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Futuristic fashion: How AI technology is shaping the garment industry

Barbara A. Manko *, Lisa Kovalchick and Pratibha Menon

Department of Computing & Engineering Technology at Pennsylvania Western University, California, PA USA.
Barbara A. Manko ORCID ID: https: orcid.org/0000-0001-6916-5717
Lisa Kovalchick ORCID: https://orcid.org/0009-0001-6009-8535
Pratibha Menon ORCID: https://orcid.org/0009-0006-8295-5354

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Abstract

Fashion is inspired by beauty and nature, by the changing demands and choices of people, and by the visions of designers. Today, however, it is also inspired by digital technology in various ways that are redefining the landscape of the garment industry. Increased data, digitalization, and technological advancements such as 3D printing are increasing speed to market, allowing for customization, and making sustainable operations possible. As the digital landscape grows, purely conceptual offerings may become big business for brand names. Through literature review and case studies, possible future outcomes are explored.

Keywords: Analytics; Digital Fashion Design; Digital Advertising; Big Data; Digital Fashion Image; Japan; Digital Reality; Management

1. Introduction

In April 2020, Donatella Versace was quoted in Vogue, saying, "The world as we knew it is over." As the pandemic threatened the status quo of the fashion industry, cancelling shows and redistributing resources to sew masks instead of collections, Leitch talked to various famous designers to ask how they thought the industry would change for the better as a result. Various answers included discovering a new lease on creativity and passion, taking advantage of streaming platforms to take the place of in-person shows, and focusing on sustainability by reusing fabrics and rethinking the design process. It is a philosophical debate outside the scope of this paper to determine if (now going into 2025) we have created a new normal or largely returned to the old way of doing things.

Digital technology is reshaping many industries, including one that always has been strongly associated with the human touch: fashion. Previous attention was given to digital technology and how anyone with a computer take advantage of existing software platforms to personalize a fashion staple: the t-shirt (Manko, 2023). In contrast, this paper surveys the various ways in which new technologies are being used and having an impact within the more established world of fashion and how designers can take advantage of influencers, social media marketing, and CAD technology to further develop their brand. We begin with an overview of the subject, from historical times to the present. Following sections then examine particular new technologies and trends in more depth. The paper closes with brief case studies that illustrate how fashion is moving in truly "futuristic" directions in order to allow customization globally, illustrated by the accessibility to Japanese street fashion.

* Corresponding author: Barbara A. Manko.

2. The Landscape of Fashion and the Impacts of Technology: An Overview

Most people understand the vast distinction between runway fashions and the ready-to-wear versions that consumers see in stores, and also the differences between name-brand designer clothing and "fast fashion" choices at bargain prices. All of these together are considered the modern fashion industry, and they amount to a big global business. Although the lower-priced sectors of fashion can be hard to distinguish from the apparel market generally, the luxury sector alone is sizable. From the designer houses of Paris to Italy, South Africa and Japan, the high-end fashion business was recently estimated to have a worth of about $300 billion (Fani et al. 2021).

In the distant past, more than two hundred years ago, "the latest fashion" would be defined in Paris annually, and local seamstresses would then create wardrobes for the privileged to wear based on those designs. With the Industrial Revolution and evolution of manufacturing, standardized choices with uniform quality became more readily available, cheaper, and allowed for a greater selection. Now, with digitalization, big data, and virtual technology, the evolution of the fashion industry can once more offer custom creations, but this time at affordable rates. As with any fashion, some customers are willing to pay a higher amount for personalized experience and do not see price as a barrier (Sharma et al. 2021), while others must be more budget conscious. Digitalization allows for improvement in many aspects of fashion development, with better communication and marketing and development of processes that support advancement in the industry (Nobile et al. 2021).

Many enterprises are moving toward mass customization. However, there is still some lead time that must be built in when converting from mass production of standard items. Even though consumer-driven demand can move rapidly, limiting these businesses to turnaround times of a few days or weeks and cost to amounts comparable to mass production, quick response requires product variety and high flexibility (Kielarova and Pradujphongphet, 2020). This can be aided by computer-aided design (CAD) software, which allows communication among the manager, customer, product designer, engineers, and technologists to process a preset variety of parameters through a system (ibid). Jin and Shin (2021) define "hyper-personalization" as "offering solutions tailored to consumers' specific needs, be it tangible, such as a product, or intangible, such as variety."

New models of fashion will require new models of learning, as fashion design students will need to incorporate AI, VR, 3D and 5G technology into their learning platforms, according to Guedes and Best (2018). At the time of their study, the authors observed that most fashion instruction in Europe continued to follow traditional pathways, with the use of technology limited to offering lecture-based education in new spaces, such as online. They commented that "a new generation of fashion designers will relate and interact with their sector differently," redefining processes that range from the "traditional manners of creating, manufacturing and selling fashion, to traditional ways of communicating and interacting with the fashion consumer" (ibid).

Even in the initial research for this publication, the discussion was focused around advancements in digital technology, with only passing mention of the implementation of AI. Liang et al (2019) explained that because the technology is new, the research is also limited. They focused on the Echo Look to determine consumer attitudes toward AI, but explained that "smart in-store technology, mass customization technology, augmented reality, virtual try-on, and virtual personal assistants" would revolutionize the way consumer behavior evolves.

No matter what the era, people are interested in the latest styles and in making a good impression by being current on trends. Fashion magazines continue to be sources that they consult, and the sources are now expanding to social media. Current fashion trends are often set by influencers on social media sites like Instagram, which the fashion industry uses as tools to "depict idealized digital-cultural-era lifestyles" (Suh, 2020). The online fashion and textile sector has one of the highest volumes of sales, with different qualities of service for different segments of customers, depending on the demand (Castro-Lopez et al. 2019). Consumers have lower levels of trust when it comes to mobile platform use, and luxury brands do better by fostering feelings of exclusivity in their customers. For this reason, social media marketing can support existing marketing channels but will not replace it, especially for Generation Y (Parker and Kuo, 2021).

The industry uses a "bottom-up strategy" when implementing fashion software that meets the needs of users (Fani et al. 2021). Examples of this may include the many print-on-demand graphic T-shirts that are available on sites such as Amazon, Etsy, Zazzle, or Printify; or sites like eShakti that allow customization of dress length, sleeve and neckline with a fit guarantee. Many sites now offer models of various sizes, or the ability for users to visualize what a garment will look like on them by entering their body dimensions and specifications.

Werdayani and Widiaty (2021) discuss how the use of these virtual fitting rooms is starting to change conventional ones. Virtual room technology can function offline or online, and be web or mobile, using 2D or 3D fashion design, digital

communication, e-commerce, e-magazines or e-books, and be internet-based or ICT-based (ibid). It is easy to break into the digital marketplace. To sell on Amazon, for example, users only need "an Amazon account, a supported smartphone, and the Amazon Go app to register their entrance into the store" (Hauser et al. 2019). Brands like Nike and Adidas are able to offer highly customized options using 3D virtual reality-based solutions (Sharma et al. 2021).

Other forms of digitalization are taking hold in fashion as well. To gain a better sense of their uses and effects, let us now consider some particular applications of digital technology, along with trends in how the fashion industry deploys them.

3. Big Data in Fashion

According to previous research by one of the authors of this paper, the collection and analysis of "big data" is spreading across many industries, with growing investments aimed at benefits that can range from improved business efficiencies to faster innovation cycles (Manko, 2022). Today's fashion enterprises collect large amounts of data from websites, stores, and apps, using it to identify preference and to better meet market demands. Data mining can be used to analyze the output from various sources (Wazarkar and Keshavamurthy, 2018). Analysis can be challenging, due to the volume and unstructured nature of so much data, but classification allows for efficiency in categorizing users as they try to remain up to date on the latest trends and styles (ibid).

The presence of big data in fashion allows for personalization and virtual fitting, ensuring each customer gets a custom experience. Today's technology allows data to be filtered through design-support and recommendation systems. Zhao et al (2021) conclude that using big data platforms to offer designs based on the factors consumers want may "overcome the emphasis in traditional design on the subjective aesthetics of fashion designers," as customers make their choices based on factors important to them, such as comfort, durability, versatility, or sustainability.

4. Virtual Fitting Systems

Since the 2010s, increasingly sophisticated digital moving images have been developed, and their use in fashion and sports brands (Uhlirova, 2020) increases a website's possible offerings. Virtual fitting systems allow consumers to bring the fitting room to the living room, by using virtual mannequin fittings or an identified comparable real human body. Zhao et al (2021) rightly point out that "a customer will not buy [the item] if it does not fit well." Currently, there are drawbacks, as the fit of the garment is simulated based on direct contact with the body, so it is harder to predict how looser-fitting clothing will look. Some consumers still find it hard to identify with avatars that they don't feel adequately represent how they themselves would look in the outfit, and therefore the virtual experience is seen as a weak substitute for in-person shopping (ibid). It is possible to upload images and personal information to represent the shopper, so the display gives a realistic portrayal of the final product, but Zhao et al (2021) warn that this could create personal information risks.

When it comes to fit, anyone who has ever tried to order dress shirts for a wedding party knows how difficult it can be to get the right sleeve length, shirt length, and neck measurement for every member of the party, especially if budget-conscious planners don't want to order custom tuxedos. The problem is also evident when trying on jeans. A size 10 in a dozen different brands will fit a dozen different ways, with cut, color, distressing, waistline, stretchiness, fit, and flare just some of the variables. An in-person shopper can go through every item on the rack and still not find one pair that fits right. Being able to enter body measurements and customize options helps ensure that an online buyer won't need to alter the pants in order to wear them. (See Figure 1.)

5. 3D, 360-degree Views

Another digital capability that is now available allows the customer to personalize a design and then rotate through a 3D virtual display. One drawback is that current virtual-fitting platforms are "relatively simple," limiting the options available. Also, most customers lack design knowledge, so they cannot always achieve the desired look through their own efforts. Adding expert recommendation systems can help create looks that suit the customers and work from a fashion standpoint. However, these may also then lead to increased time and cost. (Zhao et al. 2021)

6. Trends in the Use of Technology

A major focus of digital technology in the fashion industry is concerned with website graphics and user interaction. Jo et al (2020) describe the limitations that exist in current search methods when shopping online: in order to get the best results, users must plug in the right text information, but while they may be able to readily describe what they want,

they may not know the correct terms to use to produce matches. The authors suggest that, with development, the technology exists to allow users to sketch a broad idea of what they're searching for, and a generative adversarial network (GAN) could then extract properties of the sketch to search for similar images. With VR capabilities, it may soon be possible to browse in a virtual space that better emulates traditional stores. Jo et al also explain that once basic values are set for the recommendation model, suggestions will improve over time as the program learns, based on the preferred fashion profiling.

It is possible for simulations to meet a matching error of less than 5 percent by using big data on human body characteristics to build a neural network model, rather than the current process that seeks a high correlation coefficient between human body parts and output clothing (Cui et al. 2021). More work can also be done with building digital functionality into the clothing itself (Giri and Stolterman, 2020). Some companies, like Svaha, offer virtual reality designs printed on their material, which can be scanned with a smartphone to see the animation. At present this is a fun way to incorporate the company's science, technology, engineering, and mathematics (STEM) philosophies, but the same technology could lead to many other advancements.

According to Hauser et al (2019), a survey showed that "92% of retail businesses consider digital innovation as vital or very important." Comments included calling it "something retailers can't afford not to do" and "one of the most powerful tools [they] have in being able to learn about what [their] customers need."

Technology is reshaping the industry in several ways. Giglio and Conti (2022) place the main trends into three categories: digitalization leading to mass personalization, advancements that will make the idea of seasonal apparel obsolete, and technology that will make the idea of connected clothes "extreme." "Connected clothes" have the ability to monitor the wearer's physical condition, by incorporating micro-instruments that can measure heart rate and other biometric data. The movement to embed such devices in clothing also includes the use of new high-performance or sustainable fabrics. The focus in this case is on optimizing the material's usability in certain conditions. So-called 3D textiles, which are produced using digital technology along with advanced fibers, can be made more durable than conventional fabrics and can also keep the wearer more comfortable in variable weather by providing micro-climate control (ibid). Although such high-performance material is still in early development, it is clear that 3D fabrics will be able to benefit those interested in achieving high-performance results (ibid).

7. CAD Technology

Automating the design process allows for digitalization to lead to personalization. Consider the previous example of a men's formal shirt. A system can be built on the basis of existing garments and product styles, programming a 3D CAD tool with data from the designer's process. The consumer is then able to choose design attributes such as fabric, color, collar and cuff type, sleeve length, etc., and is given peace of mind by having designer feedback on the final result. The more data that is input into the system, the more the system learns, and service can be extended in the future by adding more definable parameters. (Sharma et al. 2021)

Wang and Zhong (2022) further discuss how using CAD technology for computer grading can "provide nonstandard body-shaped clothing pieces, which can meet market demand…and improve product competitiveness." This can improve the fit and comfort of clothing for all wearers, regardless of size and shape.

8. 3D Printing

3D printing technology has several advantages. New products can be developed quickly without using specialized tools; shortening the production cycle reduces cost and improves speed to market; and increasing speed to market results in higher levels of competitiveness (Zheng et al. 2021). The fashion industry has been slower to implement 3D printing than other fields, such as architecture, because working with fabrics makes the relationship between the 2D pattern and the 3D garment harder for software to predict (McQuillan, 2020). Nonetheless, many clothing companies are now using 3D design software, and fashion curricula are adding courses to teach its use. McQuillan suggests that "accurate 3D software for garments has had a significant impact on the fashion industry in the last five years" (i.e., since 2015), and can contribute to the goals of zero-waste production and hybrid textiles and fashion. The development of user-friendly digital tools could make the use of 3D textiles economically and ecologically sustainable at an architectural scale (Giglio et al. 2022).

Parametric designs, which are fluid and often based on shapes found in nature, "produce greater effects when combined with 3D printing technology" and allow mass production of an infinite number of design possibilities (Jeong et al. 2021). These ornate designs blur the line between design and programming (ibid).

9. Zero-Waste Fashion

The fashion industry currently operates in a system of "take, make, use and dispose" (Bang and DeLong, 2022). Lower-quality products are cheaper to produce, which allows for more consumption but also more waste (ibid). There are several campaigns to increase sustainable clothing. Some brands, like Rothy's, use recycled single-use plastic bottles to make thread for shoes and bags and incorporate other sustainable production methods. There are also campaigns that encourage upcycling, thrifting, and buying used. The fashion industry has recognized that it can be detrimental to the environment. For example, a number of firms now partner with a nonprofit group called Global Fashion Agenda, which promotes "industry collaboration on sustainability in fashion" (Global Fashion Agenda n.d.).

Environmental impacts can occur throughout the product life cycle: not only in producing fabrics, but also in shipping goods overseas and selling items that may soon be discarded. Therefore, in order to encourage "circular fashion" with consumer cooperation, "unused clothes are collected, donated, and sold to waste operators, charity organizations, and used shops" (Nagano, 2022). Every year, before championship sporting events like the Super Bowl in American football, two sets of souvenir garments are produced—a set for the fans of each team that might win the title—and the unused, losing team's merchandise is donated to charitable organizations in third-world countries. With an eye on the planet, it is possible for "new zero-waste methods that more profoundly integrate the design of textile with the design of form in a truly holistic systems-based approach … [which can lead to] redesign of the industry as a whole" (McQuillan, 2020).

Daukantienė (2022) started with the premise that the fashion industry is the second-most polluting in the world, and after a literature review, concluded, "the integration of complex decisions into the business models of both manufacturing and marketing companies must be implemented to develop the sustainable fashion industry from a long-term perspective."

10. Case Study: Japanese Fashion

Although an in-depth analysis is beyond the scope of this paper, the fashion scene in Japan could provide a very interesting laboratory for future studies of the use of technology in fashion. This is because of the unique nature of the Japanese market. Their fashions reflect many diverse influences, and styles are both industry-designed and user-created.

Japan is known for a culture that combines traditional and cutting-edge elements. Notable traditional elements include the country's history, shrines, kimonos, and tea ceremonies; while modern shoppers enjoy such things as the latest consumer technologies, the Hello Kitty franchise, interesting food choices, and so-called street fashion. In the West, Japanese street fashion is often referred to as "Harajuku," the district in Tokyo where many different and highly expressive styles are worn by young people parading through the streets. Tokyo shopping districts such as Harajuku, Shibuya, and Ginza offer some of the world's trendiest and *avant-garde* creations (see for example, Harberger, 2022). By using technology, Japan is able to offer the same individualized menu choices for fashion as are seen in the country's many vending machine options.

Tradition and innovation blend in various ways in Japan. While many schoolchildren are required to wear uniforms, since the 1980s schools have allowed more individuality in hair and attire (Tamura, 2007). Postmodern fashion in Japan has evolved from street fashion (Kawamura, 2006). To an outside eye, street style may appear to be a combination of Western influences (e.g., a Superman logo or jeans) and more traditional Eastern clothing, such as a kimono or the required school uniform. (See Figure 2 for examples.) Winge (2017) explains that the scene is even more nuanced: "Youth typically create their distinctive street style with handmade clothing combined with select store-bought items worn with specific style guidelines. The Decora group, for example, practices a subcultural bricolage."

The main components of street fashion include:

- A distinctive look that allows wearers to identify as members of a group, fostering a sense of social connection, unity and belonging.
- Fashion is produced by anyone with an idea. Teens are the "gatekeepers" and "agents" of street fashion.

Looks must be inexpensive and the speed at which fashion changes is cut down to a matter of weeks, rather than following the previously established seasons (Kawamura, 2006).

Source: Pexel artists NEOSiAM, Mnz and Mica Asato: used by permission.

Figure 1 A variety of blue jeans.

Source: Pexel artists Meijii and Quŏc-boá, used by permission.

Figure 2 Examples of Japanese style

Japanese fashion is not limited to street fashion; it is also changing in the adult world. A recent media movement dubbed #KuToo pushed back against company dress codes requiring high heels for women, which has influenced fashion in a modern and feminist twist (Nonaka, 2020). However, Japan's global competitiveness in the apparel industry has declined since the 1990s (Donzé and Fujioka, 2021). The current focus is on the young adult Asian consumer as fashion becomes a sign of status in society (O'Cass and Siahtiri, 2013). The elderly population is also growing, exceeding 30

percent, and as the current youth population ages into adults, their fashion demands may affect the market offerings (Chen et al. 2016).

There are independent designers, trade associations, retailers, apparel companies, and fashion media in Japan, but they focus on a small and specific piece of Japanese fashion, leading to a lack of global influence (Donzé and Fujioka, 2021). The incorporation of Western elements in their fashion brings influence from outside, and the often over-the-top looks do not always translate internationally. However, Donzé and Fujioka conclude that Japan's brands have weakened more due to "issues of production and technology." The authors write that fashion companies must increase their flexibility to meet consumer demand, as well as to ensure that their efforts remain profitable, and this makes Japan an interesting place to watch for new trends in fashion technology.

11. Case Studies in Digital Reality: Atacac and The Fabricant

Our sense of community has expanded to include the digital. The ability to share, interact, and construct knowledge virtually has been embedded in everyday life, until relationships online become as strong as those created in person (Neil, 2019). Särmäkari (2021) extends this to fashion, saying that "fashion itself can be considered as a history of technology." The art of fashion design has been affected by technology, as

…digital platforms and social media have boosted fashion dissemination, immediacy and accessibility, distributing fashion authority to diverse assemblage of participants, blurring boundaries between production and consumption, professionals and amateurs, physical and virtual, material and intangible, as well as object and image. (ibid)

Techno fashion is currently seen as a tool for virtual product development or a marketing tool for online stores, but in the future, fashion may increasingly be offered as a "*digital-only end-product* for virtual use" (ibid). Once a design exists entirely digitally, it is limitless. A Swedish fashion company, Atacac, is exploring these possibilities.

Founded in 2016 by fashion designer-researcher Rickard Lindqvist and digital artist Jimmy Herdberg, Atacac is a microfactory using the "kinetic garment construction theory" that Lindqvist developed for his PhD thesis. This includes a pattern-cutting paradigm that takes into account the relationship between the body and the clothes when the wearer is in motion as well as when stationary. Linkqvist uses CLO3D software to design from a pattern and presents the clothes digitally to buyers for approval. Many garments are pre-purchased before production begins, and the earlier an item is ordered, the less it costs. Relatively few clothes go into inventory and they carry the highest price tags. Lindqvist believes that in the future, name-brand fashion designers can profit from e-clothes as easily as they currently do from bags or perfume (Särmäkari, 2021).

Meanwhile, in Amsterdam, a studio called The Fabricant is exploring a co-creation approach to fashion. The company has announced that its mission is to "Build a new fashion industry where everybody participates and profits." (The Fabricant, 2022) Further, as the company's "Manifesto" states:

In this new reality, a kid in Dakar stands as much chance as a kid in Paris of becoming an influential fashion force, with the tools to bring their ideas to life and a network of supporters that promotes, distributes and sells their work. Collaborations happen in real time across the planet, making multi-creator digital collections that give each of us the chance to be recognised and monetise our efforts for the long term (ibid).

As of November 2022, items shown in The Fabricant's online Marketplace included avant-garde coats and jackets, boots, cape-like "headdresses," exotically-themed pantsuits and more. Each garment was displayed online in a rotating 360-degree concept view, along with text that named the persons or groups who had partnered with The Fabricant on the design. The text also described the materials from which an actual garment could be made. Prices were listed in both cryptocurrency and US dollars, with many designs priced in a range between about $40 and $400 (The Fabricant, 2022a).

In the co-creation process, a client or partner brings an idea or a design brief to The Fabricant. The idea is then worked into a fully realized design through storyboarding, and is draped on an avatar. The story and the digital garment create an experience that is itself an end product, almost a combination of fashion and animation. The Fabricant envisions this new fashion industry as completely digital (Särmäkari, 2021).

12. Summary

Futuristic fashion: How AI technology is shaping the garment industry

The paper examines how digital technology is revolutionizing the fashion industry, driving changes from design and production to marketing and consumer experience. It highlights the growing impact of tools like big data analytics, 3D printing, CAD, and virtual reality, which are enabling mass customization, sustainable practices, and interactive digital experiences. The study discusses how social media and influencer culture are shaping trends, and presents case studies—such as Japanese street fashion and digital-first companies like Atacac and The Fabricant—to illustrate the fusion of creativity and technology. Ultimately, the paper concludes that fashion's future lies in greater personalization, sustainability, and digital innovation, urging designers and educators to embrace new skills and adapt to a rapidly evolving landscape

13. Conclusions

Given the recent focus on innovative technology, creative street-fashion looks may expand globally through digital platforms, where the looks can be displayed virtually on avatars and where there is less constraint as to what comprises "fashion." The evolution of fashion will continue to change the world's view as technology allows for more personalized production, environmental sustainability, and "smart" tech wear that communicates with the body in various ways. This will be accomplished in part with the development of new platforms, as well as the use of current resources like CAD, 3D printing, data analytics, and social media. Purely digital "outfits" allow fashion designers unchecked creativity when resources are limited in the physical world and digital reality is no less "real" because it doesn't exist physically. The community of fashion can offer ways of expression and belonging in the digital space as easily as it can on the streets of Tokyo. The future of fashion is full of limitless possibilities. Further study is needed to analyze the effects of AI technology in the fashion industry, especially in the areas of consumer behavior, process development, and sustainability.

Compliance with ethical standards

Disclosure of conflict of interest:

No conflict of interest to be disclosed.

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