The Case of Fabric and Textile Industry: The Emerging Role of Digitalization, Internet-of-Things and Industry 4.0 for Circularity

Chapter · September 2021

DOI: 10.1007/978-981-16-1781-2_18

CITATIONS
55

READS
3,309

2 authors:

Ari Happonen
Lappeenranta – Lahti University of Technology LUT
216 PUBLICATIONS **3,468** CITATIONS
SEE PROFILE

Malahat Ghoreishi
LAB University of Applied Sciences
18 PUBLICATIONS **509** CITATIONS
SEE PROFILE

The Case of Fabric and Textile Industry: The Emerging Role of Digitalization, Internet-of-Things and Industry 4.0 for Circularity

Malahat Ghoreishi and Ari Happonen

Abstract In the circular economy (CE) world, design is a vital tool to transform waste to wealth to enhance material recycling for new products (e.g., design for modularity, design for disassembly, etc.). Industry 4.0 technologies and digital innovations have recently provided positive impact towards CE transition, for instance through data-analysis of products lifecycle. In this regard, a close collaboration is required between industries, consumers and policy makers for a more detailed and precise data on product lifecycle and waste collection as well as consumer behavior. Accordingly, digitalization can help in tracking and tracing products through transferring the real-time data on products' location, condition, availability, etc., which can boost product-life extension through sensors and digital platforms. In order to have a more efficient and effective CE solution, close collaboration is required among various actors of textile circular ecosystem, where the consumers are the core of such ecosystem. In this sense, IoT plays an essential role by transferring information and data to all the actors and improving their awareness of new circular opportunities. This paper focuses on how utilizing IoT will increase the opportunities of textile circulation towards a higher effective ecosystem and maximizing products value.

Keywords Industry 4.0 · Circular Economy · Internet-of-Thing · Textiles · Circularity · Sustainability · Sensors

1 Introduction

Fast fashion has been recently one of the significant concerns of environmental experts which makes huge pollution worldwide. Sustainability solutions have a very slow implementation to prevent social and environmental negative impacts

M. Ghoreishi (✉) · A. Happonen
LUT University, Lappeenranta, Finland
e-mail: Malahat.ghoreishi@lut.fi

A. Happonen
e-mail: Ari.happonen@lut.fi

of textile industry with the growing of "middle-class" population. Therefore, there is a vital need of collaboration between all segments of the fashion industry ecosystem, in particular the role of policymakers and governments to create sustainable supportive frameworks. The Global Fashion Agendas chief sustainability officer Morten Lehman stated in 2019 that *"While it's encouraging to see 12.5% of the global fashion market taking concrete action toward circular business models, we must urgently address major roadblocks collaboratively to pave the way for a systemic shift towards circularity"*. Ellen MacArthur Foundation [1] reports that less than 1% of the used materials in clothes production are recycled. In addition, the amount of used clothes collection for recycling is under 15%, whereas 73% end up to the landfills or being burned. Currently, fashion industries have realized the opportunities that circular business models can bring to the textile companies, for example increasing the value chain by recycling the used materials instead of wasting finite resources. Implementing circular solutions of collecting and recycling fibers would bring EURO 80 billion value to the world economy by 2030 [1].

According to European Parliament [2], 2–10% of environmental impact in Europe is due to clothes industry. Additionally, European Commission reported in 2013 that textile industries alone generate approximately 16 million tons of waste in EU annually. According to the report, this high amount of textile-based waste is generated due to the lack of transparency and poor level of data sharing between all the actors of the clothes industry ecosystem, such as manufacturers, retailers, suppliers, and specially consumers. From waste point of view, huge amounts of water and chemicals are required in all stages of producing raw materials, spinning, weaving, and dyeing fabrics, as can be seen in Fig. 1.

Due to the growth in new styles and fashion as well as increasing population in middle-class, clothes production has been increased enormously over the past 15 years [1]. On the other hand, studies on customers' behavior show that huge

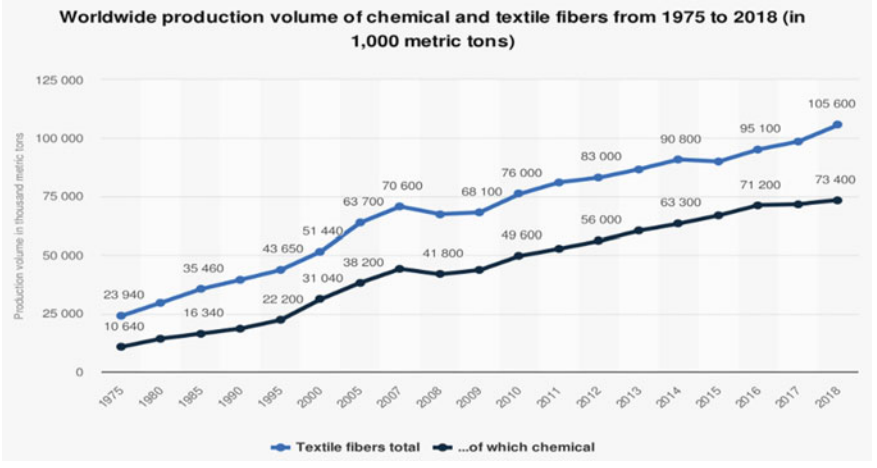

Fig. 1 Periodical production of textile fibers and chemical (*Source* Garside 2019)

amount of clothes are thrown away before they are damaged or unfunctional [3]. In other words, willingness to pay and purchase the clothes are higher than consumption of the products. Thus, customers play the key role in contributing to high environmental footprints. Moreover, apparel industry is highly based on linear model in all phases of producing, distributing and disposing of their products. Current system is highly extracting large volumes of materials to produce fabrics and garments from non-renewable resources which will be used in a short period and will end up huge landfill waste. It is discussed if the textiles and clothing industries implement eco-friendly designs in their processes, fashion industry will turn hugely to a more sustainable economy model [4].

2 Circular Economy in Textile Industry

The circular economy (CE) has recently gained attentions of policy makers and businesses as a solution to enhance sustainability goals. In a CE world when products, materials, and components face their end-of-life, they will be used as raw material in processes of new material production to reduce waste landfills which is called closed-loop and is in contrast with linear economy model, "take-make-dispose" [5]. The CE has contributed significantly on industrial development by minimizing waste and optimizing finite resources so that materials maintain their economic value for possible longer time which leads to a more sustainable process [6]. Such outstanding benefits of CE can help companies with their quest to be constantly competitive and to minimize their environmental footprints. Circular strategies such as reuse, restore, refurbish, repair, etc., enhance productivity and resource efficiency [7]. Circular solutions offer positive effect on value creation as well as *"customer value proposition, supply chain, value networks of the companies and capturing the value of new offerings"* [8].

As mentioned before, consumer has an enormous role in achieving sustainability goals in the fashion industry. Consumer attitudes on use, wash, repair, rental, and loan as well as quality consideration in purchasing clothes rather than several purchases are highly affective factors in transition toward circularity in fashion industries. In addition, customer collaboration with textile industries regarding recycling and returning the old and used clothes to the companies are considered as high impact factor in moving toward CE. Therefore, having the right mindset, knowledge, and consumption guidelines is highly important in value creation based on CE principles. Accordingly, it is essentially required to have close collaboration among all the segments in the value network to help pave the way for circular innovations for companies.

Circular business models such as rent (clothes rent to slow the loop), design products for re-use or recycle (circular fashion), design for better quality that can convince customers to buy less but higher quality (slow fashion) [2] have been recognized as the solutions for the negative footprints made by textile industries. According to Smits et al. [9], textile industries can transform their linear business strategies to circular strategy based on three approaches as follows:

Table 1 Principles of circular fashion

	The production perspective		Customer perspective
Design principles	Source and production principles	Lifetime extension	Behavioral and usage model
Purpose	Local source and production	Reuse, recycle or compost all remains	
Longevity	Zero toxicity	Supportive service for long life	Use, wash and repair with care
Resource efficiency	Efficiency consideration	Wide and high-quality collaboration	Rent, loan, swap, secondhand or redesign instead of new purchase
Recyclability	Good ethics work mood		

Source Brismar [10]

- Material flows circular strategies, e.g., reuse wastes as resources and generate value.
- Servitization strategies with focuses on non-ownership and more as service.
- Efficient use of resources which leads to sufficiency.

In this regard and considering the circular feasibility of mentioned business for fabric industries, Brismar [10] identified sixteen key principles for circular fashion framework which aims to support sustainable textile and fashion industry as illustrated in Table 1.

Understanding and identifying the business ecosystem approach for textile circulation is essential since circular ecosystem consists of various networks including different companies, individuals, organizations, and digital technologies to enable the circularity in the ecosystem and life cycle. Fontell and Heikkila [11] introduce the circular business ecosystems as business ecosystem approach as follow: *"Circular business ecosystems are business ecosystems, which together create products, solutions and services based on the principles of a circular economy and apply circular business models in their way of operating and doing business"*. Circular business ecosystem of textiles is illustrated in Fig. 2.

In this system, the goal is to reduce additional consumption, efficient, and on-time maintenance services for the products as well as preventing waste generation in order to save resources and enhance businesses. As can be seen from Fig. 2, the major dominant business models in textile circular ecosystem are repair, reuse, and recycle. Furthermore, users consisting of induvial consumers, professionals or organizations are the core in textile circulation ecosystem and make it a significant consumer-oriented ecosystem. The main goal in all the loops is to maintain material flows and create value where the loops strongly depend on users' attitude and behavior. According to Fontell and Heikkila [11] the role of retailers has been increasing in re-using textiles. It is discussed that their role will be more involved in near future not only in offering new clothes based on virgin materials, but also clothes which

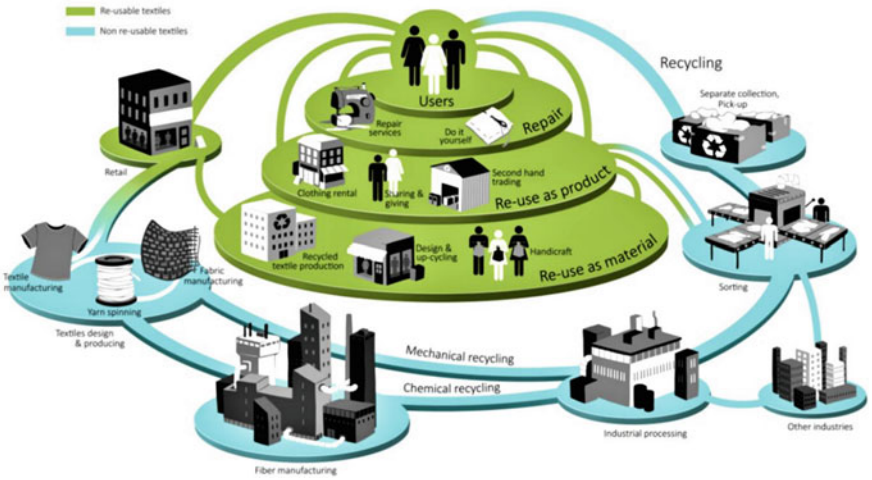

Fig. 2 Circular ecosystem of textiles (*Source* Fontell and Heikkila [11])

are made by recycled fabrics, upcycled or second-hand. Retailers are capable to help increase sustainable knowledge of consumers and help them in making more sustainable choices due to their close interactions with end-users and customers. Van den Berg and Bakker [12] mention that product design plays key role in CE, therefore the first step in moving to CE is to design products that are first of all "be loved, liked, or trusted longer". Consumers will keep their favorite clothes for longer time and in some occasions till the products are broken down. Table 2 shows the circular product characteristics introduced by Van den Berg and Bakker [12].

Based on Table 2, in textile industries, clothes should be designed with better quality fabrics and fibers which enables reuse and repair of textiles as products or as materials. Repurposing and redesigning pre and post-consumer textiles aim to eliminate textile wastes at design stages. If the fabrics and garments are in acceptable, good condition they can be re-purposed or up-cycled by transforming materials into new products with similar or higher quality or can be transferred to the next users. Design for modularity and standardization in fashion industry is related to clothes design which matches various combinations. Clothes designs should take into account the easiness for the users to care and repair the products by providing guidelines and instructions for users. Moreover, providing spare parts or related information on maintenance services while selling products support design for ease of maintenance in textile industries. In design for upgradability, clothes are designed for adaptable usage, e.g., use of the same clothes for several occasions. Buttons and zippers are made of different materials than garments in textiles, therefore designing for reassembly or disassembly helps in easy removals of such materials from the products and makes it easier to re-use fabrics. Finally regarding the recycling of textiles and garments, it is important that consumers have the determination to choose if the clothes can be reused or should be recycled. All the principles above help to

Table 2 Product design strategies in circular economy

Adapted from Van den Berg and Bakker [12]

keep the material flow, however in current infrastructure it is difficult to handle the whole flow, especially regarding collection and sort of discarded clothes.

3 Digital Solutions for Textile Circularity

Despite of all the advantages that circular economy models can bring to the economy, society, and environment, transition toward circularity might be of high challenge and costly for various businesses [13]. Antikainen et al. [14] discuss that Industry 4.0 (the fourth industrial revolution) such as IoT (Internet-of-Things), AI (artificial intelligence), Big Data, and 3D printers (three-dimensional printers) can pave the way of moving toward circular models for businesses. Pillsbury and Lübben [15] mention that *"digital networks and interaction can create an integrated system of actors, assets and stakeholders where not only supply chains can be real-time tuned with the factory but also retail channels and even products and final customers can communicate and exchange data within the system"*. Such technologies can support products' visibility by providing precise information and real-time data through intelligent sensors on products' condition, location, availability, and assets. Industry 4.0 technologies should make it possible to produce eco-system of "smart factories", "smart networks", and "smart products". In such eco-systems, the improved data transformation on information about markets and end-users' demand helps in the complexity on decision-making for the companies. Zhong et al. [16] define the roles of Industry 4.0 in CE as follows:

- Design: Smart design, smart prototyping, smart controller, smart sensors
- Maintenance: Real-time control and monitoring, Collaborative decision-making
- Control: Big Data analytics, data-enabled prediction, and data-based modeling
- Scheduling: Marketing, warehouse management, transports
- Monitoring: Technology makes the real-time sharing of information possible.

According to Ghoreishi and Happonen [17], Industry 4.0 technologies are capable of transferring tremendous amount of data. Such technologies connect real-time data on product design (e.g., resource use to reduce the consumption) which helps businesses in decision-making in the production process. In addition, monitoring products through digital technologies help companies in predicting maintenance and future requirements for maintenance services so that organizations can prevent extra costs related to the maintenance and services will be done just at the time they are needed. Moreover, digitalization connects data on supply and demand through shared platforms and apps which transfer information between organizations and customers [18].

4 IoT and Circular Fashion

Industry 4.0 paradigm plays a significant role in circulation in apparel industries due to the mass data generation in all the activities within the ecosystem. Ingemarsdotter et al. [19] define the opportunities that IoT can bring to support circular strategies as shown in Table 3.

Different sensors, platforms, and applications of machine learning can connect more efficient interaction among the actors of the ecosystem to accelerate circulation.

Table 3 Integration of IoT opportunities and CE strategies

CE strategies	IoT application
Servitization business models	Helps in enabling performance-based service contracts by the monitoring system performance Enables more attractive service models
Maintenance business model	Facilitates maintenance and adaptation through precise data records on installed products and parts Enables predictive and condition-based maintenance services
Reuse and/or remanufacturing business model	Enables tracing and tracking used products and materials Enables more accurate estimation on products' lifetime
Design for durability business model	Reducing faults in product design through data collection and analysis on material condition

Utilizing data to track and trace the product brings the opportunity to manage life cycle of the product and to enhance predictive maintenance, re-use, and recycling processes. Hence, the openness of data and sharing precise data and information among different actors of circular textile ecosystem is essential to achieve circular goals. Huge data on fiber composition and chemicals used for dyeing and manufacturing the yarn can be analyzed faster with the reduction in flaws of prototyping and manufacturing processes. This way helps resource optimization and efficiency as well as accelerating the recycling of materials and other circulation processes. Moving toward "smart factory" via implementing innovative technologies creates significant sustainable benefits and higher efficiency worldwide [20]. Figure 3 illustrates different implications of Industry 4.0 technologies in fashion industry.

Utilizing RFID tags that can hold all the relative information regarding the materials and chemicals in the products can help the circulation in the ecosystem. In addition, implementing these tags will help in tracking product availability in shops and analysis of customers' behavior and demands. Hence, these tags can help transferring precise and real-time data without retailers involvement to the manufacturers so that they can make better decisions in manufacturing products and provide services for the end-users. Furthermore, since there is enormous data to be collected on life-cycle assessment of the products, digital technologies can enhance transparency, availability, and reliability of data [21]. However, the circulation of such data within an ecosystem has been challenging due to the lack of data availability.

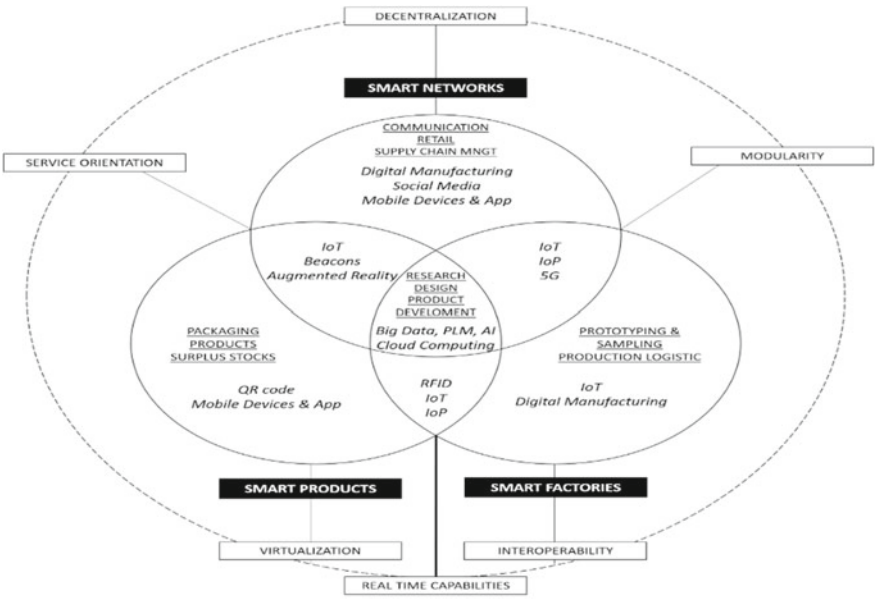

Fig. 3 Fashion principles and Industry 4.0 technologies (*Source* Bertola and Teunissen [21])

Traditional fashion business models were based on design, for which industry 4.0 technologies can create smart networks. In this regard, digital platforms are the fundamentals in circulation of textiles. Through these platforms which are programmed by machine learning algorithms, consumers can rent, borrow and resell clothes which enhances the re-use business model in circular economy of textiles. Moreover, AI-based platform and IoT sensors can help in optimization and management of warehouses. Data on availability of the products in the storages and warehouses will transfer to the managements and helps in predicting consumers' need and therefore, prevents extra production. In a smart fashion system, which is built upon IoT, Blockchain, and AI, products are produced based on the quantity of markets' demand. Traceability of such products makes it possible to track the entire lifecycle and to customize, optimize and upgrade products according to users' demand.

The modern embedded technology age buzzword IoT is gaining an increase of market value with 2020 $1.7 trillion reaches [22]. The IoT has gained focus of smart manufacturing industries recently in the processes of high-speed monitoring and controlling data transformation in industrial systems. Implementing IoT in such systems accelerates interaction between devices and human-to-device interactivity in a more trustable and faster way. The IoT is described as an ecosystem in which devices are connected to each other or to the Internet to monitor the status of objects, gathering data, and transferring useful information through applications via Internet networks. Smart objects, Radio Frequency (RF) technologies as well as machine-to-machine communication are the main building blocks of the IoT [23–25]. To enable interactions and communications between physical objects and devices, the IoT needs some essential components such as Radio Frequency Identification (RFID). RFID tags are known as Auto-ID technology to help identify the objects, e.g., following high value items in supply chains [26]. By use of RFID tags, objects can communicate even in wireless situations to transfer information that helps in monitoring data on smart objects. Implementing sensors in the smart objects in addition to RFID tags makes it possible to measure data on quantity changes, temperature, and such types of information [21]. As can be seen in Fig. 3, in the factory level IoT is used in production sphere through fast prototyping and sampling through which the production quantity will be more precise and closer to the market demand and prevents overproduction. The IoT applications which are used in retail help in communication with customers and by use of sensors they can analyze and track the lifecycle of products. Moreover, the IoT can help in smart product design and development as well as smart packaging. For example, customers can track their products easily via mobile application, where the application utilizes sensors related augmented data, collected from the smart packages. However, to enable this function, (1) correct smart solutions in supply chains management, Big Data, and assets fleet-level analysis [27] (2) warehousing decarbonization [28], (3) possibilities and challenges to implement digital solutions, and 4) artificial intelligence-based approaches as enablers for highest level circularity solutions [29] are required to be considered in ecosystem. The integrated architectural model in Fig. 3 presents the 6 design principle (Modularity, Interoperability, Decentralization, Service orientation, Virtualization and Real-time capabilities) for the implementation of Industry 4.0 technologies into the context of fashion industry

[30]. Combination of such applications will lead to a more circular system that is more cost-efficient and have less footprints.

Furthermore, integration of IoT and CE accelerates logistics, supply chain management, and asset management with sufficient knowledge of infrastructure and product reusability, etc. For example, IoT can be used as sensors in devices that are reusable, and the materials can be recycled. Products that are utilized by sensors such as QR, can enable the process of recycling the components of products when they face end-of-life [31]. In this case, reverse logistics will help the used products to retain their value and return in the cycle of life. Since one of the key roles of CE is to make durable and long-lasting materials, IoT can help in transforming precise data on assets' condition to improve the quality of products. Finally, IoT can speed up data collection in product as a service CBMs which has a huge contribution in CE and reduces negative environmental impacts.

5 Conclusions and Discussions

The emerging role of Industry 4.0 has recently revolutionized almost all business and consumer life activities. In near future, smart connected clothes with digital passports will support the precise data on materials, designs, lifecycles as well as consumers' demands and recycling methods. In product level, tracking the garments and clothes helps companies in waste management, e.g., by identification and fabric content recognition, digital technologies can boost the process of recycling and waste management, hence help the textile industries in their circularity processes. IoT sensors together with AI-based platforms and Blockchain applications can help all the actors of the textile industry ecosystem to transfer real-time data and knowledge on the product's lifecycle and circular solutions in each process. In addition, such technologies can help in upcycling and recycling of the second-hand clothes through digital platforms which can help products to retain their value and simultaneously reduce the consumption of virgin materials. IoT and AI can help in fast prototyping, prediction, and reducing the number of faults in apparel industry, therefore boost CE by reducing the wastes from prototyping and improving and optimizing the energy efficiency.

In this paper, we focused on the opportunities and advantages of integrating digital technologies for textile industries, specially IoT. The study proved that there is lack of literature and scientific studies conceptually and empirically on this specific area. There is huge interest and opportunities for qualitative and quantitative studies in this field to analyze how apparel businesses identify their circular ecosystem and how digital solutions can help them to reach their circular and sustainable goals. Therefore, further research in this field is highly recommended. Since the availability of the data plays an important role in implementation of digital technologies, further research on challenges and barriers that textile industries face in integration of Industry 4.0 and CE is suggested. Finally, policies and regulations are required to be followed

by all the actors of the ecosystem in order to reach sustainability goals in a secure manner.

References

1. Ellen MacArthur Foundation (2017) A new textiles economy: redesigning fashion's future
2. Perliament E (2019) Environmental impact of the textile and clothing industry What consumers need to know
3. Laitala K (2014) Consumers' clothing disposal behaviour - a synthesis of research results. Int J Consum Stud 38:444–457. https://doi.org/10.1111/ijcs.12088
4. Moorhouse D, Moorhouse D (2017) Sustainable design : circular economy in fashion and textiles sustainable design : circular economy in fashion and textiles. Des J 6925:S1948–S1959. https://doi.org/10.1080/14606925.2017.1352713
5. MacArthur E (2013) Towards the circular economy volume 1. Ellen MacArthur Found. https://doi.org/10.1162/108819806775545321
6. Tukker A (2015) Product services for a resource-efficient and circular economy—a review. J Clean Prod 97:76–91. https://doi.org/10.1016/j.jclepro.2013.11.049
7. Blomsma F, Kjaer L, Pigosso D, McAloone T, Lloyd S (2018) Exploring Circular Strategy Combinations - Towards Understanding the Role of PSS. Procedia CIRP. 69:752–757. https://doi.org/10.1016/j.procir.2017.11.129
8. Urbinati A, Latilla V, Symposium DC-II (2018) undefined: the role of product design in circular economy business model. Researchgate Net
9. Smits H, Cunningham G, Wilting J, De Roos Feinberg C, van 't Hof K (2015) Business models and circular strategies for textiles
10. Brismar D (2019) Green Strategy | Sustainable and Circular Fashion Consulting—Towards a more sustainable and circular fashion industry, https://www.greenstrategy.se/en/
11. Fontell P, Heikkila P (2017) Model of circular business ecosystem for textiles
12. Van den Berg MR, Bakker CA (2015) A product design framework for a circular economy. PLATE (Product Lifetimes Environ Conf Proc) 365–379
13. Nascimento DLM, Alencastro V, Quelhas OLG, Caiado RGG, Garza-Reyes JA, Lona LR, Tortorella G (2019) Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. J Manuf Technol Manag 30:607–627. https://doi.org/10.1108/JMTM-03-2018-0071
14. Antikainen M, Uusitalo T, Kivikytö-Reponen P (2018) Digitalisation as an Enabler of Circular Economy. Procedia CIRP. 73:45–49. https://doi.org/10.1016/j.procir.2018.04.027
15. Dutzler H, Germany PS, Schrauf S, Geissbauer R, Strategy P, Müller SR, East SM, Bohsali S, Australia P, Burns P, Spooner N, Vermeire P, Brazil P, Valiño R, Canada P, Wetmore M, Denmark P, Vedsø J, Nieminen K, France P, Romac B, Le Bellac V, India P, Mukhtyar K, Italy P, Caragnano G, Japan P, Kawai T, Okamoto K, Scharff C, Mexico P, Urioste CZ, Khurana A, Mulders M, Poland P, Dziurdzia M, Singapore P, Spain P, Isasi CK, Theron P, Sweden P, Lindblad F, Baldinger G, Atkin N, Jukes D, Shaw D, Pillsbury S, Jaruzelski B (2018) How industry leaders build integrated operations ecosystems to deliver end-to-end customer solutions
16. Zhong RY, Xu X, Klotz E, Newman ST (2017) Intelligent Manufacturing in the Context of Industry 4.0: a review. Engineering 3:616–630. https://doi.org/10.1016/J.ENG.2017.05.015
17. Ghoreishi M, Happonen A (2020) Key enablers for deploying artificial intelligence for circular economy embracing sustainable product design: Three case studies. In: 13TH INTERNATIONAL ENGINEERING RESEARCH CONFERENCE (13TH EURECA 2019). AIP Publishing, p 050008
18. Jabbour AB, Jabbour CJC, Filho M, Roubaud D (2018) Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Ann Oper Res 270:273–286 https://doi.org/10.1007/s10479-018-2772-8

19. Ingemarsdotter E, Jamsin E, Balkenende R (2020) Opportunities and challenges in IoT-enabled circular business model implementation – A case study. Resour Conserv Recycl 162:105047. https://doi.org/10.1016/j.resconrec.2020.105047
20. Kortelainen H, Happonen A, Kinnunen SK (2016) Fleet service generation—challenges in corporate asset management. In: Lecture Notes in Mechanical Engineering. Pleiades Publishing, pp 373–380
21. Bertola P, Teunissen J (2018) Fashion 4.0. Innovating fashion industry through digital transformation. Res J Text Appar 22:352–369. https://doi.org/10.1108/RJTA-03-2018-0023
22. Wen Z, Hu S, Clercq DD, Beck MB, Zhang H, Zhang H, Fei F, Liu J (2018) Design, implementation, and evaluation of an Internet of Things (IoT) network system for restaurant food waste management. Waste Manag 73:26–38. https://doi.org/10.1016/j.wasman.2017.11.054
23. Gubbi J, Buyya R, Marusic S, Palaniswami M (2013) Internet of Things (IoT): A vision, architectural elements, and future directions. Futur Gener Comput Syst 29:1645–1660. https://doi.org/10.1016/j.future.2013.01.010
24. Borgia E (2014) The internet of things vision: Key features, applications and open issues. Comput Commun 54:1–31. https://doi.org/10.1016/j.comcom.2014.09.008
25. Bai TDP, Rabara SA (2015) Design and Development of Integrated, Secured and Intelligent Architecture for Internet of Things and Cloud. Computing. https://doi.org/10.1109/FiCloud.2015.23
26. Hämäläinen H, Salmela E, Happonen A (2007). RFID on Item Level Tagging in Supply Chain with High-Valued Products. https://doi.org/10.5281/ZENODO.3376601
27. Kärri T, Marttonen-Arola S, Kinnunen S-K, Kortelainen H, Kunttu S, Hanski J, Ahonen T, Valkokari P, Uusitalo T, Horn S (2017) Fleet-based industrial data symbiosis: Data to Business Knowledge (D2BK) model. https://cris.vtt.fi/en/publications/fleet-based-industrial-data-symbiosis-data-to-business-knowledge
28. Minashkina D, Happonen A (2020) Decarbonizing warehousing activities through digitalization and automatization with WMS integration for sustainability supporting operations. E3S Web Conf 158, 03002 https://doi.org/10.1051/e3sconf/202015803002
29. Ghoreishi M, Happonen A (2020) New promises AI brings into circular economy accelerated product design: A review on supporting literature. In: E3S Web of Conferences
30. Hermann M, Pentek T, Otto B, Pentek T (2015) Design Principles for Industrie 4.0 Scenarios: A Literature Review Competence Center Corporate Data Quality (CC CDQ) View project Industrial Data Space View project Design Principles for Industrie 4.0 Scenarios: A Literature Review
31. Moktadir MA, Ali SM, Kusi-Sarpong S, Shaikh MAA (2018) Assessing challenges for implementing Industry 4.0: Implications for process safety and environmental protection. Process Saf Environ Prot 117:730–741 https://doi.org/10.1016/j.psep.2018.04.020