of software developers. In case of digital fashion, diffusion is described to take place primarily in the digital space. In addition to the online forums already mentioned (Interviewee 6), YouTube tutorials (Interviewee 7) are also considered a common medium of diffusion. Problems and achievements are shared through word of mouth (Interviewees 6 & 8), thus creating bottom-up innovations.

"That's the best thing in innovation, a tool that's just bottom up build. [...] It's not even a very new structure [referring to the internet forums], it's been on since the start of the Internet. You just collaborate on a global scale on the same project, you don't have to know who everyone is, you just have the same goal. And it just makes the tool work very, very well" (Interviewee 7).

This finding is in line with the assumption of non-spatial proximity accounting for knowledge diffusion, promoting innovation (Kim, 2024). While physical proximity was mentioned by interviewees in the section on the Dutch digital fashion ecosystem, there clearly exists cognitive, social, and institutional links between digital fashion actors independent of geographical agglomeration, making it a "massively digital inline community" (Interviewee 6).

In contrast to the traditional fashion industry, there is a greater willingness to share knowledge in digital fashion (Interviewee 7). In addition, the diverse composition of the system has the advantage that collaborations between actors are "a lot more fluid than [in] traditional fashion" (Interviewee 1).

However, the dynamics between the actors and within the system in general are not without tension. For example, there is tension between purely artistic or conceptual approaches and the need for commercial viability. Interviewee 7 explained that some innovations, e.g., AI-supported design tools, tend to be developed for interest groups that have less to do with artistic practice and therefore do not really advance it. On the other hand, two interviewees described how a lack of business model and scalability for some innovations meant that they were not accepted by the masses (Interviewees 3 & 5). Another area of tension emerged between sustainability and digital innovation. However, this will be discussed in more detail in the following section.

There are many obstacles to the dissemination, implementation, and adoption of innovations. Interviewee 6 cites the lack of interest in digital fashion among the general public and the industry as a key obstacle. Technical limitations caused difficulties for Interviewee 2 in his experiments with digital fashion and even prompted him to leave the field until new opportunities arise through new technologies. One example was the provision of digital products in physical space, phygital products. The need to merge virtual and physical products was also highlighted by Interviewee 3. With regard to educational institutions for fashion designers, Interviewee 5 criticized a lack of qualified personnel who are familiar with developments and innovations in digital fashion.

The analysis of the digital fashion system shows that a systemic approach is suitable for interpreting the innovation system. The interviews have shown that digital fashion takes place within a larger and diverse network. This network is characterized by actors who are partly directly connected to digital fashion, e.g., digital fashion designers, research in digital fashion, but also actors who expand the system, e.g., software operators such as Lens Studio (operated by the social network Snapchat), and coders. The interviewees were also aware that they are embedded within a social discourse. This determines, on the one hand, the public attention that digital fashion receives, how educational institutions respond to the digitization of the fashion industry, but also how digital fashion is perceived in relation to social issues such as climate or social crisis. This

suggests that interpreting the system within a socio-technical approach may be a promising approach.

The diffusion of innovations can be analyzed using Roger's (2014) stages of diffusion. The interviews show that knowledge about digital innovations is mainly disseminated through informal channels. Interviewees 8 and 11 emphasize the role of content creators and influencers who share tutorials and content online, enabling rapid dissemination that is often more effective than traditional educational institutions.

"[Creating] new content, getting followers. I think that is really like a great diffusion model for innovation these days, more so than educational institutions doing it"
(Interviewee 11)

Interviewee 6 also confirms that people wait until an influential community member uses a technology before jumping on the bandwagon themselves. This behavior can be explained by socio-psychological network effects (see Kretschmer et al. 1999). Through information cascades, information from previous users of a new technology spreads, is adopted by followers through social contagion, and is then reproduced. Since, in the context of digital fashion, the digital space, in line with electronic word of mouth, is at the forefront, the assumption of Zhou et al. (2019) that social media influencers are establishing themselves as fashion opinion leaders can also be reinforced. In addition to this digital space for knowledge diffusion, physical events and meetups (e.g., Immersive Tech Week or Digital Fashion Week) are also mentioned as important places for exchange, sharing knowledge, and convincing others.

Regarding the implementation phase, it became apparent that established brands are implementing digital tools primarily to increase efficiency and reduce costs. Interviewee 3 commented that 3D modeling shows potential for implementation across the entire fashion pipeline, from conception and design to communication between factories and the distribution of physical fashion items, as well as the corresponding application of digital twins in marketing. Interviewee 11 was more critical in this regard, criticizing that the technology is not yet sufficiently developed to offer a seamless translation from virtual to physical. With regard to the strategic diffusion of Wirth et al. (2019), this potential for scaling was often viewed critically. While digital tools could accelerate production and make it more efficient, some of the interviewees fear that this will not lead to greater sustainability, but rather to even higher production and more consumption.

The confirmation phase can be identified as one of the biggest barriers to diffusion. Three of the interviewees expressed skepticism about the widespread acceptance of purely digital fashion, as consumer demand is not yet sufficient and the technology is not yet suitable for mass production. Interviewee 3 also points out that many executives in the fashion industry are too hesitant to undertake comprehensive digital transformations because they would rather stick to the old ways. Furthermore, the low profit margins within the fashion industry were cited as a factor that would make comprehensive implementation economically undesirable (Interviewee 11).

Furthermore, the results provide insights into the validity of cluster theory in the context of digital fashion. Interviewee 6 mentioned Berlin and London as global cities that are increasingly being sought out by digital artists. It can also be assumed that the Netherlands had established itself as a hub for digital fashion through the popularity of The Fabricant and the future oriented educational offers at fashion and design schools, but that this has "dispersed" somewhat in recent years (Interviewee 5). However, there are many indications that localization and urbanization economies must also be represented in the digital space. Since knowledge diffusion among specialized but also differentiated actors in the system increasingly takes place via online forums and open-source resources, the digital space could be understood as a further dimension of local but also institutional proximity (Kim, 2024). However, it must be examined how significant the role of the digital space is in relation to physical connectedness in terms of localization and urbanization economies, as both have existed in parallel to date. In addition, the digital representation of key actors could represent a limitation to innovation processes that specialize in digital innovations.

3 Sustainability

The survey of interviewees on sustainability and the connection between digital fashion and sustainability yielded mixed results. All interviewees were aware of the negative impact of the fashion industry on the environment, but also of the associated social injustices. Nevertheless, there was an ambivalent relationship between digital fashion and sustainability in terms of the extent to which digital fashion can actually be used for sustainable purposes. For Interviewee 5, digital fashion is an important tool for paving the way for the fashion industry to become more sustainable. “I recognized very early on that digital was or could have the potential of being a very good tool to ensure a more sustainable industry” (Interviewee 5). Interviewee 5 further promoted the digital product

passport as a promising innovation. This example is a good illustration of the double-edged nature of many sustainable initiatives, which not only bring about positive change but also raise ethical questions such as data security and privacy in the digital space.

"By 2030, the European fashion industry must fully embrace digital product passports. Every garment sold or made in Europe will have a unique QR code. This code will reveal sustainable details, such as water usage and CO2 impact. For the first time, consumers will have access to the information they need to make better sustainable purchasing decisions. Companies must take greater responsibility in manufacturing. However, your wardrobe will be filled with data. Retailers will primarily control this data. You can make informed choices, but you won't have control over your buying preferences." (Interviewee 5)

Several interviewees made it clear that sustainability does not only refer to the environmental friendliness of products, but also includes economic and social components.

"I think for the longest time, sustainability for me was limited to the environment. And I think that the industry focused on low hanging fruit that tended to be environmental. […] Sustainability needs to be way more diverse than that; the environment is only one part of it. It also needs to be kind of the ethics and transparency behind how something is being made? Who is doing it? Are they being fairly paid? Are they in an environment that is safe? You know, are they of working age or are they children?" (Interviewee 3)

The problem of unsustainability is like a 'bottomless pit' (Interviewee 8). Shifting the responsibility for solving this problem solely to digital fashion is not only described as harmful (Interviewee 7) but also offers only minor solutions in relation to the problem without bringing about systematic change (Interviewee 8). Interviewee 6 took a rather skeptical stance toward sustainability promises and criticized the fashion industry's affinity for greenwashing.

"I think the sustainability thing is a bit of a red herring. I think fashion loves itself and it will never change as an industry. They just come up with excuses to keep doing what they're doing. And if they say it's more sustainable, then they'll be like, yeah, we can keep doing it" (Interviewee 6).

The origin of this skepticism lies, on the one hand, in concerns that digital processes themselves could have a significant environmental impact. These include the energy consumption required to operate the technologies, but also fossil resources such as rare earths, which are needed to manufacture the hardware. Furthermore “tech or digital [tools] are very exclusive to people that can pay for subscriptions and hardware” (Interviewee 8). On the other hand, questions were raised as to whether digital fashion, when integrated into existing systems geared toward mass production, actually leads to greater sustainability. Or whether it instead only enables efficiency gains for faster consumption. A comment on the short lifespan of digital fashion was particularly revealing in this regard.

“I think people are not dealing with digital fashion in the same way as they do with real fashion. [...] You don't want to go back to things you've already tried. In a digital world, you want to move on, try new things. [...] You don't go back to your old digital pair of trousers because you like them so much. You've seen them. So I think it's the opposite. I mean, you try 10 outfits a day and never go back to them. So I don't think there's any longevity there.” (Interviewee 2)

Despite skepticism that “brands are willing to turn a blind eye to things if it means they're still getting something for the cheapest price” (Interviewee 3), several examples were cited that already contribute to sustainability or could do so in the future. Circular concepts were discussed, yet often met with the realization, that technological limitations to, for instance recycling, does not allow a truly circular economy. In addition to the possibilities of digital innovations in waste reduction through 3D sampling or made-to-order production, a best-practice start-up from the United States, Clara, was presented. It specializes in distributing digitized processes from design to manufacturing to specific market segments, especially influencers.

“They work primarily with influencers who want to create a collection to expand their brand. They give them the full process of design prototypes, branding, packaging, manufacturing, the whole thing, and everything is digitized. And they work with small local manufacturers, local to San Francisco. So small runs. And that was really quite successful as a business model. So I would say that was a good example of taking digital, heading it

towards one segment market, and then offering a complete process which was all digitized right through to the finished garment." (Interviewee 5).

Interviewee 8 further added that they "see lots of potentials, but it needs more than [that]. It needs a mind and behavior change" on the producer as well as consumer side.

Several conclusions can be drawn from the analysis of the interviews on sustainability. First, there seems to be a prevailing understanding of sustainability that encompasses not only the environment, but also economic efficiency and social dimensions. This suggests that awareness of sustainability has moved beyond the "low hanging fruits" to a broader interpretation. Nevertheless, the statements do not fully reflect the conceptual definition of sustainability in the sense of the Three Ecologies or Culturally Sustainable Development.

Analyzing the interviewees' statements on the digital fashion industry in terms of the principles of cultural sustainable development (Throsby, 2019), the results can be summarized as follows. With regard to intergenerational justice, the majority of interviewees see the potential of digital fashion to make the industry more sustainable and secure it for future generations. For example, through waste reduction in prototyping or on-demand production. However, the prevailing reality is that digital innovation is often used to accelerate consumption and greenwashing, while the high energy consumption of digital infrastructures and the failure to address consumer behavior hinder real systemic change.

The principle of intragenerational justice demands equal access to cultural capital for all members of a society. Here, too, digital fashion offers enormous potential for democratizing design and creative expression by lowering barriers to entry and facilitating access to knowledge and tools via online platforms and communities. Critical voices, however, point to the continuation or emergence of social injustice, such as the underpayment of digital artists (Interviewee 6) and the existing digital divide in terms of hardware access and digital literacy (Interviewee 8), which still hinders full intragenerational justice.

However, the principle of diversity is clearly more visible in the context of digital fashion. The interviewees see diversity as a key driver and positive outcome of the digital transformation in fashion. This includes the diversity of identities and forms of expression, the interdisciplinary collaboration between artists, technicians, and designers, and the expansion of the circle of creators through accessible digital tools. The openness of the

digital space promotes the emergence and collaboration of different actors, which strengthens the cultural diversity of the industry.

A precautionary principle, i.e., a responsible attitude toward future developments, was also present. All interviewees expressed deep concerns and skepticism about current developments in digital fashion. The danger of greenwashing, the increased energy consumption of AI and NFTs, the potential acceleration of consumption, and social impacts such as job losses and exploitation were identified as risks. In addition, there was a clear demand that the industry should think beyond purely commercial goals and critically question the "intentions" (Interviewee 8) of innovations in order to avoid unintended negative consequences.

With regard to the interconnection of economic, social, cultural, and environmental systems, all interviewees agreed that digital innovations in fashion cannot be viewed in isolation. They recognize the complex interactions between ecologies. It is clear that technological advances (e.g., AI, 3D modeling) have a profound impact on the entire value chain, influencing consumers, enabling new forms of expression, and at the same time raising new environmental and social issues. The challenge is to consciously shape these links in order to promote systemic change towards a truly sustainable fashion industry, rather than simply exacerbating or shifting existing problems.

An underlying lack of systematic approach can be identified as the biggest obstacle in the analysis. Despite the potential and challenges discussed, a coherent and systematic approach to innovation in digital fashion that takes all CSD principles into account equally still seems to be largely lacking. Diffusion often occurs organically and is driven by short-term trends or commercial interests rather than by an overarching vision of culturally sustainable development. This highlights the dependence of culturally sustainable development on the willingness of stakeholders to embrace a fundamental paradigm shift. Current developments are therefore still a long way from fully meeting the ideals of CSD. The findings from the interviews also make it clear that technological or process-related digital innovations alone are not enough to achieve truly systemic effects in terms of sustainability. It would also require social and cultural change in line with the social and mental ecology (Guattari, 2000). With regard to innovation, sustainability therefore does not play a reliable role as a driver of innovation.

Conclusion

The aim of this academic paper was to examine the understanding of digital fashion as an innovation system and to analyze the implications of this relatively new ecosystem for the sustainability movement in the fashion industry. The results show that digital fashion can indeed be understood as a multifaceted innovation system, but that its relationship to sustainability is characterized by ambivalence and challenges.

The study emphasizes that digital fashion is not a uniform concept and that there is no “one-size-fits-all” definition. Rather, it is an umbrella term that is interpreted differently depending on the background of the actors involved. For practitioners with a traditional fashion background, digital fashion is primarily seen as a practical tool for increasing efficiency and optimizing sustainability in existing processes. Actors with a digital-creative background, on the other hand, see it as an independent, expressive medium for artistic development and identity creation. System- and business-oriented experts emphasize the strategic and commercial potential for efficiency, cost reduction, and market expansion. This dual perception (digital fashion as an independent product and as an interactive tool) is a key finding. The Dutch ecosystem, exemplified by pioneers such as The Fabricant and early educational offerings from AMFI, demonstrates the importance of local networks, an innovation-friendly start-up culture, and geographical proximity for the emergence of radical innovations. The shift from the NFT hype to functional AI tools and their potential to democratize fashion design through lower barriers to entry also became apparent. However, challenges include a precarious labor market, lack of mass acceptance, insufficient government support, and educational deficits.

The study also confirms that innovation in the creative industry cannot be captured exclusively by rigid, STEM-based metrics. Instead, innovation in digital fashion is understood as a process that is based more on the adaptation and combination of existing technologies and knowledge bases rather than on purely radical inventions. A wide range of innovation types were identified, including process, product, business model, organizational, social, service, and marketing innovations. There is a tension between the pursuit of efficiency and commercialization and the desire for artistic expression and accessibility. The diffusion of innovation in the digital fashion sector primarily takes place via informal, digital channels such as online forums and social media, which is accelerated by socio-psychological network effects and the role of influencers as fashion opinion leaders. Despite its digital nature, physical events remain important for knowledge exchange and convincing stakeholders. Barriers to diffusion include a lack of public and

industrial interest, technical limitations, and a general reluctance on the part of the traditional fashion industry to embrace comprehensive digital transformation.

The study also reveals a strong awareness of the environmental and social injustices of the fashion industry among the interviewees. However, the relationship between digital fashion and sustainability is ambivalent. While digital fashion has the potential to make the industry more sustainable through waste reduction and demand-driven production, there is concern that it will instead accelerate consumption through efficiency gains. The interviewees were critical of greenwashing and the high energy intensity of digital infrastructures. The lifespan of digital fashion is perceived as short, which reduces its sustainability impact. Analysis based on Throsby's (2019) principles of cultural sustainable development (CSD) and Guattari's (2000) model of the three ecologies shows that digital fashion has potential for inter- and intragenerational justice and cultural diversity, but also carries risks such as exacerbating existing inequalities and a lack of systematic approaches. The consensus that technological innovations alone are not enough and that social and cultural change is necessary underscores the complexity of the issue. Sustainability is therefore not yet a reliable driver of innovation in digital fashion.

This work contributes to the academic literature by adding a practice-oriented perspective to the field of digital fashion research and closing gaps in the systematic analysis of innovation processes. The results confirm that the traditional, STEM-based understanding of innovation, as criticized by Wijngaarden et al. (2016), is insufficient for the creative sector. Instead, the study reveals that innovation in digital fashion is more in line with Caves' (2000) definition of the new combination of existing components. The applied systemic approach to innovation research, in particular the socio-technical system approach, has proven promising for capturing the complexity and diversity of actors in the digital fashion ecosystem. The analysis of the Dutch ecosystem supports the concepts of cultural districts (Santagata, 2011) and localization and urbanization economies (Lorenz & Frederikson, 2011), even in the digital age. The role of digital space as a dimension of proximity that promotes knowledge exchange complements Kim's (2024) notion of non-spatial proximity.

The present study has methodological limitations. The relatively small sample size (11 participants) limits the generalizability of the results and focuses primarily on the digital fashion ecosystem in Central Europe. The dispersed nature of the digital fashion community made it difficult to get in contact with experts. However, focusing on experts and the tightknit ecosystem compensated for the small sample size. An inter-coder-

reliability test could have further strengthened the validity of the interpretation of themes. As the study was exploratory in nature, future research could quantitatively test the hypotheses derived here. It also remains to be investigated to what extent digital networks can actually compensate for or replace the need for geographical proximity, rather than merely complementing it. In addition, future research should develop a systematic approach to integrating all CSD principles into digital fashion innovation in order to fully exploit the potential for culturally sustainable development.

For society, digital fashion offers the potential to democratize design and creative expression and change consumer behavior by redefining the value of fashion and moving away from the fast fashion cycle. At the same time, risks such as the exacerbation of inequalities, surveillance, and greenwashing must be taken seriously. A “mind and behavior change” is needed among both producers and consumers to achieve true sustainability.

Political decision-makers should recognize and promote the innovation potential of digital fashion to shape the industry in a future-oriented way. This includes supporting start-ups, addressing ethical issues surrounding AI, and developing incentives (e.g., environmental taxes, subsidies) that promote systemic transformation rather than simply increasing the efficiency of the existing system. A just transition must be ensured so that the burdens of the transition are not shifted unilaterally to disadvantaged groups or regions.

It is crucial for key players in the digital fashion ecosystem to accept the dual definition of digital fashion and intensify collaboration across traditional disciplinary boundaries. Educational institutions must adapt their curricula to equip the next generation of fashion designers with the necessary digital skills. The industry should shift its focus from short-term profit margins to long-term, holistic sustainability goals. Only by consciously shaping the links between economic, social, cultural, and ecological systems can digital fashion unleash its full potential as a catalyst for a truly sustainable fashion industry.

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Appendices

Appendix A – Overview Literature Review

Table 2

Thematic overview of literature review

Thematic Field	Author	Year	Title	Abstract Summary	Journal
Design	Christopher J. Parker, Simeon Gill, Adrian Harwood, Steven G. Hayes & Maryam Ahmed	2022	A method for increasing 3D body scanning's precision: Gryphon and consecutive scanning	Research on precision of 3D body scanning methods	Ergonomics
	Yeonghoon Kang and Sungmin Kim	2019	Three-dimensional garment pattern design using progressive mesh cutting algorithm	Developing core module of computer-aided three-dimensional garment pattern design system	International Journal of Clothing Science and Technology
	Guangzhou Zhu and Wenfang Song	2020	Patterns simulation in the 3D virtual stitching and try-on system	Presenting a method for the patterns simulation in the 3D virtual stitching and try-on system	International Journal of Clothing Science and Technology
	Seolyoung Oh and Dongae Suh	2021	Mannequin fabrication methodology using 3D-scanning, modeling and printing	Presenting a method to fabricate a fitting-mannequin using 3D-scanning, modeling and printing technologies	International Journal of Clothing Science and Technology
	Fanke Peng, David Sweeney, Philip Delamore	2012	Digital innovation in Fashion – How to ‚Capture' the user experience in	Investigating consumer adoption of 3D body scanner applications	International Journal of Industrial Engineering and Management

			3D body scanning		
	Holly McQuillan	2020	Digital 3D design as a tool for augmenting zero-waste fashion design practice	The role of 3D software in zero-waste fashion design, industry and education	International Journal of Fashion Design, Technology and Education
	Yining Wang, Eunju Ko & Huanzhang Wang	2021	Augmented reality (AR) app use in the beauty product industry and consumer purchase intention	Researching the impact of AR applications on consumers' purchase behaviour and brand awareness in beauty industry	Asia Pacific Journal of Marketing and Logistics
	Behnaz Farahi	2015	Material behaviours in 3D-printed fashion items	Presenting advances in material technologies and 3D-printing and its effects on tailoring	Architectural Design
Consumer	Yining Wang and Eunju Ko & Huanzhang Wang	2021	Augmented reality (AR) app use in the beauty product industry and consumer purchase intention	Researching the impact of AR applications on consumers' purchase behaviour and brand awareness in beauty industry	Asia Pacific Journal of Marketing and Logistics
	Marc Herz, Philipp A. Rauschnabel	2019	Understanding the diffusion of virtual reality glasses: The role of media, fashion and technology	Studying consumer reactions to wearable VR glasses	Technological Forecasting and Social Change
	Nada Sarkis, Nada Jabbour Al Maalouf, Elias Saliba & Joseph Azizi	2025	The impact of augmented reality within the fashion industry on purchase decisions, customer engagement,	Exploring the transformative impact of AR in the fashion industry, specifically how AR influences purchase decisions,	International Journal of Fashion Design, Technology and Education

			and brand loyalty	enhances customer engagement, and fosters brand loyalty in an increasingly digital consumer landscape	
	Juyeon Park and Jennifer Paff Ogle	2021	How virtual avatar experience interplays with self-concepts: the use of anthropometric 3D body models in the visual stimulation process	Exploring how the perception of one's virtual avatar can affecr the viewer's self-body perception.	Fashion and Textiles
	Emmanuel Sirimal Silva, Francesca Bonetti	2021	Digital humans in fashion: Will consumers interact?	Analyzing consumer attitudes towards the propensity to interact with digital humans to uncover possibilities for fashion businesses to diversify their operations.	Journal of Retailing and Consumer Services
	Tomoe Masuda	2012	Design images and fashion consciousness by gender and age using 3D-garment simulations	Analyzing the commonalities and differences in consciousness of design image and clothing life style using 3D garment simulation	Journal oft he Japan Research Association for Textile End-Uses
Body	Kaixuan Liu, Jianping Wang, Chun Zhu, Edwin Kamalha, Yan Hong, Junjiee Zhang & Min Dong	2017	A mixed human body modeling method based on 3D bidy scanning for clothing industry	Proposing a method to create a digital human model (DHM) to serve clothing industry	International Journal of Clothing Science and Technology

	Fanke Peng and Mouhannad Al-Sayegh	2014	Personalised virtual fitting for fashion	Developing and testing the garment size recommendation app, ShapeMate in terms of user-experience and implementation within fashion e-commerce sites	International Journal of Industrial Engineering and Management
	Asimina Vasalou, Adam N. Joinson	2009	Me, myself and I: The role of interactional context on self-presentation through avatars	Investigating whether diverse online environments can prime users to create distinct avatars that emphasize particular characteristics	Computers in Human Behavior
	Andrew Brownridge and Peter Twigg	2014	Body scanning for avatar production and animation	Development and production of a realistic virtual human for animation	International Journal of Fashion Design, Technology and Education
Virtual	Veronica Arribas & José A. Alfaro	2018	3D technology in fashion: from concept to consumer	Investigating how 3D digital technology can bring value to the fashion along the value chain	Journal of Fashion Marketing and Management: An International Journal
	Emmelie Gustafsson, Patrik Jonsson and Jan Holmström	2021	Reducing retail supply chain costs of product returns using digital product fitting	Investigating how fit uncertainty impacts product return costs in online retailing and how digital product fitting can reduce fit uncertainty	International Journal of Physical Distribution & Logistics Management
	Fanke Peng and Mouhannad Al-Sayegh	2014	Personalised virtual fitting for fashion	Developing and testing the garment size recommendation app, ShapeMate in terms of user-experience and implementation	International Journal of Industrial Engineering and Management

				within fashion e-commerce sites	
	Cuomo, M. T., Tortora, D., Festa, G., Ceruti, F., & Metallo, G	2018	Managing omni-customer brand experience via augmented reality – A qualitative investigation in the Italian fashion retailing system	Investigating whether AR affects costumer behavior toward brands in the retailing system	Qualitative Market Research: An International Journal
	Miell, Simeon Gill & Delia Vazquez	2018	Enabling the Digital Fashion Consumer through Fit and Sizing Technology	Discussing the utilization of fit and sizing technology through the omni-fit model	Journal of Global Fashion Marketing
	Abdellah Ibrahim Mohammed Elfeky & Marwa Yasien Helmy Elbyaly	2021	Developing skills of fashion design by augmented reality technology in higher education	Research on the use of AR technology in the education field in fashion design	Interactive Learning Environments
	Greder, K. C., Pei, J., & Shin, J.	2020	Design in 3D: a computational fashion design protocol	Application of diverse 3D approaches to fashion design when creating a garment	International Journal of Clothing Science and Technology
	Byoungho Jin, Gwia Kim, Marguerite Moore and Lori Rothenberg	2021	Consumer store experience through virtual reality: its effect on emotional states and perceived store attractiveness	Examining whether consumers' store experience through VR, compared to website experience, can attract them enough to perceive the online store as appealing	Fashion and Textiles
	Frances Ross	2012	A Study of How Small and Medium-	Research on the adoption of new technology in	Fashion Practice

			sized Enterprise Tailors Utilize e-Commerce, Social Media, and New 3D Technological Practices	anthropometrics (measurements), manufacturing, and e-commerce	
Printing	Sohyun Kim, Hyunjin Seong, Yusun Her and Jaehoon Chun	2019	A study of the development and improvement of fashion products using a FDM type 3D printer	Determining the limitations of 3D printed clothing production process and suggesting complementary measures to offset those limitations	Fashion and Textiles
	Lushan Sun & Li Zhao	2018	Technology disruptions: exploring the changing roles of designers, makers, and users in the fashion industry	Exploring the changing roles of designer, makers, and users among industry, and academic professionals through technological disruptions	International Journal of Fashion Design, Technology and Education
	Greder, K. C., Pei, J., & Shin, J.	2020	Design in 3D: a computational fashion design protocol	Application of diverse 3D approaches to fashion design when creating a garment	International Journal of Clothing Science and Technology
	Philipp A. Rauschnabel and Young K. Ro	2016	Augmented reality smart glasses: an investigation of technology acceptance drivers	Drivers of smart-glass adoption in potential costumers	International Journal of Technology Marketing
	Marlene M. Hohn and Christian F. Durach	2021	Additive manufacturing in the apparel supply chain - impact on supply chain governance	Examination of how additive manufacturing may impact global supply chains regarding structures of interorganizational	International Journal of Operations & Production Management

			and social sustainability	governance and the industry's social sustainability issues	
Supply	Tsan-Ming Choi	2019	Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains	Exploring different consumer utility driven operations models, highlighting the values of blockchain technology supported platforms specifically for diamond authentication and certification	Transportation Research Part E: Logistics and Transportation Review
	Phuc Hong Huynh	2021	Enabling circular business models in the fashion industry: the role of digital innovation	This paper examines digital circular business models in the context of the fashion industry and its multiple actors.	International Journal of Productivity and Performance Management
	Tsan-Ming Choia, Suyuan Luo	2019	Data quality challenges for sustainable fashion supply chain operations in emerging markets: Roles of blockchain, government sponsors and environment taxes	Establishes theoretical models to explore how data quality problems affect sustainable fashion supply chain operations.	Transportation Research Part E: Logistics and Transportation Review

Appendix B - Interview Guide

Table 3

Interview Guide (~ 32 Questions)

Sections	Questions
Part 1 Interviewees' Background	- Can you tell me something about yourself as an artist/creative worker/field of study? - How did you end up in this position/sector? - Why are you here, and not somewhere else (e.g. why not in traditional fashion industry or tech-startup; why in or not in the Netherlands)?
Part 2 Digital Fashion	The aim of this part is to understand the interviewee's understanding of and involvement in digital fashion. - Definition and understanding of digital fashion: o How would you define digital fashion? What do you think digital fashion encompasses? What is your vision/mission in Digital Fashion? o What different forms or applications of digital fashion do you know and use(e.g. virtual clothing for avatars, digital accessories, augmented reality filters, digital collections)? o How did you personally come into contact with digital fashion and how do you use it (professionally/privately)? - The role of the digital fashion community in the Netherlands: o How would you describe the digital fashion community (in the Netherlands/Local/national area)? Are there specific characteristics or dynamics; similarities and differences with other countries? o Which actors or groups/institutions are

	particularly active in this community (e.g. designers, platforms, consumers, technology providers, policymakers, schools)? o How do these actors interact with each other? Are there collaborations or networks, events, key intermediaries, Face-to-Face practice? *(Network activity as a precondition for learning through interaction)* - Importance of different aspects in digital fashion: o What do you think are the most important aspects in the current development of digital fashion (e.g. creativity, technology, commercialization, representation, accessibility)?
Part 3 Innovation	This part aims to explore innovation processes within the digital fashion community. - Definition and perception of innovation in digital fashion: o What do you understand by innovation in the context of digital fashion? Are there differences to innovation in traditional fashion or other industries (e.g. STEM sectors)? *(Different meanings of "novelty" in creative industries)* o In what type of innovation where you involved in or contributed to? o What types of innovation do you see in digital fashion currently (e.g. product innovations like new virtual garments, process innovations in creation or distribution, new forms of user experience)? *(Different types of innovation like*

	product and process innovation; incremental vs radical innovation) o Can you give examples of innovations in digital fashion that have emerged in recent years? (And that you contributed to?) o Who or what do you think is driving innovation in digital fashion the most (e.g. technological developments, consumer needs, artistic expression, sustainability efforts)? *(Consumer demands as an important factor)* - Processes of innovation: o From your own experience, processes that you have been involved in: ▪ How are new ideas and innovations created in the digital fashion community? Are there specific methods or approaches? ▪ How are these ideas developed and implemented? What steps are typical? ▪ Does collaboration between different actors (e.g. designers, technology providers, consumers) play a role in the innovation process? If so, what does this collaboration look like? (Comparable to Urban Living Labs) *(Facilitating connections through networks to stimulate social innovation)*

	▪ How are new technologies (e.g. blockchain, NFTs, artificial intelligence) integrated into innovation processes? ▪ How are feedback loops from users or the community incorporated into the further development of innovations? *(Embodied learning and feedback as part of the innovation process in the creative industries)* ▪ Are there obstacles to innovation in digital fashion? If so, what are they (e.g. lack of standards, technical limitations, mass acceptance)? ▪ Any differences between now and during Covid? - Diffusion of innovations: o Can you give an example on how new innovations spread within the digital fashion community and beyond? Looking back at the key actors within the community (institutions, trade fairs, events, etc.) *(Diffusion of innovations as an important aspect)* o What factors influence the acceptance and diffusion of innovations in this field?
Part 4 Sustainability	This part examines the role of sustainability in the digital fashion innovation process. - Understanding sustainability in digital fashion:

	o What does sustainability mean to you personally and what does it mean to you in the context of digital fashion? Which aspects are particularly relevant (e.g. reducing physical waste, transparency in production processes, ethical aspects, longevity of digital goods)? o To what extent can digital fashion contribute to a more sustainable fashion industry (e.g. systemic change or incremental solutions? What potential do you see? o Are there any tensions or challenges in combining digital fashion and sustainability? - Innovations for sustainability: o In your opinion, which innovations in the field of fashion and digital fashion in particular are already contributing to greater sustainability? (e.g. virtual try-ons to reduce returns, digital collections as an alternative to physical samples, NFTs to track material origin, etc.)? o What is the most important contribution to sustainability so far, in the near and far future? o In what other areas do you see potential to advance/accelerate sustainability in the near future (5 years) and far future (20 years)? o Are there any best practices or inspiring examples of sustainable innovations in the digital fashion community in the Netherlands? - Barriers and drivers for sustainable innovation:

	○ Who are actors/institutions at local/national/international levels that hamper sustainability innovation and what their role could or should be? ○ Who are actors/institutions at local/national/international levels that facilitate sustainability innovation and what their role could or should be?

Appendix C – Overview Coding

Figure 2

Selection of Codes & Concept Mapping