CHAPTER 1

Trends of Emerging Technologies in the Fashion Product Design and Development Process

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Abstract This chapter introduces the technology innovation transpiring in the field of fashion product design and development by covering the entire industry pipeline. As a potentially transformational industry, it is promising that various leading-edge technologies would play a significant role in designing and developing personalized fashion-related products. This chapter provides the theoretical foundation to analyze the cases of the collaboration between innovative technology and fashion demonstrated in the rest of this book. It also delineates the main innovative technologies (e.g., renewable textiles, 3D printing, wearables, robotics, artificial intelligence, augmented reality) currently employed by fashion

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companies, starting from the stage of material development, product design and development, production, to end-consumer engagement. The chapter also deliberates on the future of technology innovation in the fashion industry.

Keywords Technology innovation · Digital transformation · Industrial revolution · Design and product development · Fashion industry

Introduction

The fashion industry has been subject to rapid changes, having grappled with rising expectations concerning circular fashion and technology innovation. Since the COVID-19 crisis that started in early 2020, the industry's landscape has been transforming at a more vigorous pace, which has accelerated the full integration of leading-edge technologies in various stages of the fashion product development pipeline. This evolution is not an option anymore, but an unavoidable survival mechanism required to respond to the dynamic business demands during and post the COVID-19 pandemic.

Compared to other industries, the fashion industry is still in the process of the full realization of the fourth industrial revolution (Industry 4.0), which is a cyber-physical systems revolution with advancements in technologies involving artificial intelligence (AI), machine learning, robotics, Internet of Things (IoT), 3D printing (3DP), additive manufacturing, virtual/augmented reality (VR/AR), and wearables (See, 2019). The pandemic bolstered the tangible adoption of such innovation in the fashion industry and the idea of the next industrial revolution (Industry 5.0) is already being discussed, which is essentially the interaction and collaboration between human beings and machines (Vollmer, 2018). The industry will be kept evolving with the next level of industrial revolution from time to time and we should be ready to be onboard in this disruptive change through product and process innovation.

Two volumes of the book series in practice on global fashion brand management written by Jin and Cedrola (2018a, 2019) have covered the concept of product and process innovation in the fashion industry and presented various cases of product and process innovation occurring in

the fashion supply chain. According to Jin and Cedrola (2018b), innovation is "the development of new products, production processes, business practices or forms of organization" (p. 2) and product innovation in textiles and clothing sectors occurs at three levels in materials, styles, and product development (p. 5). Jin et al. (2019) state that "process innovation is a new or significantly improved way of doing things in a business that typically increases production levels and decreases costs" (p. 2). To reach both product and process innovation in the fashion supply chain, technology innovation plays a significant role in each stage of the industry pipeline.

Considering this era of disruptive transformation that we have encountered in the fashion industry and society (Bendoni et al., 2015), businesses and consumers' priorities are shifting; however, the lack of investment in those emergent technology innovation fails to fully meet the rising demand. Thus, this chapter discusses technology innovation in fashion product design and development, covering the entire industry pipeline by introducing the key innovative technologies (e.g., renewable textiles, 3D design, 3DP, wearable technology, robotics, AI, AR) used across processes, ranging from material development, product design and development, and garment production to end-consumer engagement. The chapter also discusses the future of technology innovation in the context of circular fashion.

Technology Innovation in the Circular Fashion Industry

Material Innovation

During the wave of a global pandemic, fashion companies demonstrated that sustainability, bettering the planet and people, remains a top priority and digital technologies are the means by which companies can leverage fashion brands to manufacture products more sustainably (Sourcing Journal, 2021). For instance, companies are cutting back on single-use plastic by investing in renewable energy and the protection of biodiversity. Patagonia, the outdoor apparel company, by partnering with Infinited Fiber Company (IFC), actively advocates textile circularity with the utilization of fibers made from textile waste (Friedman,

2021). IFC focuses on the scalability of its technology implementation as a part of the bold movement of textile circularity (TextileExchange, 2020). This circularity movement has been escalating, reinforced by several other companies. The LYCRA Company's COOLMAX® and THERMOLITE® EcoMade fibers, made from 100% textile waste, exemplify textile circularity (The LYCRA Company, 2021). TENCEL™ cellulosic fibers are also a part of nature's cycle, provided that they are compostable and biodegradable, and thus, completely eco-friendly (Tencel, 2021). Other examples of sustainable alternative fibers with lower environmental impact (e.g., soy, bamboo, eucalyptus, stinging nettle) were showcased in Jin and Cedrala's study (2018b, pp. 7–8).

Leading fashion companies have explored the development of sustainable fashion products, utilizing biomaterials out of plants' byproducts. Miomojo, a premier Italian fashion brand, sells luxurious plant-based leather bags made from natural materials, such as apple peels and cores, cactus, and corn (Hannon, 2021a). Mycelium, derived from fungi such as mushrooms, is also one of the sustainable materials increasingly adopted as a leather alternative (Hannon, 2021b). Adidas' latest concept shoe, Stan Smith Mylo^{tm}, is one such example (Adidas, 2021). Gucci's Dementra is a new animal-free luxury material containing more than 77% plant-based materials, including viscose, wood pulp, and bio-based polyurethane (Chua, 2021). Another example is Nike's use of pineapple leather in its new sustainable sneakers (Binns, 2021). These emerging sustainable products are the outcomes of efforts in material innovation that have duly considered their impact on ecosystems. An increasing number of future-forward sustainable materials will shortly be developed, considering the increasing popularity and adoption of textile circularity. This movement has already been escalated by technology advancements and the shift in consumers' interest from fast fashion to circular fashion.

Product Design and Development

Product innovation in textiles and clothing sectors occurs at three levels in materials, styles, and product development (Jin & Cedrola, 2018b, p. 5), and process innovation is "a new or significantly improved way of doing things in a business that typically increases production levels and decreases costs. Such innovation might come in the form of new processes or techniques, new equipment, or new software" (Jin et al., 2019, pp. 2–3). Technology innovation is a key player in the product design and

development process in the current digital transformation era. Jin et al. (2019) well provided the overview of process innovation during product development by implementing various technologies such as 2D computer-aided design/manufacturing (CAD/CAM), 3D garment simulation, and big data and deep-learning algorithms (pp. 8–11). The following parts present the current implementation of various 2D and 3D technologies in the product design and development process since then and discuss the urgent needs to nurture the next generation of workforce.

The fashion industry is exhibiting an increasing involvement in connecting the virtual world to the physical one. For instance, Optitex provides an integrated 2D/3D platform that facilitates the quick creation of realistic 3D digital garments, which empowers apparel and soft goods companies to revolutionize the way they develop, produce, and market their products (Optitex, n.d.). In July 2019, Alvanon announced a new collaboration with Under Armour to inspire fashion brands to embrace 3D virtualization (Alvanon, 2019). They collaborated to develop new 3D tools, particularly working with 3D avatar size sets, to create better products with enhanced sizing and standardization. In August 2019, Tukatech opened its library of over 750 virtual fit models for all the global brands, retailers, and 3D users in the fashion industry, intending to help the industry establish the foundations for digital development (PR Newswire, 2019).

Numerous companies, including Target, have already turned into 3D virtualization of products to reduce the time and cost of product design and development and to minimize physical sampling. The author of this chapter witnessed the company's realization of the commitment to implement 2D/3D programs (e.g., Optitex, CLO, Browzwear) in their product design and development process over the last decade. The PI (Product Innovation) Apparel Conference held in Los Angles in February 2018 also revealed to the author the fashion industry's rigorous experiments with 2D to 3D conversion in its daily activities of pattern-making and prototyping. At the conference, industry presenters articulated the need for 3D sample makers/operators/creators who could precisely understand the foundations of pattern development and garment fit. They urged for academic institutions to equip next generation workforces to work in a digitally revolutionizing industry. It is time for fashion educators to work together with industry professionals and build the talent pipeline—the next generation of fashion creators who can comfortably reorient themselves from operating with 2D to working with 3D.

Garment Production

Compared to the application of digital technology in the product design and development stage of the fashion industry, its utilization in garment production (e.g., additive manufacturing, automation with robotics) is still in the early development and/or adoption phase. Considering that automation with robotics is the main trend in other industries, the fashion industry must align with this movement, despite the complexities of its implementation at the garment production level.

The fact is evident by this enlightening statement, "The smart factory is a digitally enabled manufacturing facility in which the physical production process is fully integrated with a supporting digital technology ecosystem" (Stomp et al., n.d., p. 4). Garment production implements various digital technologies of Industry 4.0, including IoT, AI, machine learning, additive manufacturing, data integration, and robotics to digitize manufacturing operations, linking the entire production process. This digital transformation would eventually facilitate automation in the garment production line.

Micro-factory

The concept of micro-factory or on-demand production, the current focal point in the fashion industry, responds to the societal pressure that emphasizes sustainability and digital transformation, along with the consideration of consumers' demands on customization and personalization. At the Texprocess event in 2019, the MICROFACTORY, coordinated by the Deutsche Institute fur Textilund Faserforschung (DITF) and partnered with industry, showcased a fully integrated production chain from design to finishing (DITF, n.d.). Recently, the British garment manufacturer, Fashion-Enter Ltd., which partnered with Zund UK, demonstrated a sustainable micro-factory concept in London, utilizing digital cutting technology and advanced workflow processes (Textile World, 2021). The company already partnered with Kornit Digital for garment printing and customization. Further, its on-demand garment manufacturing efforts enable fully automated digital cutting with minimal manual intervention (Images, 2021). Another example, Amazon's automated on-demand clothing factory, was introduced in Jin et al.'s (2019) study, stating as "The entire process of apparel production—from printing textiles and cutting patterns to sewing—is automated with minimum human supervision" (p. 11).

Automation with Robotics

Automation in garment production facilitates on-demand garment manufacturing. The application of robotics also fosters automation in this manufacturing process. Sewbots by SoftWear Automation is a good example that revolutionized the fashion supply chain, promoting on-demand, made-to-measure production (SoftWear Automation, n.d.). However, compared to other industries, automation with robotics in garment production is still limited. Most sewing robots currently available in the market are capable of producing simple products, such as t-shirts, but are not advanced enough to produce sophisticated garments. The success of automation with robotics in garment production relies on the way fashion manufacturers can seamlessly integrate this advanced technology with other digital technologies (e.g., AI, additive manufacturing, CAD) in production facilities. Skilled 3D operators, who have acquired fundamental knowledge on apparel pattern-making principles, should be entrusted with managing these automated facilities.

3D Printing and 3D Fabrication

Advancements in 3D printing, also referred to as additive manufacturing, enable the fashion industry to incorporate this technology into the on-demand manufacturing process to create personalized and customizable wearables, considering circular fashion. 3D printing has been much utilized in producing fashion accessories, such as shoes, bags, and jewelry, which has proven the scalability of 3D printed fashion accessories for commercialization. For instance, Adidas introduced the first mass-market 3D printed shoe, called Futurecraft 4D, in 2017, in which the midsole was printed with light and oxygen using the Carbon Digital Light Synthesis™ technology developed by a company called Carbon (Sanger, 2017). This concept upgraded to ADIDAS 4D within two years, showcasing the potential of data-driven design and digital manufacturing on a global scale (Adidas, 2019). Other examples include Julia Daviy's sustainable 3D printed bag and jewelry collections (Daviy, n.d.).

At the moment, the majority of 3D printed garments have been created through selective laser sintering (SLS) with nylon or fused deposition modeling (FDM) with other rigid filaments, for example, Nervous System's (2014) kinematics dress and Kim et al.'s (2019) 3D printed dress. Most 3D printed wearables are composed of rigid hinge-joint interfaces or interlocked chainmail (e.g., Chen, 2020; Nervous System, 2014, 2017), resulting in limited flexibility compared to apparel made

from traditional textiles. Although designers started adopting flexible 3D printing materials, such as thermoplastic polyurethane (TPU) in wearables' design (e.g., Cui & Sun, 2018; Sun, 2018), its application has been limited to small pieces of wearables, such as bras and gloves.

In 2017, Danit Peleg, the founder and creative director of 3D Printed Fashion, launched a revolutionary platform on her website allowing customers to order personalized 3D printed jackets (Peleg, 2018a). She also offers the digital files of the 3D garment, supplied to customers who can print their garments using their 3D printer (Danit Peleg, 2018b). Nervous System's kinematics cloth also enables the creation and purchase of custom-fit 3D printed garments, reflecting one's body shape, garment shape, pattern density, and textile structure (Nervous System, n.d.). The use of 3D printing has also expanded to luxury fashion brands such as Atelier Versace and a high-end jewelry company American Pearl (Jin & Cedrola, 2018b, p. 23).

3D printing is revolutionizing the fashion industry by enforcing the adoption of circular fashion through the disruption of the traditional fashion supply chain. Research and development are encouraged for developing 3D printed wearables with its material innovation, which can fully mimic garments made of traditional fabrics in terms of functionality and wearability.

Consumer Engagement and Experiences

The disruptive nature of the fashion industry movement has allowed consumers to digitally engage in the product design and development process, which better fulfills their demands through the features that enable customization, personalization, and virtual try-on. Advanced technologies, such as AI, machine learning, AR, and VR in the era of Industry 4.0, have enhanced consumer engagement and enriched their experiences with wearables (Rahman, 2019). Fashion brands utilize AR technology for different purposes, including fashion shows and consumer try-on experiences with the help of smart mirrors (PYMNTS, 2019; Zadidi, 2018). For the past few years, AR technology has rapidly evolved in both traditional and online fashion retail platforms to better engage with consumers. The COVID-19 crisis has underscored the relevance of AR technology for online fashion retailing because of its capability to allow consumers to experiment with different fashion products without visiting physical retail stores. However, its applications in apparel design and

development have not been widely explored. Integrating AR technology in wearables is a novel way of digital product creation, which enables the wearer to better communicate with other people and try on products by utilizing their multiple sensory system (Min & Kim, 2019).

Wearable technology, part of product innovation according to Jin and Cedrola (2018b), is also employed to increase consumer engagement and experiences with products for the purpose of improving their health and well-being. Consumers often consider Google glasses, Apple Watch, Fitbit, and Bluetooth headsets as wearable products (Gartner Inc., 2017). Although smart clothing or smart footwear is one type of wearables integrating information technology and wearable computing devices, they are still at an early adoption stage in fashion. Followings are a few examples of smart clothing that were introduced in Jin and Cedrola's (2018a, 2018b) work on innovations in product development (pp. 24–25): Tommy Hilfiger's solar-powered jacket, Ralph Lauren's smart shirt with PoloTech™, Under Armour's athlete recovery sleepwear, and Levi's Strauss & Co's smart commuter jacket partnered with Google. Wearable technology, one of the promising technologies to promote human beings' needs and desires, requires substantial research and development on smart or e-textiles, smart clothing, and wearable robots with the holistic integration of other advanced technologies, such as AI, machine learning, and AR to thrive in the new digital landscape.

Conclusion and Future Trends

The fashion industry has been rapidly interrupted by the COVID-19 crisis, owing to country-wide lockdowns, factory shutdowns, travel bans, unavailability of labor, raw material shortages, soaring logistics costs, retailer and supplier bankruptcies, and a surge in online demand. All these factors compelled the companies in the industry to rethink the way they operated, which facilitated an overhaul through the integration of a digital platform in their entire product design and development process. The global movement on sustainability also circled into each stage of the fashion supply chain, which has been fostering the current trend of circular fashion.

This introductory chapter discussed technology innovation that has emerged at each stage of the fashion supply chain, including material development, product design and development, production, and consumer engagement in the context of circular fashion as shown in

Fig. 1.1. In the current state of industrial revolution (Industry 4.0), this chapter depicted the prevailing uptakes of technology innovation occurring in renewable materials, wearable technology, 3D visualization and prototyping, 3D printing, on-demand micro-factory, automation with robotics, customization and personalization, and consumer engagement through AR and VR, which helps minimize the time to market, reduce costs and waste, and improve efficiency. This technology innovation will be continuously evolving throughout the forthcoming industrial revolution process.

Scalability is one of the key challenges concerning the complete integration of emerging technologies. To scale its capabilities, the current barriers, including process, culture, and talent, should be revisited.

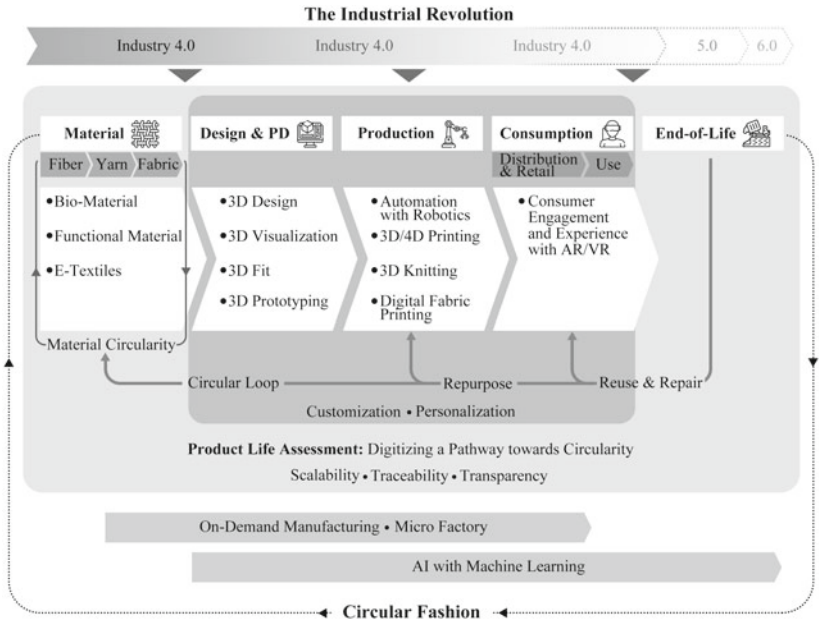

Fig. 1.1 Technology Innovation throughout the Circular Fashion Pipeline (*Source* Developed by the author)

Existing supply chain models cannot function with the disruptive innovations evolving with the current digital fashion industry movement (JustStyle Magazine, n.d.). The future of fashion supply chain should comprehensively reflect the disruptive innovations and consumer demands during the process of product design and development. Transparency, traceability, and collaboration are the key assets for the industry success. The COVID-19 pandemic has been a decisive turning point in this industry, enabling its accommodation to the digital transformation movement. For instance, Calik Denim addresses the incorporation of sustainability, transparency, and digitalization, through the QR code integrated system, which shares the lifecycle assessment (LCA) scores of the products calculated with 8 parameters. In addition, the system allows the tracing of fiber origin, certificates, and other vital and relevant information (Warren, 2021).

Over the last decade, the need for workforces with a fresh and productive blend of skills, possessing production floor experience and skills in advanced digital technologies, has gradually become apparent. The upscaling of workforces in the fashion industry in terms of talent is thus highly encouraged. Fashion programs around the globe can play a major role in nurturing agile workforces through close collaboration with industry partners. People working in various sectors, including academia, design and development, manufacturing, retailing, and supply chain, should be familiar with emerging terms and definitions (e.g., 3D operator, material designer, digital global footprint) utilized in the digital landscape of the fashion industry. Workforces in the digital and circular fashion industry need to be more flexible to work as a cross-functional team to better align with the course of direction of the industry. A new industrial revolution will continually evolve and, thus, everyone should be ready for constant disruptive changes.

Sources of Further Information

For additional information and news regarding technology innovation in the fashion industry, please reference the following collection of resources.

- Add Ease LLC (https://www.addease.nyc/): A full-service 3D apparel and technical design agency.

- Artistic Denim Mills (ADM; http://admdenim.com/index.php): A company that seeks to introduce innovation and unique market solutions throughout the value chain in the denim industry to produce premium denim fabrics and garments for high-end customers.
- Browzwear (https://browzwear.com/): A company providing 3D fashion design, development, and merchandising solutions.
- CLO (https://www.clo3d.com/): A virtual fashion simulation company revolutionizing the design process with true-to-life 3D garment simulation.
- Fashion Enter (https://www.fashion-enter.com/): A non-profit social enterprise striving to be a center of excellence for the sampling, grading, production, and learning and development of skills within the fashion industry.
- Kalypso (https://kalypso.com/): A Rockwell Automation company focusing on the digital transformation of the value chain, from product to plant to end user.
- Lectra (https://www.lectra.com/en): A company empowering customers through industrial intelligence. Their software, hardware, and services build agility and efficiency into every process, from design to production.
- MOTIF (https://motif.org/): An apparel knowledge hub that connects professionals around the world with the skills and industry expertise they need to transform their businesses, lives, and careers.
- Nervous System (https://n-e-r-v-o-u-s.com/): A generative design studio that works at the interaction of science, art, and technology using 3D printing technology. They create computer simulations to generate designs and use digital fabrication to realize products.
- Optitex (https://optitex.com/): A company providing end-to-end fashion design software for various industries including fashion.
- PI Apparel (https://apparel.pi.tv/): A membership community for apparel and footwear professionals which helps to adapt and thrive in a digital world.
- Seamless Design Solution (http://www.seamlessdesignsolutions.com/): A company helping fashion apparel companies to become more cost effective, agile, and sustainable through virtual technology.
- Self-Assembly Lab (https://selfassemblylab.mit.edu/): A research lab at MIT inventing self-assembly and programmable material technologies.

- STITCH 3D (https://www.stitch3d.com/): A software as a service startup helping fashion product creators to scale 3D collection development.

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