

# Digital Fashion Technologies & Practices: Design Driven Sustainable Transition in Fashion Industry

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## Abstract

Contemporary clothing manufacturing, purchasing and consumption models have made the fashion industry the second most polluting industrial sector. This contribution aims at analysing promising technologies, methodologies and practices that are tackling environmental sustainability issues related to the fast-fashion industry. The contribution analyses how, leveraging on technology innovation, the combination of tangible processes, such as the selection of production means and materials, and intangible practices, such as digital fashion, designers can contribute to the sustainable transition of the fast-fashion sector mediating between customer expectations, production economy constrains and environmental sustainability.

## Keywords

Fast fashion  
Digital fashion  
Sustainable transition  
Design driven innovation  
Enabling technologies

## Fast Fashion Environmental Impacts

Contemporary clothing production, purchasing and consumption models have made the fashion industry the second most polluting industrial sector. Every year, it is responsible for more emission of greenhouse gases than the aeronautical and naval industries combined (European Environment Agency, 2022). Its production methods pollute rivers and degrade soil contributing to biodiversity loss (McKinsey cited in Ellen MacArthur Foundation, 2021). Synthetic materials, which most clothes are made from, spread into the ocean in the form of microfibers.

During the last 20 years, clothing production has doubled whereas the use life has significantly shortened: it's estimated that each piece of clothing is worn 7-10 times on average before it is thrown away (Grand View Research cited in Ellen MacArthur Foundation, 2021). 87% of disposed clothing goes to landfill or it's burned and only 1% is correctly recycled (Textile Exchange, 2020). One reason for this is that textiles are made from complex intertwined threads (Fashionary, 2020) connected to hard components such as accessories, buttons and fasteners which are difficult to disassemble during disposal (Fantin et al., 2020). Such environmental impacts are amplified in the fast fashion sector: a production-consumption system characterized by a fast and dynamic creative process that allows brands to bring to the market new products every week. Fast fashion creates a globalized distribution that exploits standardized production delocalized in low salary countries where brands commission production to third-party factories avoiding direct production risks (Jayot, 2020). As highlighted by Jayot (2020), fast fashion is characterized by a continuous offer of new products that generate a fast esthetical obsolescence and a global standardization which steps away from customer's desire of individualism and customization.

This production-consumption model has a strong impact also on social sustainability aspects such as the working conditions of factory workers: starting from the 2013 events of Rana Plaza, where a building hosting 5 garment factories collapsed due to heavy production machines overloading the structure (Allchin & Kazmin, 2013), the Fashion Revolution movement (<https://www.fashionrevolution.org>) is trying to raise awareness among citizens, governance and companies about fast fashion social, economic and environmental impact, promoting more sustainable working condition in the fashion industry.

This contribution aims at analysing promising technologies, methodologies and practices that are tackling social and sustainability issues related to the fashion industry in order to evaluate which design driven approach can help the fashion industry transition towards a more environmentally sustainable system.

## Materials & Technologies Circular Transition

More sustainable and circular processes that involve the whole production chain, starting from raw material sourcing to product disposal, are necessary for containing environmental impacts of the fashion industry and, in particular, those of fast fashion (Earley

& Goldsworthy, 2015; Goldsworthy et al., 2018). Fast fashion is a complex productive system that involves a number of actors operating under strong economic and competitive stress (Niinimäki et al., 2020). In order to foster this transition, the fashion industry needs to adopt new design-driven approaches that combine circular and sustainable manufacturing process, conscious materials selection and the promotion of responsible consumption models (Circular Fashion, 2018; Coscieme et al., 2022; Goldsworthy & Earley, 2018).

The use of smart manufacturing technologies allows production optimization, making prototyping and production phases faster, cheaper, and more sustainable. The digitalization of the design phase, and in particular the use of 3D textile modeling software to visualize the relationship between shape, pattern and textile waste production, represent a significant support towards zero-waste production processes (McQuillan, 2020). By way of example, the knitting machine manufacturer Shima Seiki produces knitting technologies capable of making an entire garment from a single thread with a single machine by composing it in 3D (Moore & Smith, 2020). Such technologies, which work by addition not subtraction (Conti & Motta, 2019), make it possible to only consume the needed resources for the garment production, limiting industrial and pre-consumer textile waste.

The designer, as a mediator between disciplines (Celaschi, 2015), must know and handle such technologies to identify design strategies that accommodate their use. Knowledge of textile recycling technologies is also necessary: chemical composition, colors, and the presence of rigid parts are just few of the factors influencing the possibility of recycling clothes (Eppinger, 2022; Karell, 2021). Such characteristics are variables that designers need to consider and handle responsibly in order to facilitate the recycling process in a design for the end of life perspective (McKinsey & Company, 2022). These issues are of great interest for the European community since, by 2025, all member states will have to implement services and infrastructure for the separate collection of textiles.

In order to meet sustainability goals, a growing number of companies are making efforts to transition towards a circular manufacturing model, using production wastes from other industries or selecting recycled or recyclable fibers. Designers can characterize a material, identifying its unexpressed potential and introduce one sector's waste into another as secondary raw materials exploiting its potential (De Giorgi et al., 2020). For example, Napapijri's Circular series offers garments that are 100% recyclable since they are made entirely of regenerated Nylon 6. Fibers and accessories are thus recyclable without the need for disassembly since they are made from the same material. Technologies, such as RFID codes, can contain information about the origin of the material and the recycling processes. Traceability and transparency are key elements for users information and education not only about the environmental impact of manufacturing technologies (Niinimäki, 2017), but also on the societal level as they can contribute to the monitoring of the working conditions of fashion workers (Ellen MacArthur Foundation, 2021). In addition, such data-driven technologies can be key to new clothing return policies and facilitate corporate take back services for recycling and reuse.

Customer education plays an important role in reducing the environmental footprint of the fashion industry. A possible strategy is engaging the customer in the customization process of the final product taking advantage of digital tools such as on-demand decentralized production. Such technologies offer customers custom artifacts that can address individual functional and esthetic needs. The Unmade platform (<https://www.unmade.com>), for example, offers companies that want to transition to an on-demand supply chain model a software that allows users to customize the items they purchase within parameters predefined by the brand. Individual orders are integrated into existing production chains and can be produced at the same cost and speed as mass-produced items. Manipulating the matter brings awareness to the customers as it generates amazement and affection to the product building a strong relationship between the user and the manufacture and extending the use-life of the product. (Karana et al., 2017). Dutch designer Martijn van Strien's with *The Post Couture Collective* allows consumers to download, customize, produce, and self-assemble clothing patterns. Each of the items can be customized to the buyer's measurements and aesthetic taste, produced at a local Makerspace, and finally assembled by the user.

Such design strategy can improve the sustainability of this industrial sector in need of a paradigm shift towards a slow-fashion approach that can limit overproduction and overconsumption (Niinimäki et al., 2020). This "super-slow" view of using garments is compared with "ultra-fast" models by Goldsworthy, Earley e Poltowicz (2018). The researchers argue that it is necessary to propose solutions that can sustainably and circularly respond to people's need for continuous consumption. Aware that it won't stop over time, researchers have experimented with the use of low-impact rapid manufacturing technologies associated with the choice of biodegradable materials for the production of responsible disposable clothing.

### **Digital Fashion as a Tool for Sustainability**

The implementation of Industry 4.0 model into the fashion sectors plays an important role in the reshaping of a more sustainable production system capable of activating innovative design-driven manufacturing processes (Bertola & Teunissen, 2018) involving scholars and impacting on a broad context of disciplines, ranging from humanities to science and technology. Therefore, the so-called "Fourth Industrial Revolution" has been described as a model where new modes of production and consumption will dramatically transform all major industrial systems; it has been targeted by many governmental plans as a goal for a sustainable future. While general frameworks describing 4.0 paradigm are codified and accessible, implementation strategies and their implications on specific local and sectorial systems are largely unexplored. Starting from this assumption, this paper aims to provide insights on the current state of the art and major trends of the "Fourth Industrial Revolution", possibly identifying its impacts on the textile and apparel industry. Design/methodology/approach From a methodological standpoint, the study approaches the topic from the perspective of fashion

domain experts which can contribute, with a positioning essay, to better understanding Industry 4.0 (I4.0). In the field of fashion 4.0, digital fashion refers to three levels of digital technology implementation: product development and visualization, marketing and communication, virtual clothing and accessories (Särmäkari, 2021). Acting on these three levels can contribute to diminish the environmental impacts of the fashion industry leveraging on the different phases of product design, manufacturing, communication, distribution, consumption, disposal and on the object of the production itself.

Digital fashion is a topic of growing interest among academic researchers and practitioners (Joy et al., 2022; Noris et al., 2020). Further accelerated by the pandemic, a number of important fashion brands and companies have shown interest in the digital fashion market. The need for new virtual touchpoints with clients that could substitute those inaccessible because of the pandemic has opened an opportunity for brands to establish new ways to connect with clients. Balenciaga's Fall 21 collection *Afterwards: the age of tomorrow* (<https://videogame.balenciaga.com/en/>) was presented digitally using a videogame that could be played directly on a web browser. This kind of communication channel opens toward a younger audience, that of Gen Z, which is more used to interact with brands via social media and digital channels. Although in Balenciaga's presentation interactivity was limited to the virtual environment exploration, it introduced an innovative approach in how fashion show could be conceived compared to runway steaming and fashion movies. The look book, which has been shoot with real models and clothes, recalls the poses and the feel of avatar selection screens in videogames suggesting that the collection was not specifically designed for either the physical world or the virtual one but for both or, possibly, for an overlapping space where tangible and intangible spaces coexist.

The dialogue between the fashion industry and the videogame medium has also developed into new product categories designed and sold as digital only wearables. Gamers' contribution to the customization of virtual avatars, with both original designs and fan-made collections inspired by official branded releases, raises questions about the commercial relationships with fashion brands and trademarks in digital mediums (Gibson, 2021). When entering the digital domain and the videogame market, digital fashion opens to the opportunity to build a common ground for new consumers and brands where it is possible to co-create and share value beyond the tangible identity of the artifact. The development of social media platforms, fashion blogs and digital tools enable people outside the fashion system to participate actively redefining the hierarchies of fashion communication and the consumption paradigms, allowing for a more transparent, participatory and diverse industry (Crewe, 2013).

That of digital fashion is a developing market and the effects, however, one of the promising impacts could be its contribution to the optimization of production costs and to the diminishing of waste production. For example, fashion brand marketing and communication strategies leverage on social media platforms and influencers to promote new products and collections. Thanks to Augmented Reality technology, physical products could be advertised via their digital counterparts even before mass production gathering data about sales prediction and adjusting production volumes accordingly.

Platforms like Dressx (<https://dressx.com>) offer the possibility to buy and virtually wear digital clothes: the user uploads a picture and the garment is fitted on the body. Pictures are then generally shared on social media by the users and wearing clothes online will eventually be extended to video calls, AR filters, and custom avatars.

As seen in the previous paragraph regarding physical products, customers' involvement in the co-creation of new products contributes to build a stronger relation not only with the brand values but also with the product themselves. A more emphatic relation with artifacts, fostered by hybrid physical and digital touchpoints, could generate more conscious consumption behaviors. The Fabricant (<https://www.thefabricant.com>) is a fashion house designing digital-only clothes who is building a Web 3.0 platform where users can customize and trade digital garments with the goal to build a decentralized fashion economy where participation and co-creation is at the center of the fashion industry innovation.

Although the production, distribution and consumption of virtual garments has an impact in terms of resources consumption and CO2 emission, unlike physical products, some of the environmental impacts of the fashion industry (such as waste production and disposal) doesn't affect virtual products. Virtual products could represent a possible mediation between our society's continuous consumption needs and environmental sustainability limits (Lehdonvirta, 2012). However, it is worth noticing that the virtual product market has been recently characterized by a significant use of blockchain technologies for digital assets acquisition and transfer. Such technology, and in particular the Ethereum Network, is used to avoid digital counterfeiting and introduce artificial scarcity but it is characterized by a significant impact in term of energy consumption undermining the digital fashion contribution as a sustainable alternative to the continuous consumption of physical products (*Ethereum Energy Consumption Index*, n.d.). Recently, more energy efficient blockchain consensus mechanism are being developed and adopted (Bach et al., 2018) and in September 2022 the switch from a *Proof of Work* (PoW) to a *Proof of Stake* (PoS) consensus mechanism allowed the Ethereum Network to considerably lower its energy consumption. The evolution toward more efficient blockchains, the development of more fluid customer experiences and the integration of blockchain-based trading system in digital platforms users are already familiar with, could foster the growth of the virtual product market.

### **Conclusions: Tangible and Intangible Practices for a Sustainable Transition in Fashion Industry**

More sustainable production chains and more environmentally aware consumption models are necessary for the future of the fashion industry. The combination of tangible processes, such as the selection of production technologies and circular materials, and intangible practices, such as digital fashion, can constitute a range of suitable approaches to support designer's contribution to the sustainable transition of the fast-fashion sector. The hybridization of strategies acting both via tangible and intangible approaches can facilitate a smoother transition for users whose sensibility for envi-

ronment-related matters and interest and familiarity with digital tools and products is growing. Leveraging on technology innovation and on a strategic view over the fashion industry evolution, companies can sustain an ecological transition for the fashion industry and, at the same time, build new value for customers.

The use of digital technologies in the field of fashion has favored the emergence of new product categories, professionals and companies operating in virtual clothing production and commercialization. Consequently, also employees digital skills are expected to be considered more relevant and strategic by fashion companies requiring fashion curricula to be updated and integrate ICT competences (Nobile et al., 2021). This can represent a great opportunity for designer to be at the center of this sustainable transition in the fashion industry developing design driven approaches capable to mediate between customer expectations, production economy constraints and environmental sustainability.

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Advanced designer, Ph.D, Research fellow. Her research focuses on the designer's role in the transition to the new uses of polymers in fashion sector. Since 2019 she is a member of the Advanced Design Unit with whom she carries out activities of applied research and education. She attended a first cycle degree in Industrial Design and a master's degree in advanced design.

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#### References

- Allchin, J., & Kazmin, A. (2013, April 24). Scores dead in Bangladeshi garment factory collapse. *Financial Times*.
- Bach, L. M., Mihaljevic, B., & Zagar, M. (2018). Comparative analysis of blockchain consensus algorithms. *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 1545–1550. <https://doi.org/10.23919/MIPRO.2018.840027>
- Bertola, P., & Teunissen, J. (2018). Fashion 4.0. Innovating fashion industry through digital transformation. *Research Journal of Textile and Apparel*, 22(4), 352–369. <https://doi.org/10.1108/RJTA-03-2018-0023>
- Celaschi, F. (2015). AdvanceDesign Points of View. In M. Celi (Ed.), *Advanced Design Cultures. Long-term perspective and continuous innovation* (pp. 3–17). Springer International Publishing. [https://link.springer.com/chapter/10.1007/978-3-319-08602-6\\_1](https://link.springer.com/chapter/10.1007/978-3-319-08602-6_1)
- Circular Fashion. (2018). *Circular Design Kit. Design strategies for material cyclability and longevity*.
- Conti, G. M., & Motta, M. (2019). Focused practices for future changes. *DIID*, 72, 70–79.
- Coscieme, L., Manshoven, S., Gillabel, J., Grossi, F., & Mortensen, L. F. (2022). A framework of circular business models for fashion and textiles: The role of business-model, technical, and social innovation. *Sustainability: Science, Practice and Policy*, 18(1), 451–462. <https://doi.org/10.1080/15487733.2022.2083792>
- Crewe, L. (2013). When Virtual and Material Worlds Collide: Democratic Fashion in the Digital Age. *Environment and Planning A: Economy and Space*, 45(4), 760–780. <https://doi.org/10.1068/a4546>
- De Giorgi, C., Lerma, B., & Dal Palù, D. (2020). *The material side of design. The Future Material Design Cultures*. Umberto Allemandi.
- Earley, R., & Goldsworthy, K. (2015). Designing for Fast and Slow Circular Fashion Systems: Exploring Strategies for Multiple and Extended Product Cycles. *Mistra Future Fashion, Phase 2 (2015 - 2019); Design Theme*. PLATE conference.
- Ellen MacArthur Foundation. (2021). *Circular design for fashion*. Ellen MacArthur Publishing.
- Eppinger, E. (2022). Recycling technologies for enabling sustainability transitions of the fashion industry: Status quo and avenues for increasing post-consumer waste recycling. *Sustainability: Science, Practice and Policy*, 18(1), 114–128. <https://doi.org/10.1080/15487733.2022.2027122>

Ethereum Energy Consumption Index. (n.d.). Digiconomist. <https://digiconomist.net/ethereum-energy-consumption/>

European Environment Agency. (2022). *Textiles and the environment: The role of design in Europe's circular economy*.

Fantin, V., Giuliano, A., Porta, P. L., Barberio, G., Brunori, C., Chiavetta, C., Claps, D., De Carolis, R., Fontana, D., Forte, F., Genovese, A., Mancuso, E., Mingazzini, C., Pasquali, M., Puzone, M., Meini, L., Panvini, F., Loporcaro, A., Incarico, G., ... Università di Bologna. (2020). *L'economia circolare nelle filiere industriali: I casi tessile, abbigliamento e moda (TAM) e mobilità elettrica* (R. De Carolis, V. Fantin, G. Barberio, P. L. Porta, A. Giuliano, L. Meini, & F. Panvini, Eds.). ENEA. <https://doi.org/10.12910/DOC2020-005>

Fashionary. (2020). *Textilepedia*. Fashionary International Limited.

Gibson, J. (2021). When games are the only fashion in town: Covid-19, Animal Crossing, and the future of fashion. *Queen Mary Journal of Intellectual Property*, 11(2), 117–123. <https://doi.org/10.4337/qmjip.2021.02.00>

Goldsworthy, K., & Earley, R. (2018). Circular Transitions: Textile design and the circular economy. *Journal of Textile Design Research and Practice*, 6(1), 1–4. <https://doi.org/10.1080/20511787.2018.1505362>

Goldsworthy, K., Earley, R., & Politowicz, K. (2018). *Circular design speeds: Prototyping fast and slow sustainable fashion concepts through interdisciplinary design research (2015-2018)*. 84.

Jayot, E. (2020). A Designer Contribution to the Use of CNC Machines Within the Supply Chain in Order to Extend Clothing Life Span. In G. Vignali, L. F. Reid, D. Ryding, & C. E. Henninger (Eds.), *Technology-Driven Sustainability: Innovation in the Fashion Supply Chain* (pp. 27–55). Springer International Publishing. [https://doi.org/10.1007/978-3-030-15483-7\\_3](https://doi.org/10.1007/978-3-030-15483-7_3)

Joy, A., Zhu, Y., Peña, C., & Brouard, M. (2022). Digital future of luxury brands: Metaverse, digital fashion, and non-fungible tokens. *Strategic Change*, 31(3), 337–343. <https://doi.org/10.1002/jsc.2502>

Karana, E., Rognoli, V., & Giaccardi, E. (2017). Materially Yours. In J. Chapman, *Routledge handbook of sustainable product design*. Routledge.

Karell, E. (2021). *Closing the Loop through Clothing Design: Wishful Thinking or Achievable Practice?*

Lehdonvirta, V. (2012). *A History of the Digitalization of Consumer Culture: From Amazon Through Pirate Bay to Farmville* (SSRN Scholarly Paper ID 2501350). Social Science Research Network. <https://papers.ssrn.com/abstract=2501350>

McKinsey & Company. (2022). *Scaling textile recycling in Europe—turning waste into value*.

McQuillan, H. (2020). Digital 3D design as a tool for augmenting zero-waste fashion design practice. *International Journal of Fashion Design, Technology and Education*, 13, 1–12. <https://doi.org/10.1080/17543266.2020.1737248>

Moore, R., & Smith, A. (2020). Disrupting digital making for seamless knit design. *Textiles, Identity and Innovation: In Touch*. International Conference on Textiles, Identity and Innovation (D\_TEX 2019), Lisbon, Portugal, 19 – 21 June 2019, Londra.

Niinimäki, K. (Ed.). (2017). *Sustainable Fashion in a Circular Economy*. Springer International Publishing. [https://doi.org/10.1007/978-3-319-51253-2\\_8](https://doi.org/10.1007/978-3-319-51253-2_8)

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, 1, 189–200. <https://doi.org/10.1038/s43017-020-0039-9>

Nobile, T. H., Kalbaska, N., de Oliveira, R. A., & Cantoni, L. (2021). Digital Fashion Competences: A Longitudinal Study. In T. Sádaba, N. Kalbaska, F. Cominelli, L. Cantoni, & M. Torregrosa Puig (Eds.), *Fashion Communication* (pp. 17–28). Springer International Publishing. [https://doi.org/10.1007/978-3-030-81321-5\\_2](https://doi.org/10.1007/978-3-030-81321-5_2)

Noris, A., Nobile, T., Kalbaska, N., & Cantoni, L. (2020). Digital Fashion: A systematic literature review. A perspective on marketing and communication. *Journal of Global Fashion Marketing*. <https://doi.org/10.1080/20932685.2020.1835522>

Särmäkari, N. (2021). Digital 3D Fashion Designers: Cases of Atacac and The Fabricant. *Fashion Theory The Journal of Dress Body & Culture*. <https://doi.org/10.1080/1362704X.2021.1981657>

Textile Exchange. (2020). *Material change. Insight report 2020. The state of fiber and materials sourcing*. <https://mci.textileexchange.org/insights/>