UTILIZATION OF DIGITAL TECHNOLOGIES FOR THE CIRCULAR ECONOMY OF FINNISH FASHION INDUSTRY

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ABSTRACT

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Utilization of digital technologies for the circular economy of Finnish fashion industry

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The goal of this Master’s thesis is to respond to the sustainability challenges of the current fashion industry with two emerging themes, the circular economy and digitalization. The aim of the work was to research the current status of the digitalization of the Finnish fashion industry, the opportunities provided by utilization of digital tools with the contribution to circular economy, and the possible challenges related to them, based on a literature review and company examples. Due to low level of digitalization in the Finnish fashion industry, solutions for the life cycle stages of design, manufacturing, retail, and extended use phase have been sought with the help of examples from literature. According to circular economy principles, clothing should be designed to last both physically and aesthetically, minimizing raw material use.

Digitally aided tools and data can be used in designing, which enables the consideration of the whole life cycle already in designing stage. The Internet of Things (IoT), Blockchain and other technologies, which create a digital twin of manufactured products, enables tracking clothes in retail and possibly even in recycling. Supply chain and production transparency and other relevant product-related information can be easily made accessible to consumers with tags that can be read through mobile devices. Companies and third-party services offer solutions to extend the lifespan of products, such as repair services and trading of used clothing. The resource requirements of digital technologies and tools can become a challenge. However, the low level of digitization in the fashion industry can be seen as Finland's advantage, as it enables the design of a seamless digital system without path dependencies.

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Tämän diplomityön tavoitteena on vastata nykyisen muotiteollisuuden kestävyyshaasteisiin kahdella keskeisellä nousevalla teemalla, kiertotaloudella ja digitalisaatiolla. Työn tavoitteena oli kirjallisuuskatsauksen ja yritysesimerkkien avulla selvittää Suomen muotiteollisuuden digitalisoitumisen nykytila, digitaalisten työkalujen tuomat mahdollisuudet ja kontribuutio kiertotalouteen, sekä mahdolliset haasteet niihin liittyen. Suomen muotiteollisuuden digitalisaation alhaiseen lähtötasoon on etsitty kirjallisuuden esimerkkien avulla ratkaisuja suunnittelun, tuotannon, myynnin ja käyttöiän pidentämisen elinkaarivaiheisiin. Kiertotalousperiaatteiden mukaisesti vaate tulee suunnitella kestämään aikaa niin fyysisesti kuin esteettisesti käyttäen mahdollisimman vähän raaka-aineita.

Suunnittelussa voidaan hyödyntää digitaliavusteisia työkaluja ja dataa, jonka avulla koko elinkaari voidaan huomioida jo suunnitteluvaiheessa. Esineiden internet, lohkoketjut ja muut tuotannon teknologiat, jotka luovat digitaalisen version tuotteista, mahdollistavat vaatteiden seurannan myynnissä ja mahdollisesti jopa kierrätykseen asti. Toimitusketjun ja tuotannon läpinäkyvyys ja muu olennainen tuotteeseen liittyvä tieto voidaan tuoda helposti kuluttajien ulottuville mobiililaitteilla luettavien merkkien kautta. Tuotteiden käyttöiän pidentämiseksi, kuten korjauspalveluihin ja käytettyjen vaatteiden myyntiin ratkaisuja tarjoaa yritykset ja kolmannen osapuolen palvelut. Digitaalisten teknologioiden ja työkalujen resurssivaatimukset voivat osoittautua haasteeksi. Alhainen digitalisaation taso muotiteollisuudessa voidaan kuitenkin nähdä Suomen etuna, sillä se mahdollistaa saumattoman digitaalisen systeemin suunnittelun ilman polkuriippuvuutta.

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ABBREVIATIONS

AI	Artificial intelligence
CAD	Computer-aided design
EU	European Union
IoT	Internet of things
PSS	Product-service system
RFID	Radio frequency identification
QR	Quick response

Table of contents

1. Introduction

Current production and consumption patterns have led to the situation where natural resources are overconsumed in many industrial sectors. The overconsuming behavior does not only destroy natural resources but creates emissions, pollutes the environment, and causes social issues related to labor and working conditions. One sector amongst other industries that accelerates the sustainability issues is fashion industry, especially fast fashion. One proposition for solving the fast fashion issues is Circular economy, where the material is in circulation instead of linear economy model. Circular economy adoption can be supported by digitalization and utilizing different digital tools. This Master's thesis studies how digital technologies applied to circular economy of fashion industry can be utilized and what needs to be done in order to avoid negative drawbacks of digitalization in the industry.

1.1. Background

Fast fashion is a phenomenon driven by globalization and a growing middle-class population. New styles and trends are developed quicker than before, and they are often sold with lower prices. While the production of clothing has doubled from the beginning of 21st century, the number of times a piece of clothing is worn is decreased by 36%. (Ellen MacArthur Foundation, 2017.) The impacts of global fashion industry and fast fashion are diverse and world-wide. Greenhouse gas (GHG) emissions of textile production was 1.2 billion tonnes of CO_2 equivalent in 2015. (Ellen MacArthur Foundation, 2017.) Textile production uses water in multiple phases, but one of the most water-consuming activity is farming of cotton. Cotton is often farmed in areas that are already suffering from water-scarcity. (Ellen MacArthur Foundation, 2017.) Water is also consumed and polluted during the treatment and dyeing phases of textile production (Niinimäki et al. 2020).

Commonly used material in textile industry are synthetic fibers or material mixes containing synthetic materials made from plastics. Plastic-based textiles creates microplastic pollution, that can already be found from aquatic environments, atmosphere and in terrestrial environments. Microplastic particles can even end up to edible items through food chains. (Balasaraswathi & Rathinamoorthy, 2022, 4-7.) One source of microplastic pollution is the washing of textiles containing plastics, such as polyester, nylon or acrylic (Ellen MacArthur Foundation, 2017).

There are many solutions to these sustainability challenges, one of them being circular economy, where materials are in so-called loop instead of the "take-make-waste" linear economy. Circular economy practices can be applied to textile and apparel industry through re-designed or extended material use. There are 53 billion tonnes of annual fibre production only for clothing, and 73% of it is either landfilled or incinerated after use. Only about a percent of the whole fibre production is in total circulation. (Ellen MacArthur Foundation, 2017.)

As digitalization and fourth industrial revolution, Industry 4.0, have already taken a place in current world, they also have their own contribution to textile and fashion industry. Digital technologies that are used as a tool for customers and buyers of clothing can be considered the most recognizable. Digitalization is integrated in fast-paced fashion industry and particularly fast fashion. Technologies such as Artificial intelligence (AI), Virtual reality (VR), and Big data analysis (BDA) can create forecasts and analysis on current fashion trends, personalizes customers purchasing recommendations, and can assist a customer on their purchasing decisions (Akhtar et al. 2022).

In order to utilize digitalization for the circular economy of apparel and fashion industry, the technologies need to be integrated into designers and manufacturers practices. In manufacturing environment, the Industry 4.0 technologies are cyber-physical-systems (CPS) integrated in industrial processes. (Machado et al. 2020.) Technologies related to manufacturing, logistics and production demand are intended to producers and they can be applied to pursue circular economy. Currently used digital technologies in the production lines of many industries are Machine learning (ML), On-demand manufacturing, Cloud computing, and Internet of Things (IoT). (Akhtar et al. 2022.) Some major drawbacks related integrating digitalization into apparel industry are the support for fast fashion and feedback phenomenon created by improved efficiency. More efficient processes from the material and costs point of view enables increased production that can speed up the fast fashion phenomenon in the production phase.

1.2. Objectives of the study

This master's thesis studies how digital technologies applied to circular economy of fashion industry can be utilized and what needs to be done in order to avoid negative drawbacks of digitalization in the industry. The objectives behind this Master's thesis is the sustainability issues related to clothing and fashion industry. The goal of the work is to contribute to solving the issues through scientific research. This thesis aims to identify the digital technologies involved in the circular economy of the apparel industry. The output of the thesis is a study how the transition of the industry could be made in a truly sustainable way taking the possible drawbacks and challenges into consideration. The goal is to recognize the possible adverse effects of using the studied digital technologies and create guidelines for avoiding them.

The focus is on Finnish fashion industry, concentrating on clothing and sustainable fashion companies. This thesis covers the lifecycle of a garment with reuse cycles excluding sorting, recycling and remanufacturing. The subject is based on topicality since both circular economy and digitalization are major influencers in fashion industry globally. The motivation behind the work is lack of information on the topic and requirement for research regarding especially the earlier life cycle stages of clothing.

1.3. Research design

The research methodology in this master's thesis is qualitative analysis based on literature review and open data of different companies found from the Internet. The literature and analysis based on public data create a foundation for answering the research questions.

Challenges and drawbacks need to be identified in order to get a comprehensive picture about the transition towards using digital technologies in this industry.

Research questions are formed to support the goals and means of this study. The three research questions are listed below.

1. What is the current state of digitalization in circular economy of fashion industry in Finland?

2. What do digital technologies enable for the circular economy of Finnish fashion industry?

3. What are the major challenges and drawback for the digitalized and circular fashion industry in Finland?

The structure of this thesis consists of four main parts, which are theoretical study, empirical study, results, and discussion based on combining the previous chapters. Theory for this study is comprehensively presented after the introduction chapter. Third chapter focuses conducting qualitative research methodology including data gathering and analysis processes. The results of research methods are presented in chapter four. Fifth chapter discusses the results and the possibilities and challenges of the technologies. It reviews the results of this study and takes a look at the whole process. The chapter six is for conclusions, and it reviews the research process with its limitations and gives suggestions for the future research. Chapter seven summarizes the thesis work.

2. Circular economy and digitalization of fashion industry

The whole fashion and textile industry is forced to face the transition towards sustainability. Digitalization-aided circular economy is seen as a one solution to current problems in fashion and textile industry. The theoretical chapter of this thesis is a review of circularity in current fashion industry with reviewing the already utilized digital technologies. The need for change concerns all the industries related to textiles. In order to comprehensively study and review the processes it is required to open the terminology and concepts in the theoretical context.

The first sub-chapter includes brief historical overview and explains the terminology and concepts related to fashion and textile industry. The current issues and challenges of fashion industry are studied. Through those the chapter dives more deeply to the reasons why change in the industry is needed and how it is already happening. Second subchapter focuses on the circularity of the fashion, clothing, and textile industries. It introduces the processes involved in textile loop and explores circularity principles and explains how they are implemented. Third subchapter deepens it the terminology of digitalization and how the Industry 4.0 is taking over the fashion industry. It focuses on briefly exploring the current technologies that are used in textile industry and how they contribute to sustainability.

2.1. Fashion industry and its transition towards sustainability

The fashion and textile industry as a sector is a complex system including many sub-industries all being related to one another. The industry sectors this thesis mainly considers are fashion and textiles. There is no clear umbrella term for the industries as the system boundaries for each industry are in different scales or overlapping with one another. For example, fashion industry is dependent on events in textile industry, but it cannot be included in the textile industry since fashion is a social phenomenon and can include accessories or other forms of styling. Plain clothing industry is focusing on garments design and production processes. Whereas apparel industry covers the production and business aspect of the industry such as brands and retail.

The fashion industry is facing mandatory changes similar to other sectors. Sustainability aspects and enabling circular economy of the industry must be taken into account from the designing phase of the garment. Next sub chapters explore the terminology and history of fashion industry as well as the sustainability issues related to it and how the industry is changing towards minimizing them.

2.1.1. Fashion industry then and now

The history of clothing and fashion industry has long roots. The characterization of masses begun in the nineteenth century when the production of ready-wear-clothes started as the consequence of the industrial revolution. The concept of fashion changed dynamically as it was socially established. The historical events have led to speeding up the simultaneous appearance of fashion, e.g., the First World War created the need for functionality and practicality. (Loschek, 2009, 136.) Rapid visual communication, mass manufacturing and globalization has enabled the simultaneous adoption of new styles (Welters & Lillethun, 2018, 38-40).

Fashion as a term includes the concepts of temporality and change, and fashion is a social process that involves an adoption of a group of people (Welters & Lillethun, 2018, 31). Fashion is defined to have a function and meaning, although it also gives a clothing a social purpose (Loschek, 2009, 134). Current global fashion is self-organized complex system that is because humans alter their external looks regardless the time and place (Loschek, 2009, 23). Visually fashion it is often something uniform and fashionable pieces are similar to each other. Fashion as an industry is the commercialization of the phenomenon.

There are many reasons and enablers for fast fashion industry and current consumption patterns of fashion. The roots of current apparel industry and fast fashion is in late 20th century. Driven by Western capitalism and globalization in the late twentieth century the current fashion system is growing exponentially instead of linear growth. The improvement in industrial supply chain management in the 1970s accelerated the evolvement of fast fashion. One major enabler was the China's expanding manufacturing capacity. Slowly the annual two seasonal collections shifted towards continuous collection expansion in fashion stores throughout the year. (Cramer, 2021, 85-104.) Some brands launch form 12 up to 24 collections per year (Yadlapalli & Rahman, 2022, 63-83). It is normal for regular customers of fast fashion to browse the clothing stores in few weeks cycles with a goal of finding new styles and staying trendy (Joy et al. 2012).

In more details the textile industry as a system covers the material production, i.e., the fibers and fabrics for other industries that use textiles such as fashion industry and production of furniture. It is estimated that fashion related textiles accounts for 60% of global fiber production (Niinimäki et al. 2020). Material extraction in textile industry means growing of natural fibers, such as cotton and hemp or generating synthetic engineered polymers such as polyester and nylon. The fibers are spun into yarns and produced into fabrics for different use purposes. Fabric production processes are for example, weaving and knitting. Material can also be animal-based such as leather and fur. (McKinney et al. 2020, 31-51.) The created fabrics can be modified in a required way such as printing, dyeing, or modifying it to fulfil other forms of physical and aesthetic properties such as preventing it from wrinkling. In addition to clothing, produced textiles can be used for many other purposes e.g., furniture. (Senthil Kumar et al. 2021, 39-51.)

Fashion industry as a concept includes many material and immaterial aspects. It includes both the social phenomenon of adopting new aesthetical styles and the physical production chain from the designing phase to the use phase. Fashion industry is currently based on the principle of obsolescence and fast fashion accelerates the phenomenon even further. Fast fashion garments are designed and produced in short time periods. Trends are created, produced, worn, and outdated in short cycles. Clothes in fast-fashion industry become quickly aesthetically outdated or don’t serve the purpose after a certain period due to poor quality.

Fast fashion garments are usually very limited on their functionality and repairing options. Fashion industry has similar features than technology industry since it generates more alluring and improved products with continuous stream. Past idea of exclusivity and originality is replaced with massclusivity. (Joy et al. 2012.) In massclusivity the brands are quickly responding to customer demand. It refers to large production volumes where garments are like one another. Fast fashion is accelerated by rapid marketing and advertising on different platforms such as on social media (Teona et al. 2020).

The conventional linear model from raw materials to the use phase of clothing production includes designing and patternmaking, construction and sewing, production, and retail. (Whitty, 2021, 1-22.) It is estimated that the designing stage of the garment production is responsible for up to 80 % of the environmental impacts (Dissanayake, 2022, 21-40). Early stages of production determine the material source and amount of use. From the production effectivity point of view, it is wasteful. The cutting of garments use average 85% of the fabric (Whitty, 2021, 1-22). Production phase that remains labor-intensive is the assembly and construction stage of manufacturing. That includes cutting and sewing in addition to possible attachment of zippers, buttons, and labels. (Niinimäki et al. 2020.)

All the phases require a set of skilled specialists to perform each phase of clothing production. The mentioned sub-processes are separated from each other, and each phase is executed in isolation. For example, the design phase is usually in isolation from the context of actual ecosystem that the clothing is used in. The designing phases are driven by technical applications with the principles of aesthetics and economics rather than sustainability. The use of natural resources, pollution, and other large-scale issues are easy to be ignored. (Whitty, 2021, 1-22.) Designers and patternmakers might not even have the accessibility on fabric information related to its origin, properties, and production width. The latter makes it difficult to design for preventing production waste and for maximizing the fabric use. (Niinimäki et al. 2020.)

2.1.2. Sustainability issues of fashion industry

Fashion industry is a segmented industry with countless impacts on environment, society, and economics throughout the production chains. The linear production is still dominant in the industry, which means that clothing is usually manufactured, used, and disposed. The consequences and impacts of apparel industry are geographically wide and diverse. Impacts are not only created from the production of the clothing but are also generated in the use phase of the clothes, as well as in the end of the product's life cycle. (Ellen McArthur Foundation, 2017.)

Currently, production often takes place in a different country or even in a different continent as the consumption of the garments. Usually, the fashion brands and their offices are located in the Global North as well as the consumption of their products. The manufacturing however usually takes place in countries of the Global South. In many cases, it means that the production emissions and other environmental and economic impacts are unevenly distributed. As a result of this system, countries of the Global South are carrying the weight of impacts created by Global North. (Niinimäki et al. 2020.)

Usually in the countries where the products are designed and where the brands are located, the production costs are high due to policies and legislation related to workers' wages and working conditions. Production can be easily located in where they don't require complying with such regulations. The regulations related to environment, sustainability, and safety might not even exist or are poorly executed. The poor working conditions often means long working hours in facilities without proper ventilation. All the dust and substances, some of them being toxic, are inhaled inevitably. The unsafe buildings in addition to other working conditions expose workers to different risks and accidents. The workers are often paid minimum wages that doesn't reach the levels of living wages. (Yadlapalli & Rahman, 2022, 63-83.)

Chasing of low production costs accelerated the segmentation of the whole fashion system where manufacturing takes place wherever it is cheapest regardless the values and ethics. The prioritizing of financial capital has ignored the other forms of capital, which can be seen as human, environmental, and cultural capital. Production of clothing is moving from place to another chasing cheapest costs. When manufactures' working conditions improve by the improvement of the works rights and wages, the manufacturing is moved to another place. The poor and dangerous, working conditions, child labor and extremely low wages can be viewed as a modern-day slavery. (Whitty, 2021, 1-22.)

Share of the global CO_2 emissions for fashion industry is estimated to be between 8-10%, which is more than emissions from e.g., aviation (Niinimäki et al. 2020; Yadlapalli & Rahman, 2022, 63-83). The CO_2 emissions of a garment can vary a lot depending on where and how it is manufactured. Energy use, materials, transportation and use phase of the garment affects its CO_2 emissions. Carbon footprint of a garment is increased if it is manufactured with using fossil fuel-based energy and if the material itself originates from fossil fuels e.g., polyamide. The use of natural fibers can decrease the production carbon footprint as well as increase atmospheric carbon sequestration. (Niinimäki et al. 2020.)

It is estimated that especially the use of polyester increases as Asian and African consumers are adopting Western lifestyles. Polyester production is cost-efficient, and it has many desired characteristics from the textile production and use point of view. Due to those reasons 51% of the textile production is polyester-based. (Niinimäki et al. 2020.) The increase in the use of fossil-fuel based synthetic materials would increase the CO_2 emissions even more. In addition to high CO_2 emissions, synthetic fibers and textiles are not biodegradable and microplastics from washing the garments causes damage to ecosystems and marine life. (Ellen McArthur Foundation, 2017.)

Often the production requires multiple transportation phases where the garments are shipped via seas or air (Niinimäki et al. 2020). Transportation usually takes place in multiple stages in the raw material and fabric production phase, in distribution and retail, and in the end-of-life stage, where the garment is traditionally transported to incineration or landfill. The more complex and longer the supply chain is, the more traveling is required. The impacts regarding transportation phases are related to the fossil fuel production and to emissions from trucking, shipping, and aviation. (Quantis, 2018.)

The production of textiles and garment manufacturing consumes large amounts of water, as a result of which the entire fashion industry is one major contributor to sustainability issues related to water. It is estimated that for producing one ton of textile consumes 200 tonnes of water. Water usage is often resulted by cotton cultivation or finishing treatments of a textile such as dyeing, printing, and bleaching. The waste waters are a real issue if there are no regulations or treatment for the wastewater near the manufacturing plants. (Niinimäki et al. 2020.)

If the garment is made of cotton or includes cotton, the very water-intensive part of production is the cotton cultivation. For a cotton T-shirt, it is estimated that the cultivation forms up to 88% of the water footprint. The major issue related to water-intensive cotton cultivation is that it is often produced in water scarce countries. The impacts of water usage in such countries are even more problematic as the availability of water is already at a risk. (Niinimäki et al. 2020.)

Many stages in textile production involves the use of different chemicals. One contributor to chemical use in textile production in the early stages is the use of pesticides in cotton cultivation. In the manufacturing processes chemicals are used to ease the processes of spinning and weaving. At the end of the production the finishing treatment of textile and clothing usually involves chemicals some of which are even toxic. Negligently treated wastewater from any production phase can enter local waters and environment causing many issues to local ecosystem. Chemicals in the use of cultivation stages and in wastewaters decrease soil biodiversity and interrupts biological processes, destroys the environment, and even effects on human health causing nausea, cancer, or other diseases. (Niinimäki et al. 2020.)

The waste in fashion industry can be divided into two categories. Pre-consumer waste is the waste that is created in the manufacturing processes. It can refer to waste in the fiber production, cutting waste in the assembly line, or finished pieces clothing that is never sold. The so-called deadstock includes unsold and returned clothes that are a consequence of large production volumes and returned garments in online shopping. Deadstock is usually landfilled or incinerated instead of reuse or recycling, which would be better options from the environmental point of view. Post-consumer waste is clothing waste that are discarded by consumers in several years after the production. (Niinimäki et al. 2020.) The gap between production and discard is shortening as the fast fashion phenomenon increases (Ellen McArthur Foundation, 2017; Niinimäki et al. 2020).

Based on the paragraphs above, it can be stated that the textile production and garment manufacturing are a complex system with diverse cause-effect issues. As mentioned, the carbon footprint and created emissions can be lowered by replacing synthetic fossil fuel-based materials with natural fibers but at the same time, the usage of natural fibers creates different impacts along the supply chain such as large water consumption. Other example could be avoiding water usage and replacing natural fibers with synthetic materials that instead of large water footprint has high energy consumption in the production processes. It is hard to find any simple solution without causing new issues. Textile industry is dependent on different kind of materials with different properties and qualities. It is required to prevent the issues, avoid impacts and restore in order to stay within the limits on this planet. Drivers for the transition towards more sustainable and circular fashion industry is discussed in next chapters.

2.1.3. Sustainable transition of fashion industry and driver for change

Industries around the world are facing different issues but they all are related to climate change and sustainability challenges. The change in the apparel industry is already late for reaching the targets of staying within the carrying capacity of the planet. The changing attitudes and increasing knowledge of customers, legislation and policies, and wide-scale effects that are already seen in the environment put pressure on the change for fashion and textile industry, especially fast fashion. Major driver for sustainability of fashion industry and its circularity is the consumer awareness (Jia et al. 2020). They can create pressure for transition as a big group and demand certain information about the products. Companies must answer the customer demands in order to maintain thar businesses.

The comprehensive sustainability transition of the industry requires collaboration across the industry including policies, producers, retailers, and consumers. Policies can determine legislations and regulations towards slower and more balanced industry. The responsibility of producers with the help of policy tools is to prevent waste and surplus production, make supply chains more transparent and close the material loop. Retailers can contribute through business models and pricing that encourages to circular economy practices of customer and support environmental-conscious purchasing. (Niinimäki et al. 2020.) The often emerging question is that who is responsible for the change. Is it the responsibility of legislation, individuals or the companies that produce the clothing, or fashion trend creators?

The adoption of sustainability initiatives has been relatively slow compared to the impacts the industry has created. One contributor to the slowness of the process is the lack of transparency. (Yadlapalli & Rahman, 2022, 63-83.) The globalized and fragmented fashion system creates the transparency difficulties. It is hard to accurately detect the origin of raw material or to monitor the exact chemical use of textiles consumed in EU in cases where textiles are produced outside EU. (Niinimäki et al. 2020.)

One driver for the change in the industry is European Union (EU) legislation and strategies, especially in Europe and in Finland. In March 2022 EU Commission published a new textile strategy. Businesses and policymakers in EU region are focusing on improving the textile industry’s sustainability and increase circular economy. The strategy aims to influence on consumers, products that are brought to EU markets, companies in EU region, and textile waste treatment. Other aspect that the EU strategy has is to connect digitalization to sustainability transition of textile sector. EU acknowledges digitalization as a major driver for the change in the industry. (European Commission, 2022.)

The EU commission will develop requirements regarding the designing of ecological products. Requirements aim to improve the reusability, repairability, and recyclability of textiles. Imported clothes are long-lasting and produced with materials that are proven safe. Commission will also develop a criterion for chemicals used in the production of textile products that are placed on the EU market. (European Commission, 2022.)

One issue that the textile industry is facing is the discard or destruction of textiles that are either unsold or returned. EU aims to intervene the so-called deadstock by transparency obligation of larger companies. It concerns the discarded and destroyed products including textiles. They need to publicly report the number of discarded and destroyed products in addition of reporting whether the product is reused, recycled, incinerated, or landfilled after that. (European Commission, 2022.)

Related to above digitalization can be seen as an enabler of a dynamic system for clothing designers, manufacturers, retailers, and consumers. Digital precision technologies could increase the efficiency of clothing industrial processes and reduce the carbon footprint of e-commerce through reducing the number of returns of online retailers and increase manufacturing on demand. Other suggested solutions that EU introduces are the Digital Product Passport and digital label for textiles. (European Commission, 2022.) The Digital Product Passport will contain required mandatory information on product circularity (repair, recycling, disposal), product supply chain (materials, chemicals, components) and sustainability impacts. (European Commission, 2022.; Rantala et al. 2023.)

Fashion as an image should be shifted in order to enable the sustainability transition of the fashion industry and textile sector. One option is to emphasize of slow fashion, which is a contrast to fast fashion. Slow fashion slows down the whole process including the production, usage, and the disposal. One aspect of slow fashion is to design the garment piece in a way that the aesthetics or properties don’t go out of trend that fast. (Rathinamoorthy, 2020, 127-161.) Slow fashion products are usually produced with alternative values, transparent value chains, and made last longer than usual fast fashion garments (Cramer, 2021, 85-104). In some cases, slow fashion can also be referred to fashion or clothing pieces that one can create themselves by sewing, knitting or by other forms of crafting.

Sustainable textile is defined as being textile which material and production is safe for environment and humans and which material and energy inputs come from recycled or renewable sources. (Ramchandani et al. 2022, 1-12.) Hence, sustainability of a garment can be determined through its material usage, energy inputs, and other impacts on the environment. The sustainability of a product is not simple to determine since the impacts can be diverse. The term of sustainable fashion has emerged after decades of using the terms such as green, eco-, or ethical fashion (Rathinamoorthy, 2020, 127-161). The base for more sustainable fashion is the selection of less impact materials and reducing the use of them. Optimization comes relevant when considering the resource efficiency and sustainability through it. (Senthil Kumar et al. 2021, 39-51.)

Ecological fashion doesn't seem attractive to consumers of fast fashion as they don't view the clothes as stylish piece of garments. They would be more willing to buy ecological fashion if the clothes were trendy and responds current fashion since aesthetics are an essential part of fashion. From the consumer point of view, it is hard to understand the costs of a sustainable product after decades of continuously lowering prices (Whitty, 2021, 1-22). However, consumers are aware of using eco-labelled materials and recognizes the correlation between the transition towards more sustainable fashion and designers using ecological materials and labelling them according to that. (Joy et al. 2012.)

One proposed solution that especially responds to large production and consumption volumes of textiles and clothing is degrowth and slowing down then production pace. The business is shifted from large production volumes to narrowing it down but increasing the value and durability of the garments at the same time. Degrowth can be assisted by extended producer responsibility, which means that the producers and importers of garments are more responsible for product recycling and disposal than before. The development of extended producer responsibility and changes in the industry requires cooperation between policies, industry, and retailers. (Niinimäki et al. 2020).

For some customers the feeling of responsibility and anxiety of the industry can weigh heavily on their shoulders. That phenomenon has led to anti-consumerism, that is one response or striking back to vast consuming, including fast fashion. However, usually conscious customers ignore the impacts of fast fashion more easily than the impacts of consuming other goods. For example, the customers can be committed to dietary changes (vegetarianism, organic food) and recycling, but are not concerned about their fast-fashion purchases. (Joy et al. 2012.)

In order to change the whole fashion industry towards more sustainable system some changes are required in the mindset of actors in the industry. The view from linear system must be changed into dynamic and interconnected system as it is in reality. Innovations, creativity, and responsibility is restricted and limited by inherent hierarchies and discrete skillsets. The role of designing for circularity and more sustainable fashion must be highlighted. The establishing of causality perspective would help recognizing the impacts of fashion industry and enabling the life cycle thinking. Also, the other forms of capital such as human, cultural, and environmental capital would be more considered with this shift. (Senthil Kumar et al. 2021, 39-51.) Proposed solution that takes into account the mentioned aspects and changes is circular economy, where fashion is designed and produced dynamically aiming to keep the material in circulation.

2.2. Circular economy in fashion context

Circular economy of fashion industry is a regenerative model compared to the conventional linear system. It is focused on the use of renewable resources and aims to reduce non-renewables. The circular fashion industry applies sustainable fashion design strategies and aims to keep the material in circulation. The aim of circular economy in fashion industry is to maintain the highest possible value of the garment. The difference to plain sustainability goals and sustainable fashion is that the goals are open-ended whereas in circular economy they are in a closed system. (Dissanayake, 2022, 21-40.)

Resource loop can be slowed down by selling less clothing and slowing down the pace of consumption. Narrowing the resource loop can be using renewable resource inputs and minimizing the environmental damage. The loop can be closed by keeping the items in circulation and maintaining its value. (van der Ven, 2022.) Most practical circular economy example concerning fashion industry is the circulation of physical materials – textiles. Materials can be kept in circulation by reusing clothing that is in good condition, remanufacturing textiles, and clothing into new garments, or recycling the material at fiber level.

In addition to just closing the loop, it is proposed to affect the whole supply chain to make it more environmentally friendly. Nearby the production site pollutions is an issue that leads to ecological damage. Circular economy and sustainability are especially driven by legislation and governmental reinforcement. They can encourage to circular economy innovations by policies. (Jia et al. 2020.) One aspect of circular economy and sustainability of the industry is the energy efficient production based on renewable energy sources, which pursues the comprehensive sustainability transition (Chen et al. 2021).

Circular economy is not only a solution to overcome the issues of resource-intensive production but to contribute to the economic system and economic growth. Focus on circularity actions of the apparel industry has been formerly on the consumption and waste and often it is seen as a strategy for waste management. For example, in Sweden, the end-of-life stage is responsible for the smallest component of the whole apparel sector. The circularity of fashion industry requires the integration of circularity strategies to all stages of a product lifecycle. (Brydges, 2021.) It affects all the product life cycle stages considering alternative more sustainable options in each stage. The broad application of circular economy affects especially to the resource use and resource efficiency. It also encourages to improve design strategies and product usage phase extension. (Dissanayake, 2022, 21-40.)

Brands that pursue circularity of the clothing industry can encourage customers to reconsider their purchases in a sustainable way. They can reform their approaches and business goals towards achieving more durability of their products instead of fast fashion and short cycles.

Instead of just buying and disposing it soon after the trend has died, the clothing can be seen as an investment that last time. When jumping back to the history of clothing industry, clothes were investments for the individuals. However, the change also requires the change in the whole industry, which requires companies to act more responsible. (Brydges, 2021.)

One aspect of circular economy of clothing is extending the lifecycle of the product by maintaining and repairing garments and keeping them in use as long as possible. Figure 1 presents a diagram for garments circularity. Dotted line represents the closed system, which input is minimal for raw material and output is minimal for disposal of clothing. Diagram includes energy recovery of incinerated clothing and designing for circularity. The following chapters are focusing on designing for circularity, extended use phase, minimized waste and the challenges of implementing circular economy.

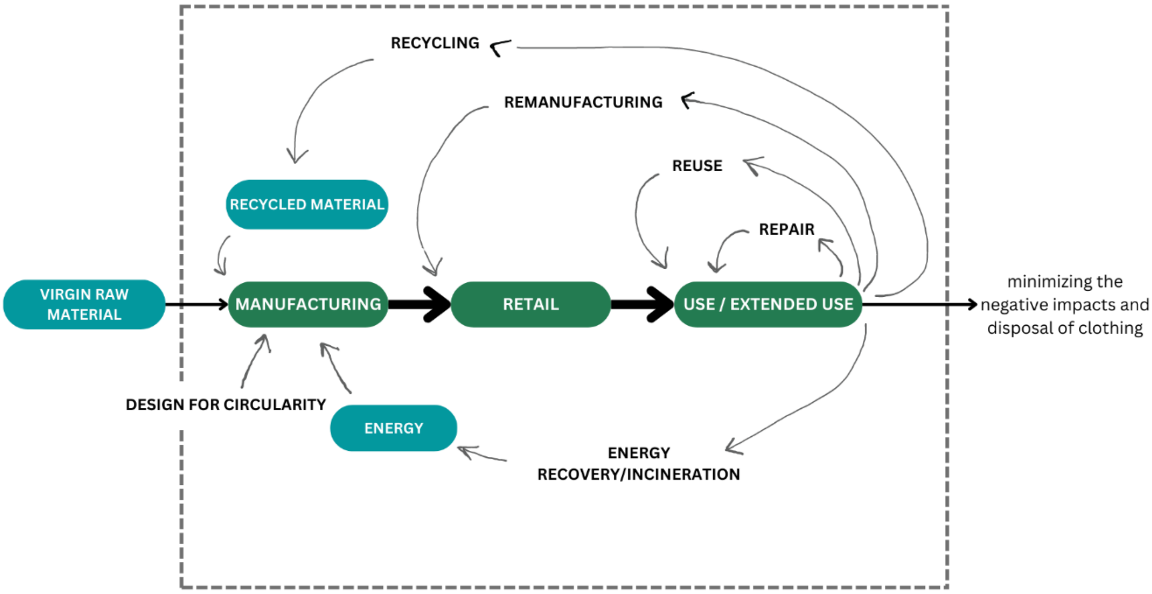

Figure 1. Diagram for garment life cycle including different circular economy aspects.

2.2.1. Design and production for circularity

Short lifecycle of a product wastes the resources needed for its manufacturing such as energy, water, and raw material. The waste generation minimizes as the need for production is reduced through extending the product lifecycle. Four strategies to make the fashion industry towards a circular economy industry are resource efficiency, circular design, product life extension and the circularity of end-of-life. Using sustainable and renewable raw materials contributes to minimizing waste generation and resource consumption. In other words, it narrows the resource loop. (Dissanayake, 2022, 21-40.)

The design and development for circularity starts from the beginning of designing the product. Circular economy and sustainability criteria must be taken into account in order to create a product that can close the loop (Jia et al. 2020). The impacts of fast fashion industry are well-known and could be considered in the designing phase, but the practical implementation is still missing. (Cramer, 2021, 85-104.) It is often ignored where the material for the design is coming from and how the garment works and behaves in practice. Currently it is excluded from the design what happens to the garments after it is no longer in use and has passed the current dominating aesthetic trends. (Whitty, 2021, 1-22.)

User-centered and problem-solving approach that is based on research is needed in order to achieve the sustainable and circular fashion system. The ignorance for the use phase has led to the situation where the use phase of the garments is shorter. The use phase of the garment can be extended by giving more consideration to the usability, desirability and engaging more with the users. It could provide designers new opportunities as emphatic designers with pushing the limits of conventional fashion design. (Whitty, 2021, 1-22.) One challenge for the designing for sustainability can be the lack of practical knowledge of the designers e.g., information about recyclability of different material blends (Karell & Niinimäki, 2019). It is needed to provide the designers guidance about how to integrate the sustainability and circularity into their designs (McKinney et al. 2020, 31-51).

The circular design strategy takes into account the possible multiple life cycles and users of the garment. The design attributes are longevity, customization opportunities, possibility for disassembly, and designs for recycling. The circular design includes avoiding fiber blends for achieving the less-complicated recyclability. Designing includes the quality of the product, which enables the long use of the garment. Material selection for the clothing plays a key role in the physical duration and longevity of the product. High product quality enables the long lifetime in the measures of wears, washes, users, and years. Other thing affecting the physical durability properties is the construction and seams of the garment. (Dissanayake, 2022, 21-40.)

The possibility for the extended use begins with the design of the clothing. The durability of the aesthetic properties of the garment must be considered such as the durability of the prints and color dyes. (Dissanayake, 2022, 21-40.) As a contrast for trend forecasting in fashion design there can be use forecasting. Use forecasting takes into consideration the garments suitability and probability for repairing, reusing, refashioning, and recycling. The capacity for lasting multiple seasons and longevity from the aesthetic point of view. In other words, it is postponing the obsolescence and enabling the possibility to respond the wearers changing needs. (Cramer, 2021, 85-104.) Brands pursuing sustainability and circular practices have already acknowledged the importance of avoiding short-lived trends. They try to design the garments to be combined with selection of different collections. (Karell & Niinimäki, 2019.)

The system that is desired from the circular economy point of view is zero-waste model found from nature. Production is made based on the demand and consumption in circular, holistic system within a limited resource. (Whitty, 2021, 1-22.) The zero-waste patternmaking and designing requires the cooperation of apparel designers and patternmakers. The designing process cannot be isolated anymore. The benefit of zero-waste pattern making is the reduction of material and textile waste in the early stages of garment manufacturing. From the reduction of materials point of view, it is also beneficial to add at least some zero-waste patternmaking strategies. (McKinney et al. 2020, 31-51.)

For zero-waste pattern making and creation one challenge is the size range of produced fabric. In practice it means at all the zero-waste pattern layouts are not identical with the fabric widths. If the layout of the fabric doesn't fill the planned fabric area, it creates some excess fabric. Also, the range of different end product sizes can create an issue that must be solved in order to implement the zero-waste patternmaking practices more broadly.

(McKinney et al. 2020, 31-51.) Zero-waste patternmaking and designing is very limited when considering different use purposes or responding to special demands (Peter John & Mishra, 2023). To prevent the challenged mentioned, the patternmaking could be integrated to the material production stages where the fabric is produced.

2.2.2. Extended use

The negative impacts of fashion industry can be minimized with the extended use phase of the garment's life cycle. The use phase of the garments can be measured by the number of wears or washes, number of users or years of use. (Cramer, 2021, 85-104.) The usage phase of clothing can be extended through repairing the product as long as it is possible, reselling, and services such as rental services, reclaim programs, and leasing programs. Reusing the garment both part of the extending the product life cycle and one alternative option for the end-of-life scenario. (Dissanayake, 2022, 21-40; Senthil Kumar et al. 2021, 39-51.)

Companies have noted that one major and concrete issue of textile industry, especially in clothing industry is the amount of waste. One example from companies to act and response to that issue is their own re-sale or rental system or partnering with secondhand businesses. (Brydges, 2021.) They resell their garments via their own- or third-party secondhand service. Such examples can be found from multiple Finnish companies, especially if they have developed a certain brand image of sustainable and durable clothing that is wanted even after many years of use.

The lifetime of a product can be extended via the utilization of product-service systems (PSS). PSS contributes to sustainability by the extending the garment lifetime, which reduces the consumption of resources needed for production of new garments. (Rathinamoorthy, 2020, 127-161.) It takes the consumer-retailer relationship to a new level. In economic terms, it helps the shift form production to service provision, which is one aspect of circular economy. For the social dimension it contributes by enabling the easy and low-cost access. Utilization of PSS also offers potentially new workplaces and improves employment of that field. PSS reduces the environmental load as it increases the reuse and recycling rates of clothing.

PSS utilization pursues collaborative consumption, which can be divided into two categories. Consumption can be utility-based that includes rental and leasing services without changing the product ownership. In redistributed ownership the product ownership changes through activities such as swapping, auction or resale. (Dissanayake, 2022, 21-40.) Collaborative consumption in addition to sharing economy is growing as they are increasingly emerged amongst younger and more conscious consumers (Niinimäki et al. 2020). The collaborative consumption has moved from local markets to global markets through digital platforms and technologies. In addition to easy accessibility, digital platforms can also offer affordable prices. In collaborative consumption the product disposal is delayed by maximizing the usage. (Dissanayake, 2022, 21-40.)

One affecting aspect to garment's usage lifecycle are labor-intensive care practices such as for example, dry-cleaning or constant ironing. The communication a about the opportunities about the garments maintaining and repair is as important as the opportunities itself. If the information about the maintainability is not clearly informed or signaled, they don't reach the consumers and wearers. (Cramer, 2021, 85-104.) Care practices and their reduction could be taken into account in the designing phase and in material selection by choosing materials that are low maintenance.

Repair options and the possibilities for modifying the clothes are determined in the design and assembly phase. The construction of the garment affects how easily it is to repair or how much the repairing requires different skills and time. The easier the repairing and maintaining the garment is made the better the options for extending it usage are. Material choice is another thing affecting the maintainability of the garment since some fabrics are hard or even impossible to replace or mend. Also, the combination of materials has an impact on the replaceability. (Cramer, 2021, 85-104.) Physical product-based PSS is focusing on maintenance and repairing then product and extending the product lifecycle through them. Repair can be provided as a service in the stores, as third-party repairing services, by offering repairing kits to customers or by providing online repairing tutorials. (Dissanayake, 2022, 21-40.)

2.2.1. Waste and its minimization

One promoter for the circular economy of textiles is the separate textile waste collection. The textile waste collection rates have differences in different countries while some countries don’t have textile waste collection system at all (Niinimäki et al. 2020). Separate textile waste collection already ambitiously started in Finland in 2023 while the EU level goal for starting the separate collection is 2025. Circularity through textile waste collection and recycling in Finland is an example of cooperation between different actors. Recycling of post-consumer textile is developed by municipal waste companies and public sector waste streams are treated by private companies. (Suomen Tekstiili & Muoti, 2022.)

Materials can be recycled into whole other purposes too or incinerated for energy recovery. Textile waste can be reused in the textile context e.g., carpets, bags, cleaning cloths, and stuffing. (Chen et al. 2021; Peter John & Mishra, 2023.) Textile waste can also be reproduced into new innovative materials such as composite materials or even floor and roof tiles (Sisodia & Parmar, 2022, 162). However, such innovative composite materials often require more research and development before they meet the requirements for usage.

In circular fashion system the end-of-life stage doesn’t necessarily mean the disposal of the garment. Giving so-called second life to the product can mean upcycling or customizing it for new purposes. One creative solution for preventing material waste and utilizing as much textile waste as possible is remanufacturing. (Niinimäki et al. 2020) Remanufacturing can be made possible already in the designing phase if the garment is designed in a way that can be remanufactured later if necessary. (Dissanayake, 2022, 21-40.)

If the garment is not put to any new purposes or given second life it can be recycled in a recycling plant. Recycling of textiles can be mechanic or chemical. In mechanic processes the textile is shred into short fibers. However, the challenge for mechanical recycling is the lowering quality of the fiber. For example, the reuse of the recycled cotton fiber is challenging since it doesn’t correspond to the properties of virgin cotton. Before compromising on strength and quality of the fabric, maximum 20% of the cotton fabric can be recycled. However, better quality can be achieved by using other recycled or virgin materials. Chemical recycling is more efficient and helps to maintain the value and quality of the fiber, which is essential in order to keep it in circulation (Niinimäki et al. 2020; Suomen Tekstiili & Muoti, 2022). Chemical textile recycling has an economic issue resulting in a situation where the recycled material is more expensive than the virgin raw material due to expensive recycling processes. (Chen et al. 2021.)

One barrier to recycling is the diversity of the products and materials (Senthil Kumar et al. 2021, 39-51). Sorting of materials with only one fiber content is easier to execute automatically. Robotic technology has been successfully utilized in automatic sorting of textiles. (Niinimäki et al. 2020.) However, sorting blended material containing natural and synthetic fibers is challenging process. Material blend can concern at fiber level, yarn level, fabric level or garment level. Cotton cellulose can be dissolved from the fabric blend e.g., cotton-polyester blend. New synthetic natural fibers can be created from the dissolvent cellulose. (Chen et al. 2021.)

In addition to already existing feasible sorting technologies there are novel technologies or alternative utilization of conventional technologies for sorting textile waste. For example, with the machine vision technology, the fiber content could be analyzed and later on the textile could be given new purpose. Example for the usage of machine vision is the estimation of polyester content on cotton-polyester blend fabric. (Mäkelä et al. 2020) With a further development it would be used for sorting textile blends that are currently hard to sort. Such technologies are beneficial especially after separate textile waste collection of households begins in EU.

2.2.1. Challenges of implementation

To conclude the former chapters, it can be said that fashion industry has its own challenges for implementing circular economy practices. The barriers are related to siloed and segmented industry and to the reason that it is very dependent on aesthetics and style. The value chain of textiles and fashion are usually the responsibility of multinational companies, including design, production, and distribution. The role of these companies in the sustainability transition is critical since they can be catalyzing the processes towards circularity. (van der Ven, 2022.) Consumers has their role too since they are ones buying the items and creating the fashion trends and maintaining fashion as a system in current world. There are also barriers created by externalities such as legislation, policies, regulations, or other local factors, that can also affect the whole sustainability aspect. (Brydges, 2021.)

The current designers' responsibility of the whole production chain is narrow. From designer point of view the wasteful garment cutting and assembly phases are problems of production – not design. In current fashion and clothing industry the surplus production is generally accepted and the approach to designing is impulsive. The designing doesn't happen in then macro-level, which means that the use of natural resources, pollution, and other large-scale issues are ignored. (Whitty, 2021, 1-22.) Designers and patternmakers might not even have the accessibility on fabric information related to its origin, properties, and production width. The latter makes it difficult to design for preventing production waste and for maximizing the fabric use. (Niinimäki et al. 2020.)

The challenges for circular economy in the fashion industry is to design garments that are up to date but avoiding short-lived trends. Timeless designs last longer but doesn't necessary appeal/attract customers in a way that fast-fashion brands do. To pass the clothing to next user and maintain it in circulation by sharing economy practices or second-hand it is required that the garment is in good condition. It is not a challenge if the garment is designed to be used multiple years, even decades. However, the poor quality is often the case in implementing extended use phase for the clothing of current fast fashion industry.

There is a difference between products, clothes in this context that are produced without keeping circulation of the product in mind and with the products that are produced by follow circular economy principles and actions. The nature of fashion industry supply chain is complex and crosses many other industries. The origin of all material is hard to trace and availability of resources, especially from sustainability aspect, can be very limited. The full scope of recycled components of a product is dependent on existing resources. (Jia et al. 2020.) One challenge for sustainable designing is the lack of practical design tools (Rathinamoorthy, 2020, 127-161). Digital tools and applications could be one solution for it by providing tools that support sustainability and circularity taking multiple aspects into account as well as the later production phases.

2.3. Digitalization for the sustainability and circular economy of fashion industry

Fourth Industrial Revolution, Industry 4.0, is utilization of emerging technologies for businesses and engineering processes. The goal for using the emerging, usually digital, technologies is not only to improve the processes and production to more efficient and flexible, but also make them more sustainable. The efficiency improvement reaches also economic efficiency by providing optimized processes. Industry 4.0 connects physical industrial world to abstract digital context with different technologies such as Artificial intelligence (AI) and Machine Learning (ML), Blockchain, Cloud computing, Big data, Internet of Things (IoT), Virtual Reality and Augmented Reality (VR & AR), and Radio Frequency Identification technology (RFID). (Machado et al. 2020; Akhtar et al. 2022; Ghoreishi & Happonen, 2021.)

Digitalization makes it possible for businesses and companies to provide their products and services for larger group of customers. Digitalizing businesses also increases the competitive advantage compared to businesses with less knowledge capital. (Työ- ja elinkeinoministeriö, 2022.) However, Industry 4.0 technologies are not accessible to all producers and manufacturers. Depending on the technologies, they have high costs and require technological skills. (Machado et al. 2020.)

Digital tools can be harnessed in processes, products and as platforms. Digitalization improves product and component tracking, optimization of the value chain, and improves circular economy practices. Digital tools as a platform connect consumers and producers through services and development of industrial symbiosis. (Berg et al. 2022.) Utilization of Industry 4.0 technologies are beneficial for decision-making in production processes providing real-time data. Industry 4.0 technologies also help to monitor the production stage and provide maintenance predictions. Digital technologies are beneficial for smart design and prototyping, real-time monitoring, and collaborative decision-making, analyzing, warehouse management, marketing, information sharing. (Ghoreishi & Happonen, 2021.)

2.3.1. Possibilities of digitalization in the fashion industry context

In the context of clothing manufacturing, digital tools increase the efficiency in cutting, sewing, pressing, and packaging (Yadlapalli & Rahman, 2022, 73). Digitalization also enables and elaborates repairing services and can make some rare materials and replacement parts more accessible to wearers through different web-based solutions or platforms (Cramer, 2021, 85-104). Industry 4.0 technologies also enable e-commerce, virtual dressing rooms for company-customer interaction, and different platforms for consumers to resell their used clothing (Akhtar et al. 2022; Faria et al. 2020).

In the production lines of many industries, especially when aiming to circular economy, digitalization and sustainability are linked together and crossed in all parts of production. Digitalization of fashion industry drives the industry towards circular economy and sharing economy practices. (Akhtar et al. 2022.) The sustainable production also has a social sustainability aspect. The safety of workers and employees of factories is improved by reducing the possible risks that the production could have. The focus for more sustainable production with the utilization of Industry 4.0 technologies in overall usually refers to minimized material and energy inputs. It includes waste management and waste minimization, reduced water inputs, more efficient land usage and energy efficiency. (Machado et al. 2020.)

In overall the digitalization of supply chains in fashion industry improves the communication between supply chain members and units involved (Yadlapalli & Rahman, 2022, 73). The benefits of tracking systems are for manufacturers to trace their products and to forecast their products' quantity and value (Jia et al. 2020). Due to lack of communication and data, companies don't have enough information about the products life cycle and what happens after the purchase (Karell & Niinimäki, 2019). Traceability and tracking technologies can fill the gap. It is assumed that product lifecycle management and tracking will be improved through the development in information and communication technologies. (Jia et al. 2020.)

2.3.2. The role of data for circular economy

The utilization of different digital technologies is based on data and information in a digital form. Data can be collected manually and managed by human labor, or it can be automatized by measuring with different sensors and meters. In textile context the collected material related data can be origin of fiber product, raw material sources, manufacturer, and production location, used chemicals, color durability for mechanical recycling, amount of textile for recycling, impact of the product such as water usage, CO_2 emissions, and geographical journey. (Berg et al. 2022.) In wider circular economy context, the collected data can be material properties, manufacturing processes and quality, side flows of the manufacturing, product life span, durability of different product components and materials, reusing the product or its components, usage rate and customer experience. (Työ- ja elinkeinoministeriö, 2022.)

Technologies that enable data collection are Radio Frequency identification (RFID), Internet of Things (IoT) with sensors, and different digital platforms that interacts with consumers. There are usually lack of data on secondhand trading, service-based solutions, and remanufacturing. Digitalized systems can improve and fill the missing data gaps for comprehensive life cycle data. New data collection methods can be altered to meet the requirements for circular economy-oriented data collection considering whether to value quality, quantity, accuracy, or usability. (Berg et al. 2022.)

Data can be utilized in decision making for product design, supply chain development and developing circular business models. It can be harnessed to improve the supply chain and used in decision making. (Työ- ja elinkeinoministeriö, 2022.) Data collection enabled by digital technologies can be combined with Life Cycle Assessment (LCA) for more comprehensive and accurate carbon footprint calculations and evaluation of product impacts on the chosen impact categories such as climate change, acidification, and eutrophication. (Berg et al. 2022.)

Collected data is not valuable unless it is managed in some way and harnessed to use. Data management is transforming the data to form where is can be readable, searchable, or manageable in some other way. Data management is essential, for circular economy, because it connects the circular economy actors and others who benefits from the data usage. Data management enables value creation based in the provided data. The wide network of data collection and sharing can be viewed as a strength of the circular economy. (Berg et al. 2022.) Data management or integration in wider scale can be implemented by using cloud-based services or blockchain technology.

Data in circular economy can be harnessed for designing the products, extending the products life span, innovative products, and services, and improving customer experience. Data is analyzed and utilized in each lifecycle step with the help of technologies such as Artificial Intelligence (AI), big data analysis, and machine learning. Analysis can provide useful information regarding maintenance needs, predictive manufacturing, planning, controlling, and be beneficial in the end-of-life activities. It can provide data on avoidable waste streams and help in efficient life cycle planning. When the information is available through digital identity or digital twin it can be easily accessed by all the actors involved. (Luoma et al. 2021.)

Valuable data for businesses is the data related to material flows, product lifecycle, customer behavior, and value chain operations. The relevant data can also be storing and inventory data, product performance, emissions. (Työ- ja elinkeinoministeriö, 2022.) Data provides information on usage patterns and how the consumers are using the product. Knowing the consumer behavior pattens helps to manufacture garments meeting the customer demand and planning resource efficient production. Businesses can create and innovate services for providing help for customers to extend their garments life span. However, comprehensive understanding of circular economy is required in order to broadly utilize data in optimization and sustainability of supply chains. Both digitalization and circular economy activities are relatively new concepts in this context and are continuously developing. (Luoma et al. 2021.)

Different digital tools and technologies are used for executing mentioned activities including data collection, management, and utilization. Figure 2 presents and summarizes how data circulates in a production system where it is collected, integrated, and analyzed. Data collection stage can involve or enable consumer interaction with the customers of the company. Collected data can be fed further to data management and integration that benefits all supply chain members. Data management required input is the collected data and possible output is data for analysis and utilization. Data analytics are beneficial for the producer as it provides information and help regarding the company operations and production steps.

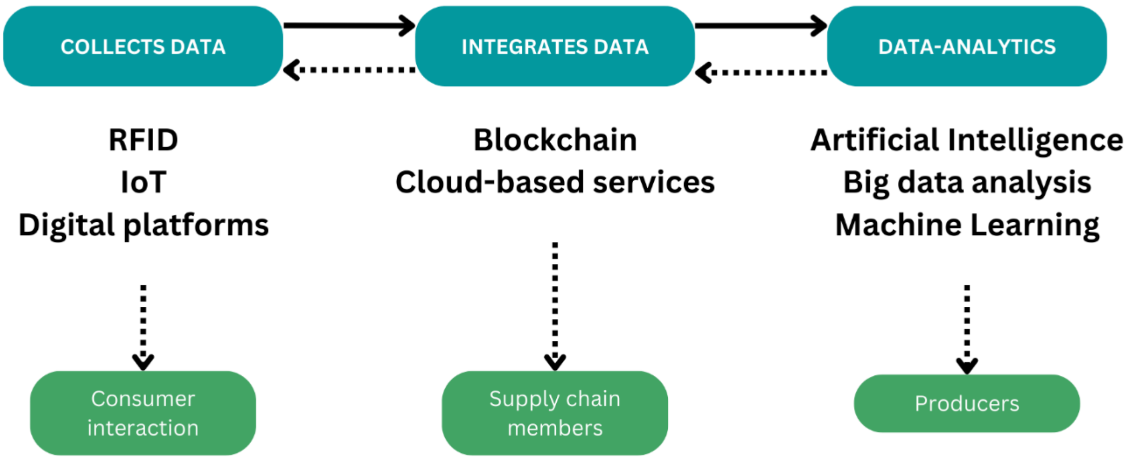

Figure 2. Diagram on data collection and usage. Adopted from Työ- ja elinkeinoministeriö, 2022. Data can be collected and used for consumer interaction and used as an input for data integration. Data integration benefits all supply chain members, and the integrated data creates a base for data-analytics that benefits the producers.

2.3.3. Challenges related to digitalization and data

One major drawback for digitalization in overall is the increased use of electricity that is required for the utilization of different digital tools and platforms. The created emissions from digitalization could be minimized through the use of renewable energy sources and calculating computing power requirement in the programming level. The higher the computing power requirement is that program demands, and the more cloud-based services are used, the more energy is required for maintaining the data centers. One option for minimizing the energy use is to increase the heat utilization efficiency. (Berg et al. 2022.)

Digital platforms can form a marketplace for products with high demand at the moment. Through the online marketplaces the value of the product can be maintained as high as possible. There are two major challenges related to secondhand markets. It is not necessary the issue of data quality but lack of standards and lack of common practices between actors who want to give material a new life and actors who want to purchase something second hand. (Työ- ja elinkeinoministeriö, 2022) One example in the clothing and fashion context could be that a person is selling an expensive fashion product through online secondhand store and another person is looking for a similar product but searching with other keywords without any relevant results. The supply and demand don’t match. Other issue could be that data, which is the product information in this case, is commonly used, but there are no common platforms where the clothing can be sold and purchased.

The proposed solutions to these issues would be standardization of data related to product information, which in practice could mean categorizing the product and mandatory fillable fields that the service provides. Other unlikely scenario would be the usage of only few commonly known online secondhand platforms, but it would require a massive change in people’s secondhand buying behavior, and it would also decrease the opportunities of smaller secondhand businesses. The standardization and common practices are urgent issue in order to keeping up with the development phase and it could solve the challenge of responding to demand on secondhand markets (Berg et al. 2022; Työ- ja elinkeinoministeriö, 2022).

The common challenges related to digitalization is related to ownership of the data, information sharing, cooperation between actors and skill requirements. (Työ- ja elinkeinoministeriö, 2022) The challenge of multi-ownership of data refers to data being owned by many participants such as smaller entrepreneurs, large factories, or organizations. (Berg et al. 2022.) Companies have concerns related to the openness of data. For example, openness of data that could be critical for competitive advantage is a big concern. However, information sharing, and open data could be partially anonymized or restricted by digital tools. (Työ- ja elinkeinoministeriö, 2022)

Data sharing and openness can have risks related to reputation, stakeholder relations, data manipulation. Usually, the risks are caused by incorrect interpretation. Interpretation of the data is challenging depending on how it is measured. For example, recorded data related to a geographical location can be result of the activities nearby or caused by something else. Ethical issues related to data sharing can concerns personal data or data that is easily linked to personal details of supply chain participants. The data should be anonymized in a way that it doesn’t create risk for the providers. (Berg et al. 2022.)

3. Methodology

Due to the complex nature of this topic, the methodological part of the thesis is made by utilizing qualitative research method. The research in this thesis is carried out by utilizing literature review and analyzing open data based on selected base companies. The goal of qualitative research is to study the topic in its most natural environment, usually in a form of text instead of numbers (Flick, 2010). The research design if this thesis is presented in Figure 3. The literature review and theoretical background forms the foundation for diving deeper into the subject. Study based on public and open data from companies' websites and reports forms the supporting element for theory and creates a baseline for the discussion. Results from company examples and literature are presented together. The analysis and discussion based on the results answers the research questions that are set in introduction chapter. This chapter gives a detailed description on the process of data gathering and collection of results.

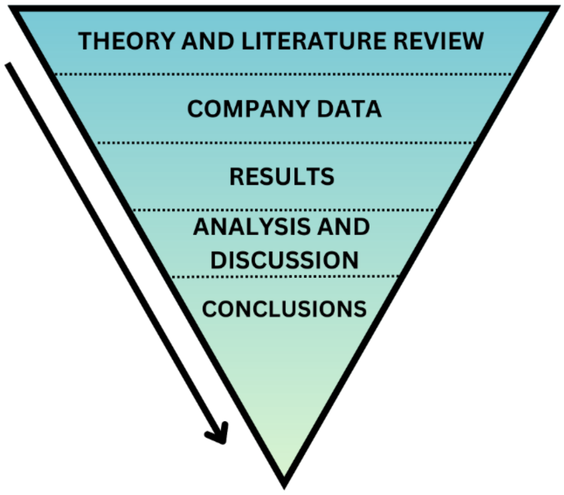

Figure 3. Research design of the thesis presented as a triangle turned upside down. Thesis research begins with theoretical research and literature review followed by gathering public data and presenting them alongside with the literature. Analysis and discussion are based on both method and is followed by conclusions of the results and thesis in overall.

3.1. Data gathering

Data for this thesis was collected with two methods. Literature review was partly carried out simultaneously with theoretical framework. Scientific journals, research articles, and books were the primary information source for finding relevant information and data for literature review phase of the thesis. Articles and books were searched by using and combining relevant keywords related to this topic such as circular economy, sustainability, digitalization, digital tools, fashion industry, clothing production, and garment manufacturing. Some of the digital tools were used as a search word for finding related research articles.

There were set two criteria for most of the sources. First criterion was that the article should preferably be peer-reviewed. Second criterion were recent publication year of the source, which wasn’t difficult criterion to fulfil. The reasoning for the criteria was that accurate and relatively new information was optimal and desired for this purpose. The specific context in the articles wasn’t a criterion as most of the technologies were applicable in many product types other than textiles and clothing. However, most of the articles were in the context of clothing production or textile industry in general, and sustainability if not specifically circular economy context.

Other data gathering method was collecting public data from websites and sustainability reports of selected companies. Process of gathering public data begun with selecting the companies that fit for the scope of this thesis. The potential companies were first listed by leaning on blog listings, newspaper articles, sustainable stockist, and a personal experience. The companies on the list were either selected or discarded whether they fit to the scope. Selected companies were focusing mainly on women’s clothing or womenswear was one of the main categories. Many of the companies included other categories too such as clothing for children, menswear, and accessories. Companies without womenswear collection or were focusing only on accessories or shoes were left out of. The selected companies had variety of fields for clothing, including such as casual, formal, outdoor, and active wear.

The reason why these companies were chosen is their transparency of operations and goals for more sustainable fashion industry. They fit to the scope of this thesis by locating the business in Finland and locating production in Finland or abroad with high ethical and environmental standards. Companies included in the study didn't match the definition of fast fashion by purpose, meaning that they either didn't renew their collection in fast cycles or if they added new pieces to collection, it was a considered move. Many companies had a permanent collection with their own classic pieces of garment. Their products are not necessary mass produced and are made to respond to customer demands.

Company-oriented research worked as a mapping study on exploring the sustainability and circularity action of Finnish fashion companies. Data and information were collected from the company websites and their possible sustainability reports. The study included exploring the level of digitalization and utilization of digital tools or digital-aided operations. The gathered data was in a form of text and words and required evaluation whether the information was relevant or useful. Sustainability related quantitative data from business and production were ignored as they don't directly serve the purpose of this thesis.

3.2. Analyzing data and collecting results

Results from literature review were collected as a text and divided into different categories by different technologies. There data was analysed qualitatively and with an evaluation whether the information was relevant and pursuing circular economy practices. For presenting the results found from literature they were written down to a table. It was described what life cycle phases the technologies could be part of and what the application of the technologies could be in real life.

Data from company examples were gathered to a table. The digital tools or digital-aided operations were categorized, and most mentioned technologies and operations were recognized. Table was organized alphabetically, and separate columns were added to different digital tools supporting circular economy (Appendix 1). The digital tools that were considered supporting circular economy were platforms for re-selling used clothes, digital guidance for taking care of the garments and maintaining their condition as good as possible. It was also recognized if the company was pursuing overall circular economy or digitalization. Practices that were counted as beneficial from the circular economy point of view were zero-waste patternmaking, minimizing waste in the production, utilizing leftover material, utilizing recycled material, and reselling second-hand clothing. Sustainable businesses utilizing digital technologies without a clear notion of pursuing circular economy goals through them were generally categorized as pursuing digitalization.

4. Results and findings

The two research methodologies for this thesis were qualitative analysis from company examples and literature. The output of the research is different digital technologies that are in use or could be used in the future. Also, the benefit and contribution to circularity is briefly reviewed. This chapter presents the results as two sub-chapters. The first sub-chapter presents the example results found from studied Finnish companies. The overall nature of the selected companies is described, and the findings are categorized and presented as sub-chapters. Next chapter categorizes and presents the technologies and examples found from literature. Third chapter summarizes the results for clear and concrete understanding of the topic.

4.1. Results from the company examples

The study focused on selection of Finnish companies identified as sustainable or slow fashion companies with women's wear being one of the main product categories. The selected companies were representing timeless designs in the means of patterns, colors, and silhouettes. Other often emerging keywords and themes among the companies were Scandinavian design, modern values, ethical fashion, and high quality of products. Many companies had focus on unique patterns and partly based their branding on the patterns. Selected companies had sustainability report or separate page dedicated to sustainability. Sustainability focused page typically included foreword related to solving sustainability issues and explanation on brand's own contribution, usually related to material selection and production ethics. Most of them recognized circular economy practices and goals for achieving them and overall sustainability. There was variation on how detailed the information about sustainability was, but all the selected companies recognized its value and relevancy.

There was variation on the domesticity of the companies. Some of them located company activities as much as possible in Finland, including design, manufacturing, and fabric creation. All the rest of the companies included design in Finland but had variation in the manufacturing phase. Some companies located their manufacturing and sewing processes both in Finland and on abroad. The most common production countries depending on the material and manufacturing technologies were Portugal, Baltic countries, Turkey, and Italy. Many of the companies had similarities on their manufacturing locations and subcontractors. Most common mentioned factories were Portugal-located factories own by Finnish Blackmoda Oy. European countries, especially Estonia were often chosen as the manufacturing location due to short transportation distance, which reduces emissions of the supply chain. Other attached items such as ribbons, buttons and tags had variety of origin but e.g., companies pursuing domesticity as much as possible were using Finland-manufactured tags and other attachments.

One general observation that was made during the exploration from companies and their websites were that they usually had transparent and longer product warranty compared to items from fast fashion companies. Most companies had their product warranty even for one year and it was valid if the clothing was maintained in correct ways and according to their instructions. Warranty often covered repairing service, to which the garment could be sent and repaired. It extends the garnet lifecycle if the same garment is professionally repaired and possible faults in the product is fixed in the beginning of its lifetime. Such operations are possible in the sustainable fashion industry where clothing has higher value and there is a motivation behind keeping the garment in good condition.

During the selection of companies that were identified as sustainable and slow fashion companies, it was noteworthy that the availability of menswear clothing was minimal. There were few examples on companies focusing only on menswear. Many of the selected companies had a category or collection for men or had unisex collection of clothing that was targeted for all. It was also noteworthy that there were multiple companies focusing only on children’s wear and many companies had large selection of children’s clothing alongside womenswear and possible menswear. It may indicate the large demand for physically durable children’s clothing and the high circulation rate of children’s clothing.

There were mentions on digitalization-aided production phases were quality assurance and overall IT innovations for sustainability, but the details were not mentioned. It, however, expresses that digitalization is acknowledged to be one of the solutions and beneficial tool for overcoming sustainability issues related to company and office operations. Many companies were utilizing digitalization as working in digitalized offices, meaning that all the "paperwork" is in a digital form and paper usage is minimized. The role of digitalization as a key towards circularity in the actual production lines is not that well recognized. Next sub-chapter presents the digital tools and platforms found to be supporting circular economy.

The results from company examples are collected and gathered to more comprehensive table that can be found from Appendix 1. Companies that were selected to this study are listed in alphabetical order. The field of the company is briefly described in the second column to give an overview on the selected companies and their variety. The most common digital tools for circularity activities have own columns and last column dedicated to digital tool has variety of different other digitalization-aided activities. It is also separately marked if the company pursues towards significantly circular economy based on the given data on their websites and sustainability reports. Circular economy activities in this context are broad utilization of recycled material or efficient waste reduction methods. There is a separate column for mentioned digitalization practices such as digital office and company operations.

4.1.1. Care guide

Care guide on the website practically means a page or multiple pages on the website that provides a guide on how to take care of the garments and their material. Care guidance was chosen as a digital tool increasing circularity since it is a web-based information source on circular practices, and it is accessible through various devices. There were a lot of variation on the guides some of them being fitted in one page with commonly known information related to material maintenance and some of them being more comprehensive. Comprehensive care guides usually had visualization of the care labels, including washing temperature and ironing temperature, guides to their specific garment of accessory categories, or guidance based on their experience and use testing of their clothing.

4.1.2. Second hand platforms

Circularity of the fashion system requires other business-oriented solutions and contributions in addition to contribution from fashion and clothing producers and retailers. During the research on Finnish fashion and clothing companies some relevant observations were made. As many of the companies were aware of the high value of their garments and are trusting their desirability and popularity, they were using online secondhand shops for their designs. Online reselling was made using platforms such as Facebook group made specifically for the brand, their own secondhand sections on websites or stores or third-party secondhand store. Two commonly used third party secondhand retailers were Ninyes and Emmy. They have specific brands they are selling based on their criteria on durability, sustainability, and high-valued clothing. Companies using the mentioned platforms usually had a section on their website with guidance on how to sell their used clothing through the platforms. Secondhand markets places for certain brands can also be created by engaged customers on a social media platform such as Facebook.

Collaboration with the secondhand platforms requires minimal contributions from the brand itself as the secondhand store is responsible for selling the item to next consumer. Such digitalized businesses enable circular economy practices for smaller companies and gathers similarly valued fashion items to same place for consumers to easily browse through websites or mobile devices. Customers can search items through desired criteria or even set up a search alert that sends a notification when a clothing of a certain style, size or a brand is added to the selection. From a consumer point of view, it makes secondhand shopping efficient.

4.1.3. Repairing services

Another third-party circular economy-oriented business that had collaboration with many Finnish fashion and clothing companies was Menddie. The purpose of Menddie was to digitalize repairing and alteration services for companies and consumers. They are pursuing to be forerunner in technology enabling circular economy practices. Consumers can use

Menddie by sending information about the repaired or altered garment to the website and by choosing desired repairing service. The purpose of the platform is to bring repairing services closer to consumers and enable life cycle extension for their products. Practically Menddie is just a platform provider for combining repairing services to consumers and clothing brands.

Companies also had their own repairing and alteration services that usually worked through filling a form online and sending the garment to repair or to be altered. Some companies had alteration and repairing services as a part of their webstore or separate section on website. Repairing services are directly affecting the garment circulation since it enables life cycle extension to the product by keeping it in use longer. Alteration services also enable a well-fitting garment that the customer can be satisfied for years. Garments with alteration possibilities usually have wider seams so that the garment is suitable to be altered multiple times to fit its owner, which enables longer lifespan for the garment.

4.1.4. Fitting guidance and pre-ordering possibilities

Fitting guides and demonstrative videos showing the garments in action is included in the category of digital technology. Carefully chosen and purchased items are most likely to be worn and used longer than fast fashion pieces bought online. With comprehensive guide for fitting to different body types helps to make a successful purchasing decision and avoids unnecessary purchases. Different fitting videos and images where the garment is worn by different sized people are counted as a digital tool, since it pursues virtual but realistic shopping experience and is accessible from everywhere and on multiple devices. Plain tables with sizes and sizing information are not counted as a digital tool for circular economy since it is normal information in websites and doesn’t pursue the goals for extended life cycle. Fit guides usually concerned especially pants and jeans, which are typically hard garment categories to be fitted well.

Other commonly performed circular economy practices from the production phase that were enabled by digitalization were pre-ordering options. Usually, the clothing brand had separate collection for garments that were made only from orders. In such cases the production was meeting the customer demands without excess manufacturing. Companies using such practices acknowledged its positive impact on circular economy and over-production avoidance. Pre-ordering system provides useful data for the company related to customer demand and most popular items. It can help the company to prepare later production quantities to match the customer demand. The disadvantage from pre-ordering collections is that customer has to wait usually multiple weeks before the garment arrives, but it is not viewed as an issue from the slow fashion point of view.

4.1.5. Computer-aided design and 3D design

Production-related operations that were common for reducing waste from manufacturing phase were different 3D designing tools and programming tools for the patternmaking. In zero-waste design the pattern piece layout on fabric is optimized and the cutting waste is reduced. For companies focusing on knitwear, the zero-waste patternmaking means programming the knitting patterns in a way that it is knitted to shape. The yarn usage is optimized, and garment pieces are attached to each other without the need for cutting and sewing. One company utilized automatized cutting technology for fabric cutting, but it was not specified how digitalized the process was.

4.2. Results from the literature

Next subchapters explore and describe the different digital technologies and their use examples found from the literature. Examples from the literature mostly consists of findings from research articles and books. The contributions to circular economy and sustainability in overall is briefly reviewed as it gives more concrete example on the technologies and their usage.

4.2.1. Digitized fashion design

The design phase of garment production and some manufacturing stages can be digitized. Computer-aided design (CAD) and 3D design software can be utilized in the design and redesign processes of the clothing. CAD application could be integrated for example, in the processes of cutting, digital printing, or pattern digitizing and virtual prototyping. Patternmaking that utilizes CAD applications can contribute to the minimizing of fabric waste. They can be utilized together with laser cutting technology and designing programs. (Hwang & Zhang, 2020, 87-107.). CAD application and 3D design can contribute to the zero-waste designing and patternmaking (Hwang & Zhang, 2020, 87-107; Peter John & Mishra, 2023).

Conventional paper patterns can be converted to computerized form by pattern digitizing. One benefit of the digitized patterns is its cost-effectivity. With the help of digitized patterns, the focus of the design is more on meeting the needs of the garment manufacturer and creating accuracy to the fabric usage. It could be used to customize and modify printed fabrics, especially in the processes of redesigning. With the help of CAD applications, the textile waste can be upcycled to new design solutions. In redesigning and remanufacturing the new pattern pieces are fitted to older already constructed pattern pieces with the help of CAD. (Hwang & Zhang, 2020, 87-107.)

Digital textile printing process that is based on the ink jet print system can be used as a contrast to conventional printing methods using a wet process. The process of conventional textile printing damages the environment as it consumes large amounts of water and dyes. In digital textile printing process different ink types are used for printing onto fabrics made from cellulous, protein-based, or synthetic fibers. However, the process of digital textile printing is not completely harm-free as it also creates textile dye waste. (Hwang & Zhang, 2020, 87-107.) Digital printing that utilizes Internet of Things (IoT) can reduce production costs and increase operational efficiency. (Alves et al. 2022.)

The digital textile printing is controlled by CAD, but the printed pattern is usually produced with the help of different creative and illustrative software. Also, the use of Artificial Intelligence based visual tools can be used for creating the prints and images, which could result as innovative textile designs. (Hwang & Zhang, 2020, 87-107.) Innovative textile design could work as a contrast to boring-seeming designs of timeless sustainable clothing and circular economy garments.

4.2.2. Artificial Intelligence in manufacturing

Artificial intelligence (AI) simulates human intelligence through algorithms. AI algorithms can be trained and developed during the use with high quality data. (Ghoreishi & Happonen, 2020.) Machine learning as a part of AI uses algorithms for learning through examples (Rantala et al. 2023). AI enables faster operating in industrial manufacturing system. It provides intelligent manufacturing with advanced level learning and complements human skills. AI technologies can work in complex environments, where they increase efficiency and reduce human involvement.

Through utilizing computer aided processes and design, more circularity-oriented products can be created. AI can utilize long-term data streams but also real-time data. Circulation can be improved by utilizing AI and its predictive data usage. AI-aided decision making can be used in reusing materials and estimating production quantities. Possible failures in manufacturing phase can be prevented with the use of AI as it can identify them. Prevented failures can help to reduce waste from production failures. AI enables rapid testing and prototyping. (Ghoreishi & Happonen, 2020.)

AI can help to enable remanufacturing possibilities and easy recycling already in the design phase of the product. In practice it takes into account the possible disassembly or sorting. For circular design and manufacturing, the technological and biological cycles of the products need to be considered. AI-based data utilization can be beneficial for the product design, e.g., material choice. (Ghoreishi & Happonen, 2020.)

4.2.3. Internet of Things

Internet of Things (IoT) can be described as an ecosystem in which the devices are connected to internet or to one another. It utilizes Internet networks for collecting data, monitoring devices and objects, and transferring data. IoT applications can be beneficial for service business models by monitoring the system performance. (Ghoreishi & Happonen, 2021.) IoT ecosystem and connectivity on another dimension could help to face the data growth that is exponential (Alves et al. 2022). For communication and interaction IoT requires additional components for example, Radio Frequency Identification (RFID), Near-field communication (NFC), Bluetooth or Wi-Fi. NFC, Bluetooth and Wi-Fi are already integrated as built-in technologies in most smart phones, which makes them feasible additional components. (Alves et al. 2022; Berg et al. 2022; Ghoreishi & Happonen, 2021.)

IoT can be used for monitoring in the physical factory environment such as monitoring weaving and embroidery machines and production output. Monitoring is based on operating data in machines. (Alves et al. 2022.) In design phase IoT collects data and analyses the material quality and condition, which prevents errors and faults. IoT-assisted monitoring of manufacturing processes are faster than conventional monitoring processes. It also accelerates the interaction between humans and devices. By its monitoring and predictions, the quality of materials and products can be improved and made to last, which is essential for circular economy implementation. (Ghoreishi & Happonen, 2021.)

IoT assists in fast and smart prototyping and sampling, which help the manufacturer to meet the customer demand by precise production. IoT can assist in smart packaging and can be used for tracking and analyzing the product lifecycle. The data utilization provides life cycle management by predicting maintenance needs, tracing reuse and tracking recycling processes. Prediction of customer needs can be used for preventing material surplus and excess production of clothing. (Ghoreishi & Happonen, 2021.)

IoT devices with integrated sensors can provide data related to physical environment, such as temperature or shipping conditions. It can be beneficial for preventing damages during transportation phases of the product. (Alves et al. 2022.) In the end-of-life scenarios, where material is recycled and treated the possible available data prevents errors in recycling. Possible available data also makes the process more efficient and optimizes resource use. (Ghoreishi & Happonen, 2021.) One challenge related to data reliability and traceability is the use of identification on a product lot instead of a single product. In such cases, only some of the products are transported, sold, and used, which doesn't concern all the products in the same lot. After the use phase when the product is recycled, it is impossible to identify exact origin and lot of the product. (Alves et al. 2022.)

4.2.4. Identifiers

Identifiers can be beneficial from the circular economy point of view by for example, tracking source components. Most used identifiers are universal product codes, Radio Frequency Identifiers (RFID), and 2D barcodes. Passive RFID tags extracts the energy from the electromagnetic field that the reader device emits. Tags are long-lasting and structurally simple (Berg et al. 2022). One application of RFID is Near-field communication (NFC). It is a technology that large variety of mobile phones already support, and it makes it a very customer-oriented version of RFID technology. Additional sensors can make the identifiers intelligent and when combined with IoT, data collection is enabled. Intelligent identifiers can provide data about for example, location and accessibility. Logistics workers and manufacturers can utilize the data along the whole value chain. (Jia et al. 2020.)

Identifiers could provide information about the fabric and materials and how the products are manufactured. The information about recyclability and recycling options could be added to the identifiers. (Jia et al. 2020.) RDID tags can also help in product availability tracking and in analysis of customer behavior. As the RFID tags can contain information about the materials and used chemicals, they can be utilized in the recycling processes as well as in other life cycle stages. (Ghoreishi & Happonen, 2021.) Product information can be stored and tacked through creating a digital twin of the product. Digital twin can be made through the utilization of IoT. Desired asset of the physical product can be traced and tracked through its digital version. (Alves et al. 2022.)

There are challenges regarding tags and identification of RFID tags and 2D codes and barcodes. For example, RFID tags are hard to produce in large production volumes. RFID tag production requires advanced programming and high production costs. Barcodes and 2D codes are easy and cheap to produces but they can easily be reproduced or copied. (Alves et al. 2022.) Optical codes that don't contain any harmful substances can be easily recycled with the product, so it doesn't affect the recyclability of the product and can be easily used with different types of products. However, they are physically vulnerable and has a short reading range. (Berg et al. 2022.)

Consumer-friendly identification usually refers to identification that can be executed through the use of smart phones or other easily accessible devices. The signaling and communication can be implemented through Quick Response (QR) codes that are embedded in the garment for example in the form of a tag or label. It links the garment to a digital source such as website that can provide information generally or specifically of that garment. (Cramer, 2021, 85-104.) Adding QR codes to garments can provide verification and authenticity to the clothing (Alves et al. 2022). Users can have access to the information added to QR code and they can base their decision regarding the further use of the garment on the information given with the code. In ideal cases the user would support circular economy by reselling or enabling the reuse of the garment.

4.2.5. Blockchain supporting supply chains

Blockchain is a relatively new technology that can be applied to various types of production supply chains. Blockchain enables a new way to record and store transaction information and provides a platform for information sharing. (Yadlapalli & Rahman, 2022, 63-83.) In blockchain technology there is no single entity controlling the system. Instead of that the data is stored in multiple locations called blocks. Blocks are decentralized network that are connected in a chain and linked each other (Alves et al. 2022). Human and machine errors are minimized in the information sharing as the blockchain technology is automated. It also protects the data from manipulation. (Yadlapalli & Rahman, 2022, 63-83.)

In fashion and apparel industry blockchain is enabling the required transparency, traceability and sustainability that is required throughout the local and global supply chains (Alves et al. 2022). Instead of conventional centralized system blockchain is decentralized ledger that connects the parts of supply chain providing real-time data. It promotes sustainability and it is estimated that brands are adopting blockchain technology as their core element in company strategies. (Yadlapalli & Rahman, 2022, 63-83.) Blockchain technology combines the information that was previously segmented and provides new business opportunities and more efficient supply chain management. For different uses and future applications blockchain technology can be integrated with other Industry 4.0 technologies. Examples on such technologies are Big Data, Cloud computing, AI and IoT. (Alves et al. 2022.)

Blockchain provides accurate and real-time data from raw material extraction to use phase of the garment and even beyond. In manufacturing phase, the spinning of yarn and fabric production can be recorded to blocks. (Yadlapalli & Rahman, 2022, 63-83.) Due to on-site information recording and real-time data, it is efficient to execute possible recalls in case of accidents or risks related to e.g., health (Alves et al. 2022). Blockchain technology provides a reliable information sharing platform in the design and manufacturing phase where possible advanced tools are used e.g., 3D product designing, virtual sampling, digitized material databases and libraries, and AI-supported planning are used. Together with other technologies such as machine learning and AI, data can be processed quickly and through those blockchain can be utilized for the decision making. (Yadlapalli & Rahman, 2022, 63-83.) Blockchain technology as an information sharing platform encourages to communication and collaboration between designers and manufactures as it was discussed to be required in more sustainable and circular fashion design.

Sustainability assurance can be executed using blockchain technology. It helps the brands and companies to reach towards or achieve their sustainability goals and targets. In addition to e.g., enabling authenticity raw materials and traceability of the material journey, blockchain technology minimizes the costs and time for information sharing as the information is recorded on-site. (Yadlapalli & Rahman, 2022, 63-83.) Blockchain enables easy identification and resale, but also provides tracking of excess inventory in order to reduce waste generation. From business point of view, it helps to capture the supply chain economic value in each step. (Jain et al. 2022). Although the technology pursues sustainability and even circular practices, it doesn't necessarily guarantee them. In many cases closing the loop and circulation are in the hands of customer or other externality such as second-hand reseller or recycling company. Other drawback of utilizing blockchain technology from environmental point of view is its power consumption and energy use (Alves et al. 2022).

Another use for blockchain technology is blockchain technology-based emissions trading, which helps to evaluate the sustainability of a garment from the emissions aspect. It also can suggest ways to compensate the emissions and lower the product carbon footprint. (Alves et al. 2022; Fu et al. 2018.) Emission unit could be traded straight from the blockchain based on data recorded there. At the same time, it reduces the need for human involvement as the process is more automatized. (Fu et al. 2018.) Emission tracking and possible trading increases economic activities and reduces emissions, but it doesn't necessary pursue circularity.

Brands and producers are also in under a pressure for adopting such technologies as blockchain. Companies are required to monitor and report their practices in addition to improving them towards more sustainable and circular practices under certain policies and certifications. It can be noted that utilization of blockchain. From the business point of view, blockchain technology also provides smaller companies the opportunity to enter global markets and international trade due to decreased trade costs. (Yadlapalli & Rahman, 2022, 63-83.)

Challenges related to the utilization of blockchain technology are related to technology, organizational issues, external environment, and inter-organizational relationships. Mostly they are related to adoption of new technologies. Blockchain is a relatively new technology and can seem complex technology that requires more examples on application on it. From inter-organizational relationships point of view, blockchain technology needs to be customized to meet the company's requirements and to fulfil successful information sharing. Also, things that effect on the adoption of the technology is the resources for investing on new technology, technical expertise, and management support. (Yadlapalli & Rahman, 2022, 63-83.)

4.2.6. Digitalization for retail and reselling

Digital technologies are beneficial for the retailer-customer interaction and for customer interaction between themselves. Online stores can develop the purchasing experience by creating more realistic experience while visiting an online store on a website or via smart phone. Stores can add virtual product images and samples instead of physical display (Alves et al. 2022). Online stores can utilize AI algorithms and Virtual reality (VR) for creating virtual dressing rooms. It can help customers to choose styles and garments according to algorithm-based recommendations. Customer's device with camera works as a dressing room "mirror" and with the utilization of augmented reality the customer can see what the garment would look in use. (Akhtar et al. 2022.)

Virtual dressing rooms are not broadly adopted yet, but they have a huge potential in online shopping and accessibility on brands that doesn't have global network of physical stores. Such technology can also have a potential on reducing unnecessary purchases and shipping them. Such innovative technologies help analyzing the appearance and fit of the garment and can even give alteration suggestion before the purchasing decision (Dissanayake, 2022, 21-40). Alteration suggestion possibilities beneficial for creating the garment to fulfil and satisfy the customer needs. It also pursues ideology of slow fashion and prevents unnecessary purchases as the garment is made and altered to fit the customer.

Mobile applications enabling circular economy practices are related to trading and selling of already used clothes. Trading of secondhand clothing are actions between two users and application works as a service or a platform for reusing clothing. Payments and additional activities are provided in the platform in order to make the application as customer oriented as possible. Some applications have the option for loaning. Benefit of mobile applications for sharing economies or secondhand garment trading is accessible for consumers regardless the time and place. (Faria et al. 2020.)

Digitally provided product-service systems (PSS) pursues collaborative consumption, which means rental and leasing services, where the ownership of the item doesn't change or swapping, auction or resale between consumers. (Dissanayake, 2022, 21-40.) In ideal situation PSS pursues circular economy and reduces environmental impact through it while reducing consumption and delivers economic benefit. The value of consumption would be disconnected and transferred to alternative material consumption by replacing personal ownership. (Armstrong et al. 2015.) Data usage in PSS encourages companies for optimized product design, lifetime management, maintenance, and circular economy practices such as reuse and recycling. (Luoma et al. 2021.)

4.3. Summary of the results

For creating a comprehensive foundation for analyzing and discussing about the results and their contributions to circular economy they are presented together in a Table 1. First column presents the digital tool or digital-aided practice found from literature or case companies. Second column lists the life cycle phase or phases where the mentioned technology is used or could be used. Third column gives examples how the technology would be applied or how it would be used. Fourth column presents an example of a company if the mentioned technology is used in some of the case companies.

Table 1. Digital technologies, their use in life cycle phases, and an example on application and possible example company if found.

Digital technology or digital-aided technology	**Life cycle phase**	**Application examples**	**Company example if found**
3D modelling	Design	Designing in 3D, zero-waste patternmaking	Aarre (3D knitting), Halti, Voglia
Artificial Intelligence (AI)	Design	Visual designing, designing for circularity	
	Manufacturing	Data analyzing, decision making, identifies possible failures, testing and prototyping	
Blockchain	Whole supply chain	Information about material origins, information sharing platform, efficiency to manufacturing, tracking, and tracing, transaction information	
Computer Aided Design (CAD)	Design	Virtual prototyping, zero-waste patternmaking, remanufacturing, waste minimization	Alpa, Kaino, Morico, Vimma
Digital care guidance	Extended use	Extending the clothing lifecycle by providing care and maintenance information	Almost all
Digital platform (third-party or company-owned) for ordering repair, maintenance, and alterations services	Extended use	Extending the clothing lifecycle by repairing and maintenance of the garment	Aarre, Alpa, Halti, Kaiko, Kaino, Nanso, NP Housukauppa, papu, R-Collection, Voglia
Digital printing	Manufacturing	Minimizing water and dyes of printing process, innovative textile design	Pure Waste, R-Collection, Uhana
	Design	Data collection, analyzing	

Internet of Things (IoT)	Manufacturing	Monitoring, testing, and prototyping	
	Transportation	Shipping conditions monitoring	
	Whole supply chain	Tracking	
Pre-order	Retail	Manufacturing on demand, avoids excess production	Lilja the Label, Lille, NOUKI
Quick Response (QR)	Retail	Information about materials, chemicals, and manufacturing	
	Extended use	Information about authenticity, repair guide	
Radio Frequency Identification (RFID)	Manufacturing	Information about material origins	
	Retail	Information about materials, chemicals, and manufacturing	
	Recycle	Information for recycling	
Mobile applications, virtual secondhand shops (third-party or own by a company)	Extended use	Accessible secondhand trading	Aarre, Alpa, Blaa, Glope Hope, Kaiko, Kaino, Marimekko, MIAM, Morico, Nanso, PaaPii, Papu, Vimma, YO ZEN
Virtual reality, purchasing aid	Retail	Virtual product images in online stores, virtual dressing rooms, assisting in purchasing decisions	Aarre, Blaa, NP Housukauppa, Very Nice

Technologies included and summarized in the table were all examples found from literature and company examples that were considered most relevant and contributing to circular economy in the context of this thesis. Overall digitalization activities of a company were excluded from the table. Other excluded technologies were digital-aided help for choosing a size such as calculator or a chat bot. As seen from the table, there was variation and even distribution between all the life cycle phases within the scope, from design to retail and extended use.

It can be briefly summarized that technologies found from the literature was covering all the lifecycle steps within the scope. Examples from the literature had more contribution to earlier life cycle steps, especially manufacturing and supply chain activities. Digital-aided tool examples found from companies were mostly focusing on moderate retail and extending the use phase of the garment. Production related activities were digital-aided designing phase including CAD and 3D design, and digital printing in manufacturing phase. Only connection found was that both only jeans and pants focused companies applied digital-aided purchasing decisions in their retailing activities. There were no other clear correlations found between the technologies from companies and their fields, size, or possible resources.

5. Digitalization of the fashion industry in Finland

The discussion in this chapter is based on the results and theoretical framework while answering the research questions set in the introduction chapter. The first sub-chapter is strongly based on the results of the study on company examples and explores the current state of digitalization in fashion and circular economy context in Finland. Second subchapter is answering the second research question and discusses on the possibilities that digital tools provide for the circular economy of Finnish fashion industry. The chapter strives to create the overall picture on how more circular and digitalized fashion system in Finland could be achieved and what technologies it would include for minimizing the negative environmental impact.

5.1. Current state of digitalization for circular economy of Finnish fashion industry

The goal of the first research question that was set in the introduction chapter was to map out the current digitalization-related tools and practices that contributes to the circular economy of Finnish fashion system. The data and information for answering the first research question is mostly formed based on the results from company study and relevant sources supporting the topic. The results showed that currently most implemented circular economy practice is extending the use phase of the garment with the help of different digital solutions. There were some examples regarding the designing and manufacturing phase such as utilization of digital designing tools. Other observations regarding digitalization were company and business-related activities that are outside of the circular economy scope for the fashion industry itself but indicates the overall level of digitalization.

Solutions for extending the use phase is providing information on the care, offering maintenance services owned by the company or a third-party company, and providing accessible secondhand trading through different platforms. The observations that were made concerning third party- secondhand stores and repair services proved that digitalization related to life cycle extension is strongly based on platforms on the internet. The solutions still require effort from consumers as the whole process cannot yet to be fully digitalized or automatized. However, they are beneficial from the circular economy point of view and can make the whole life cycle extension of a product easier. Things that are affecting how sustainable the use of services is are related to platform servers and transportation phases of the clothing. Platform-based businesses can affect their environmental impact and energy use by choosing low-carbon servers for their websites. In order to minimize the environmental impact of reselling used clothing or repairing the clothing, more environmentally friendly transportation options can be chosen.

The examples on aiming towards circularity principles was waste minimization aided by digital design tools and zero waste design. As expected, there was some correlation between companies that pursued circular economy and were using digital tools in the designing phase. It was acknowledged to be an efficient way for reducing material waste or even a way to produce zero waste garments. Utilization of digital tools in the designing phase is resource-efficient in multiple ways in addition to reduced cutting waste. It saves the number of needed samples and prototyping, which could be a significant change for companies working with expensive materials and seeking to minimized waste. The utilization of computer-aided design software's in overall save time and makes the design and production processes more efficient for smaller companies or individual designers.

Companies have different baseline for implementing sustainability and circular economy practices. A significant factor is choosing the manufacturing places and subcontractors, which have an impact in the sustainability of the manufacturing phase. Also, the types of garments they are producing, and the types of materials affect the circularity. For example, outdoor wear e.g., waterproof jackets or technical wear are usually constructed with multiple materials in order to achieve desired properties and functionalities of the garment. Also, companies having garments that are used in sporty activities can have issues keeping the clothing in circulation due to hygiene issues.

The type of manufacturing effects on material flows and waste material. Well-fitting garments that consist different kinds and sizes of pattern pieces are harder to make zero-waste garments compared to loose-fitting garments. Garments with looser fit can also cover multiple sizes and need for altering the garments can be avoided. Knitwear and garments with knitted fabric has beneficial baseline for executing zero-waste pattern making and garments. Knitted garments can be knitted into pattern pieces for each size with optimized yarn usage without causing any waste material.

Fast fashion as it is in the global context is not possible in the context of Finland. Even if the designing and prototyping could be done relatively fast with the resources of many Finnish company the fast production with low cost wouldn’t be possible. Labor costs for the actual manufacturing of the garment are so high that the production quantities and prices of the garments couldn’t match the fast fashion scale. From the results of studying Finnish companies and the theory of circular fashion it can be stated that Finnish fashion industry pursues slow fashion in one way or another. The level of sustainability and circularity are in the hands of the companies, without neglecting the role of customers and their demands.

Finnish Ministry of Economic Affairs and Employment states that current digital ecosystem still strongly leans on web-based platforms and tools for project management, which are traditional digital tools. (Työ- ja elinkeinoministeriö, 2022.) It concerns all digitalization for circular economy, but the phenomenon can be seen from the results of company-oriented study. Most of the used technologies and digital-aided tools are rather traditional. The tools are harnessed for achieving companies’ circularity and sustainability goals, but the technologies are not new even if they are innovatively used. Finland is still missing scalable circular economy operations that are utilizing digitalization. However, Finland has potential to be one of the leading counties in the digitalization of circular economy. Finland is a forerunner of material innovations and has high rate of digitalization. It is still needed to have operations that are combining both. Also, the lower baseline for digitalized circular economy can be viewed as an opportunity. It enables the development of innovative solutions and systems from the beginning without path dependency. (Työ- ja elinkeinoministeriö, 2022.)

It can be concluded that the level of digitalization for the circular economy for Finnish fashion industry is relatively low compared to the possibilities in Finland and knowledge capital related to circular economy. Many activities pursuing circular economy goals of the industry and individual companies leans on traditional tools and digital-aided solutions. The lower level of digitalization can be seen as an opportunity without path dependency on the development. The next chapter, which also answers the second research question explores the opportunities Finnish fashion industry has and how digital tools can be implemented for circular economy.

5.2. Digital technologies enabling circular economy of Finnish fashion industry

The goal of the second part of the research was to explore the opportunities for circular economy of Finnish fashion industry aided by digitalization. Examples on technologies and their implementations was searched from literature and they are combined with the results from company study and current level of digitalization. While exploring the opportunities, the contribution to circular economy is reviewed. The digitalization-aided circular economy practices are presented in different lifecycle steps within the scope of this thesis starting with design phase and ending to extended use phase.

Circular economy possibilities are enabled already in the designing phase of the garment by designing based on circularity principles. As a contrast to fast fashion designing the garments and pieces of fashion are designed in a way that they last physically and aesthetically. The benefits of circular fashion design are not only environmental as minimizing resource use also reduces the material costs. However, technologies enabling material minimization is a one-time investment but can be financially too large investment for smaller companies and individual designers. As stated earlier, the type of manufacturing highly affects the possibilities for the company to design zero-waste clothing as knitted garments can be knitted into shape but clothing that is sewed into piece requires thoughtful pattern layout on the fabric. For such designs digital tools can be beneficial and reduces the need for prototyping.

Utilization of 3D design software has been relatively slow in fashion industry even when the conventional way of patternmaking is a trial-and-error approach and takes a lot of time and resources. Patternmaking methods and designs can be more easily visualized as the virtual 3D patternmaking is more utilized and developed further (McKinney et al. 2020). It reduces the need for prototyping and the designed pattern can be exported straight to the manufacturing. Simultaneously virtually made modifications save time and materials of prototyping. The immediately seen modifications also increase room for creativity without the risk of wasting material. One limitation in designing is the fabric widths, especially if the fabric is manufactured and bought somewhere else. One possibility to overcome the issue is to develop and integrate software and fabric weaving (McQuillan, 2020).

The circularity options of a garment are defined already in the design phase. Currently in fast fashion industry the design phase focuses on aesthetics based on current trends ignoring the rest of production phases. In order to achieve more circular fashion system with less negative environmental and social impacts, the design phase should consider other production phases. Data storing and utilization makes material information accessible for designers and others involved in the designing process. The aspect of timeless designs and avoidance of short-lived trends are in the hands of designers. Current vision on ecological fashion is often that the garments are too basic and boring. AI-based tools can help in the designing process for creating fashion pieces that are the opposite of current vision.

Figure 4 presents a possible ideal situation where digitalized garment design follows circular design principles. As found from the literature and company study, CAD and 3D design tools contribute to minimization of material use or even zero-waste design. Digital patternmaking can also help to design clothes in a way that they can be easily altered to fit customers with variety of sizes and body types and enabler longer lifetime of the garment through that. In more circular fashion system, the designer’s responsibility extends to minimizing the negative impact of production by right material choices and designs that serve the circularity principles. Accessible material and impact data aided with AI can create fascinating pieces of fashion without the massive environmental burden as in fast fashion industry.

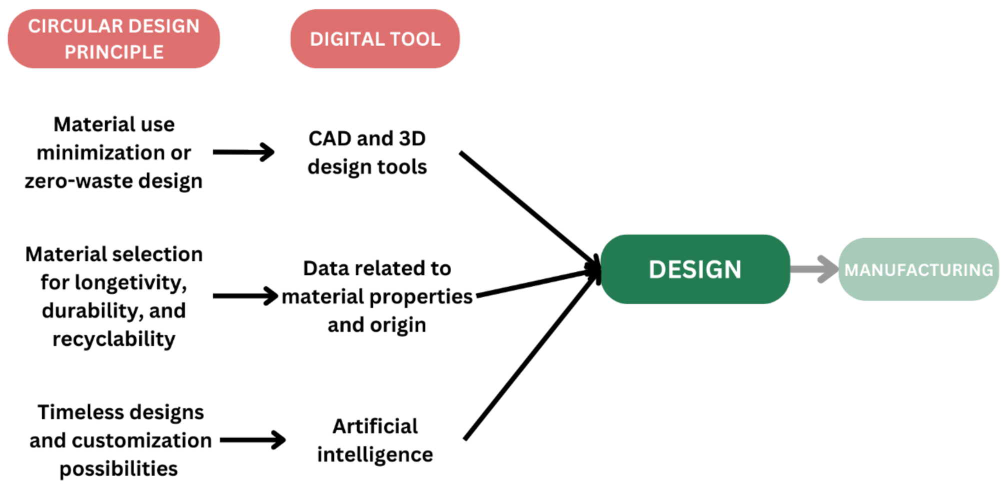

Figure 4. Designing for circularity and sustainability based on circular design principles can be aided by utilization of digital tools- such as CAD, 3D design tools, data usage, and AI.

Manufacturing processes of garments have many contributions to circular economy and sustainability. Smart manufacturing phase avoids excess production, meaning that manufactured quantities match the customer demand and number of garments ending up to use. To avoid unnecessary waste streams the garments could be designed in resource efficient way or in a way that leftover material can be used to manufacture something else. There were many examples from companies where leftover materials were used to create accessories or even separate collection.

Digitalization enables smart production and efficient manufacturing environment as presented in Figure 5. Manufacturing phase in an ideal situation could include many digital tools found from literature. Some aspects such as tracking, and traceability of a garment is becoming more common as EU develops the digital passport for garments. The examples presented in the figure are, however, company's own operations and possible pathways towards more circular fashion system. The possible technologies are listed on the left side of the figure, whereas their functions are in the middle and contribution to sustainability are on the right side.

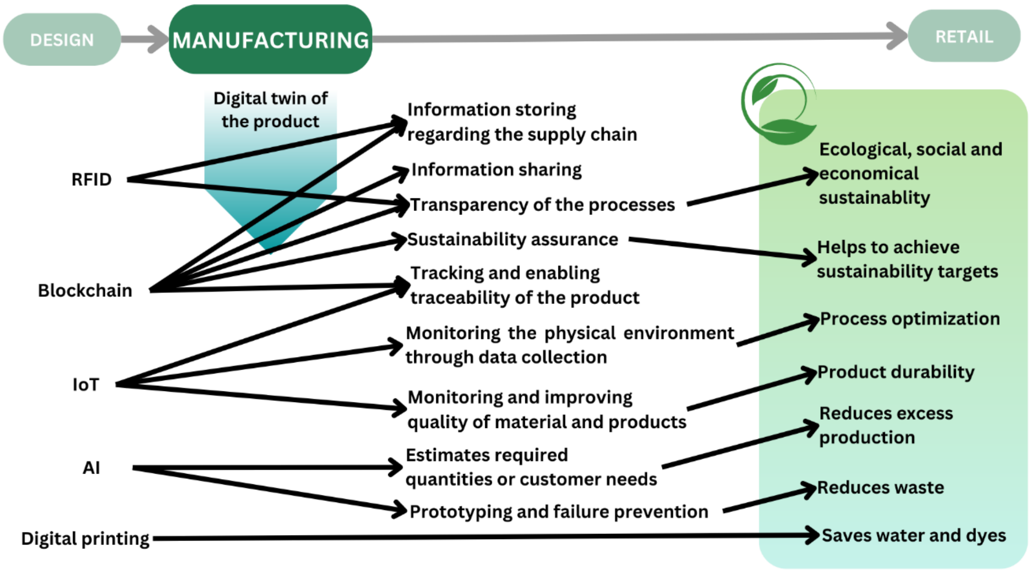

Figure 5. Technologies, their functionalities and contributions to sustainability and circularity in the manufacturing phase of a garment production.

Digitalization oriented fashion industry leans on same principles as other smart manufactured products and digitalized factory environments. Tracking and monitoring are executed digitally, and products have digital identity. There are many technologies enabling ethe creation of digital twin of the product. In its most basic form, it requires identification on the physical product and a database where the information is stored and where it can be tracked. The product can also be connected to digital networks through IoT. There weren't any examples found on tracking products in the context of Finnish fashion industry, but technologies such as IoT and RFID where already utilized in circulation of work wear. There were many studies and research on technologies and feasible solutions that were under development. Those examples justify the reason why tehse technologies were selected as possible future solutiosn in the fashion industry context.

Smart manufacturing environment includes optimization of all resources in addtitoin to material resources for garment manufacturing. The machinery and utilizaion of factory environment requires electricity and energy use, which could be monitored through digital devices. The real-time data can be stored and even calculted as emissions per produced garment, which increases certain transperacy of the production. The company might not be able to affect the digitalization of the factory enviroment if the space is not own by them or the whole maufacturing phase is outsourced to another company. The companies showded already cooperation with choosing the manufacturing locations and sub-contractors, which cretaes an opportunity for collaboration in digitalization of mnaufacturing environments.

Many companies that were selected to the company study provided trasnparent information on their supplychain including countries where the material ro the yarn for fabric comes from, and manufacturing locations. Digitalization can take the transparency even further providing real-time data and infomarion as well as reliable tracking of certain product lots. Transparency and traceability is beneficial for the companies as they can improve their operations based on them. Improvement can mean more sustanable and circular processess but also optimization in ecomomic matters. Customers will benefit from transparency as it provides information that they might be interested in based on their values. For example, some consumers value domesticity, some value high quality of materials and some value ethical and socially sustainable supply chain.

Blockchain technology as a relatively new digital tool is not yet broadly used. It is however included in an ideal and possible scenario since it is beneficial for every lifecycle step as already described in previous chapters. The main benefits for retailing phase are the transaction storing and information sharing platform. The benefits for information sharing platform reaches to reselling and life cycle extension possibilities as it provides authenticity and verification to products and their origin. Verification plays an important role in high-valued fashion items.

Consumers as a large group can act for sustainability through choosing sustainable produced garment that is transparently proven. The value of the garment is better acknowledged and it and encourage the customers to extend the products lifecycle if they have the access to supply chain information. Figure 6. presents the possible ecosystem for seamless retailing for fashion companies, where consumes are valued by providing comprehensive information on their products and where consumers have the access to desired information. Retailing stage focuses on selling new clothes, which means that reselling secondhand clothes are excluded from this diagram even if companies could have their own secondhand store.

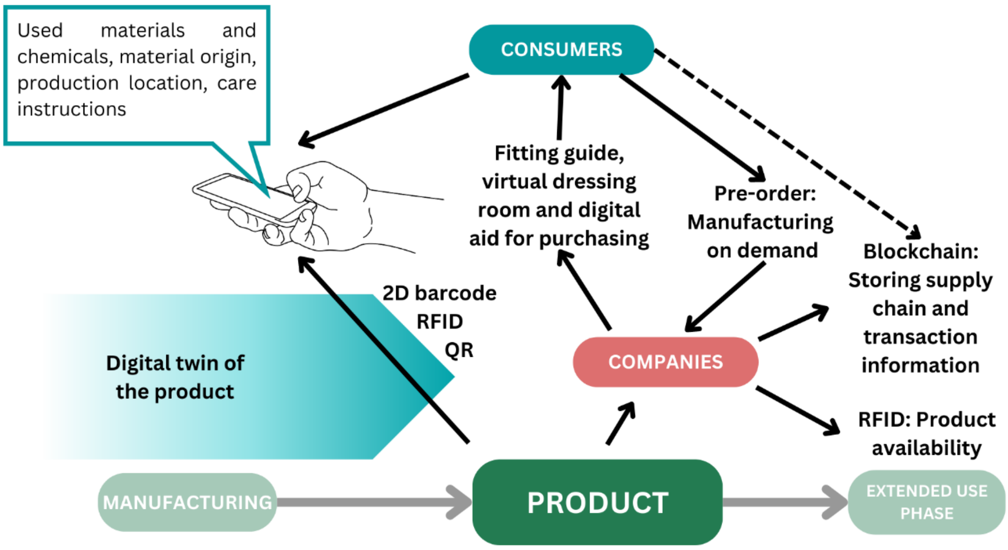

Figure 6. Ecosystem for seamless retailing of new sustainable clothes. Consumers can have the access to product and supply chain information and companies are supportive by providing guidance and aid for purchasing.

In circular-oriented retailing ecosystem the consumers are highly involved. The already mentioned information access in physical stores can be executed through the utilization of barcodes, RFID, or QR depending on the company resources. Online stores can provide the information on their website or on a product site. When aiming to long usage phase of the product companies could provide comprehensive information on sizing and other fitting-related attributes. Purchasing guidance and aid in online stores doesn't require much technical skills or other resources. Virtual shopping experience can be created by diverse product images and videos where the garment is shown in action.

Physical stores or storing management for garments can utilize RFID technology for checking product availability and monitoring stocks. AI and IoT can create predictions on customer demand based on previous and real-time data. Consumers can be involved through pre-ordering system, which is less resource-requiring equivalent for manufacturing on demand. System can be created with lower resources by creating online form or a webstore section with pre-ordering collection. Pre-ordering has an impact on production quantities avoiding excess production and collecting relevant data for predicting future production quantities. The waiting time for pre-ordered clothing is longer compared to usual purchase from a webstore. Usually, the customers of slow fashion brands acknowledge the value of pre-ordered item and longer waiting times are not viewed as an issue.

The previous steps described are the responsibility of the companies and the actors in the industry itself. In circular fashion system the consumers have their role too as they are the ones deciding what happens to the garment after it is no longer in use. Companies, third-party businesses, and other organizations can provide guidance and possibilities for consumers to extend the lifecycle of their products or recycle it properly. Proposed system of possibilities for extending the product usage is presented in Figure 7.. Extended use phase is already enabled in the designing phase of the product if it is designed for circularity.

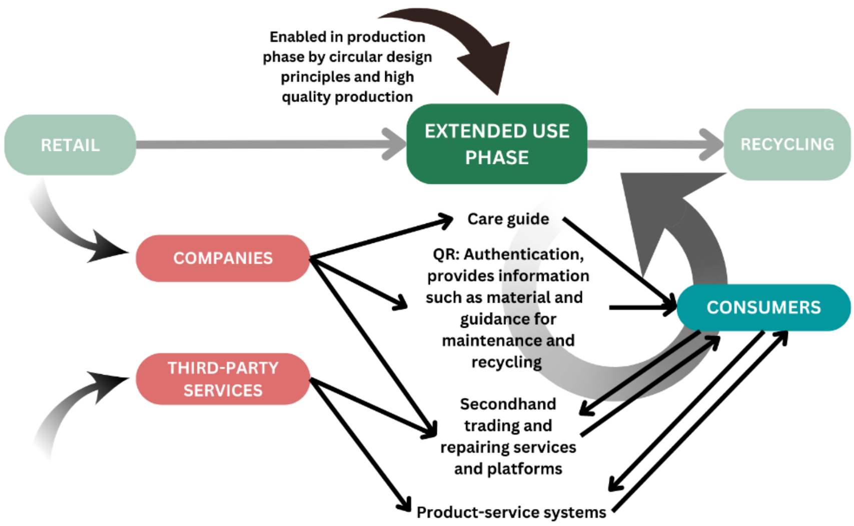

Figure 7. Proposed system for secondhand selling and platforms for extending the lifecycle of a garment.

In the figure the fading circular arrow represents recurrent usage of a garment. Recurrence is the responsibility of consumers, but it is guided and helped via different services and platforms companies and third-party businesses provide. Care guides that were found to be one example of company-enabled life cycle extension are information packages containing guidance on how to take care, wash, and repair the garments. As already presented in previous figure, care guidance can also be integrated into readable tags including other relevant information. Such tags could for example, be read through a QR code with mobile devices. QR codes integrated in the garment could also provide authenticity and consumers can rely on its origin and brand.

Product-service systems and different secondhand trading platforms can be offered by the company or another business. Third-party services are practicing circular economy as they are creating value for reusing or providing services for used clothing. For example, Menddie, that is a repairing service that many of the case companies had collaboration with, is a mending and alteration business without own physical repairing spot. Companies and consumers are only choosing the service provider through Menddie's platform. It is a platform business bringing companies, consumers and repairing businesses together. As circular economy practices are gaining more users and profits, such platforms and services are becoming more common.

For achieving active circular fashion system, the circular design concepts should be applied as early as possible in the production phase. Above described and mentioned ecosystems are desired stages for Finnish fashion industry that could be worth to pursue. Circular economy as a whole system would require multiple stages more, such as recycling and utilization of recycled raw material and remanufacturing. The criticality of implementing such technologies vary depending on the type of product and its sustainability impacts. Many presented tracking and information sharing technologies are beneficial for the later lifecycle steps although they weren't included in the scope. It proves that digitalization's role concerns the whole life cycle and in circular system the life cycle steps are connected to each other unlike in fast fashion system.

The strengths of Finnish fashion industry are its smaller scale compared to many other countries and unprofitability of Finnish-based fast fashion companies. Small scale of Finnish fashion industry enables collaboration between companies and services. Finnish fashion industry that includes many like-minded companies can work together towards common goals. Finnish Textile and Fashion as an organization is supportive towards the sustainability and digitalization goals of the whole industry. Garments can be designed to serve its purpose and circularity principles with the help of digitalization without following any existing pathways.

Advantage for sustainability transition of Finnish fashion industry is that there are no Finnish-based fast fashion companies. Finnish fashion design and production, either domestic or highly monitored manufacturing abroad, is traditionally highly valued. Valuable and high-quality garments are precondition for long and circular lifetime. The observation that was made based on the company studies were that Finnish design has maintained its value and reputation, but domination of foreign fast fashion companies has affected the position of Finnish-based companies. The popularity of Finnish-based brands is in the hands of consumers and their purchasing behavior. However, legislative actors and policymakers have a role by demanding transparency and certain level of sustainability for fashion companies.

5.3. Challenges of utilizing the digital technologies

Third research question for the study in this thesis was to recognize relevant challenges and drawbacks related to digitalization of the fashion system. The goal was also to propose actions for overcoming the challenges or avoiding drawbacks. The observed challenged are related to technicalities and lack of resources as expected but also consumer behavior and externalities. The challenges and drawbacks are based on observations made during literature review, company study and earlier discussion subchapter. Challenges are in the context of overall sustainability, circular economy, and business operations.

The challenges related to utilization of different digital technologies are related to lack of resources such as economic resources and technical skills. Broad utilization of digital tools along the supply chain requires technical skills and digitalization from all participants. In situations, where supply chain reaches areas with less digital development the utilization of mentioned technologies can be a challenge and digital tools are resisted due to many reasons. It can be due to relying on traditional paperwork or due to lack of resources such as finances or knowledge. For seamlessly working digitalization of the supply chain, it is required for all participants to utilize digital tools. Companies have the option to choose sub-contractors and others involved in the supply chain, but then some other criteria such as certain sustainability criterion might not be fulfilled. The relevant question for companies to discuss is whether to support traditional garment manufacturing or to create digital supply chain that is more traceable than supply chains relying on paperwork.

The resources needed for utilization of digital technologies are financial resources and technical knowledge. The required technical skills vary depending on whether it is utilization of software or integrating a digital system to manufacturing. For utilization of software related technologies, workers of the company can be educated for using them. One observation made during the exploration of real-life examples was that education for garment designing supports digital designing tools and digitalized designing environments. There was also literature supporting renewed fashion design concepts that included extended responsibility for designers and designing based on utilization of digital tools. Boarder digitalization on the other hand requires often personnel specialized in such technologies or at least consultation outside the company. One proposition for digitalised Finnish fashion system is third-party service for assisting companies to digitalize their operations. Designing digitalized system carefully from the beginning reduces the risks of faults and drawbacks on later utilization. System that is designed for flexibility will keep pace with the continuous development of digitalized systems.

One drawback related to utilization of digital systems is the energy consumption required for maintaining the system. All digital tools consume energy as they are machinery and software requiring energy, or they are connected to networks. All data storing and maintaining the system virtually requires energy consumption in data centres. Data centers development towards more energy efficient centers will reduce the energy consumption and indirectly decrease the emissions created. There are also options for data centers using renewable energy sources. As companies provide data and information on their websites to an increasing extent, they can choose low-carbon hosting for their website to minimize emissions from their websites.

Many of the challenges related to digitalized and circular fashion system are not technical challenges or barriers created by large investments. Earlier it was stated that Finland has advantageous position for having a small-scale fashion industry. However, it has its drawbacks. Finland as a small nation and having a lot of sparsely populated areas can have issues especially when implementing digital service and platform-based solutions for circular economy. For example, loaning or fast swapping of clothing often works better in an environment where there are physically a lot of people around. However, online secondhand selling provides participation opportunities for sparsely populated or distant areas.

There are also issues related to the nature of fashion and consumers desire to express their identity via clothing and fashion. That affects the utilization of rental services or other digitally working product-service-systems, where the personal ownership of a garment is replaced. Alternative consumption models might not serve the function and emotional meaning to some consumers as Armstrong et al. has stated (2015). Consumers can also see secondhand options unpleasant choice. The benefit of such systems, however, are the possibilities for people following alterative styles and prefers unique pieces.

One external challenge for digital and circular fashion system is the dominant position of fast fashion and online retailing. Some companies offer free returning, which accelerates the negative impacts of fast fashion as clothes are transported multiple times to customers and back. It creates an illusion on seamlessly working digital retailing and affects the perception of sustainable online retailing, where the waiting times are longer, and clothes cannot be returned similar way if they don’t meet the customer expectations. Also, the design aesthetics of sustainable fashion might not be appealing to some consumers. Sustainable fashion brands don’t follow the fast-paced trends and are more focusing on aesthetic longevity and even avoids trends. Such consumer behavior cannot be easily affected. Faster designing and prototyping phase can accelerate the production speed, which partly increases the competitive advantage for sustainable fashion companies. It can also be seen as a drawback for fashion industry and speed up the fast fashion phenomenon even more, even though it is not viewed as a problem for Finnish fashion industry.

One challenge is the integration of the digital and circular system to current global fashion system, where fast fashion is a dominant form and most of the garments are produced in countries with cheap labor and in factories without readiness for digitalization as stated many times, Finnish fashion industry is in advantageous position as the integration of digital technologies can be more easily implemented throughout the supply chain compared to many global companies. However, there is a challenge of implementing service-based systems. The technologies and platforms already exist, and consumers are adopting them to an increasing extent. The challenge is the quality of garments especially manufactured in fast fashion industry. They are not designed to last time aesthetically or physically and life cycle extension-oriented technologies cannot be applied to them to increase their lifetime.

6. Conclusions

This chapter concludes the general findings that were made during the research process of this thesis. The first subchapter discusses about the validity, impact, and contribution of this work. The second sub chapter reflects the limitations of the study and challenged that occurred. In addition, the chapter discusses on applicability of this thesis and gives recommendations for future research.

6.1. Output of the research, its validity and impact

The findings and research-related output of this study was different feasible digital solutions for Finnish fashion industry to utilize for pursuing circular economy. The results from literature and case company study were combined to a one comprehensive pathway explaining the possibilities for circularity. Most relevant and feasible findings were contributions to minimization of material use and different solutions to tracking the clothing in order to collect relevant data. Proposed systems also involved consumers as circular and digital fashion system is an ecosystem where consumer collaboration and involvement provide useful data. Especially in Finnish context consumers can be taken into account easier than in many other countries due to small scale of Finnish fashion industry.

The results were valid in the context of Finnish fashion industry as many of the results were an actual example that were already in use and other examples found were utilized in another context if not fashion and clothing production context. The feasibility of selected and proposed technologies was evaluated as well as the fit for the topic. For assessing the contributions to circularity and sustainability in overall more data would've been required. The current evaluation for contributions is mentioned without any numerical estimations. For collecting more specific data, there would've been geographically broader explorations or more examples from the technologies in use. As study was based on qualitative analysis, the numerical values and estimations weren't seen as that relevant. Also, in the context of circularity and improvement of fashion system all the information cannot be numerically measured as it includes a lot of aspects such as behavior and attitudes of consumers.

The contribution of this study is not practical contribution as it strongly relies on literature review and analysis based on public data without goal for implementing results in real-life. The impact of the study and results cannot be evaluated in this stage, but the study is conducted in a way that it could serve Finnish fashion industry by giving examples and propositions towards more digital and circular system. This thesis unifies examples and practices found from Finnish companies and from a global scale. Collective and feasible propositions are made based on the results and they were presented in discussion chapter 5. Similar studies had not been made, which justifies the topic.

The summarizing conclusions that could be made based on this study are the advantageous position of Finnish fashion industry as it has potential for developing a seamless system without the need for following existing pathways or making massive alterations to their supply chains in geographical means. Finland also has variety existing companies with different fields and focus areas, which creates a foundation for comprehensive supply for consumers interested in participation of circular fashion systems. However, the digitalization is not yet acknowledged as powerful tool for pursuing circular economy for products even if the implementation of overall digital technologies is seen as a positive development.

6.2. Limitations and future recommendations

As stated earlier, the research in this thesis is very applicable in Finnish context as the case companies are located in Finland and are working under Finnish policies and regulations. The companies have their own group of dedicated customers and their abilities to go towards circularity is also taken into account. Finland’s lower level of digitalization and smaller companies are considered advantageous in the journey towards circular fashion in a global context. The output of this study would be applicable in similar countries such as Nordic countries and many other European countries with similar standards of living. For reviewing the applicability in countries outside Europe, more knowledge and study would be required related to overall digitalization and fashion consumption.

The limitations and challenges of this thesis concerns data gathering and data availability. The utilized data was public data from companies' websites and sustainability reports, which means that the data availability was in the hands of the companies. The data and information that would've been most relevant concerning the current state of digitalization was not available. One possible reason could be the lower level of digitalization in the fashion industry in Finland. Another reason could be that companies doesn't recognize its relevancy to stakeholders to whom the websites and reports are intended to, and it has been left out from the websites. Also, the definition of digitalization or digital tools in this context is indistinct.

The broadness and relevancy of this topic resulted many recommendations for future research. Similar studies could be conducted in different geographical areas. The possibilities and challenges of different global regions could also be studied including study on possible path dependencies and opportunities for novelties. Studies could also be conducted focusing only on certain technologies as the most common and feasible ones are now recognized. Data-based circular economy of fashion also creates new opportunities for lifecycle assessment and lifecycle planning. One possible future research related to the topic would be evaluating the feasibility of more accurate life cycle and circularity assessment based on innovative and digital data collection methods.

The research focused only on textiles in a fashion context and included other fashion industry aspects such as design and clothing circulation amongst consumers. Other important topic in a global context is other fashion items such as accessories and shoes, and other textiles such as home textiles or furniture. Many of the studied companies had home textile collection and provided information related to them but the demand for transparency is lower in other textile sectors than in clothing context. Hence, one possible future research theme would be studying circulation and digitalization-oriented opportunities for other textile sectors.

7. Summary

The thesis included comprehensive review on literature regarding circular economy of fashion industry and digitalization for the circularity, methodology, results from the literature and company examples, analysis and discussion while answering the research questions, and conclusions including the research findings, impacts, and reviewing practical issues. The background and reasoning for the topic of this study is its relevancy as emerging themes in fashion industry are digitalization and sustainability, which adoption is urgent matter based on the broad sustainability issues on ecological, social, and economic scale. One proposed solution to overcome the issues of polluting the environment, large waste streams, and overconsumption of material and natural resources is circular economy. Instead of direct material extraction, production, utilization and disposing of the product, the material would circulate in a closed loop. In clothing context, it means circulation of fibers, fabrics, and other material as well as the garment pieces themselves. Circular economy can be enabled at the production and designing phase when considering all the circular economy activities including material choices and easy maintenance of the garment.

Circular economy activities can be aided with different digital tools, which can base on data collection, data integration or data utilization. In overall production processes digitalization enable efficient processes in the means of economic resources, time use, and resource use. In the circular economy and clothing production digital tools can be integrated in multiple lifecycle steps starting with design software and zero-waste design taking customer demand into account. Resource efficient manufacturing and innovative retailing reduce material flows and excess production. Platform-based solutions create endless possibilities for reuse and data provide information for efficient recycling. However, the digitalization of different company operations requires economic resources, technical knowledge and comprehensive planning and data management.

The obligation of this thesis was to define the current level of digitalization for circular economy in Finland, research what possibilities the utilization of digital technologies could provide and explore the possible challenges and drawbacks. The research in this thesis was carried out by literature review and by analyzing public data from case companies. Literature review as well as the theory section in this thesis was based mostly on research articles and books. The aim was to study possible feasible digital technologies that pursue circular economy and overall sustainability. Public company-based data was gathered from companies' websites and possible sustainability reports. Company examples were gathered to table, where the digital tools and digital-aided practices were recognized and listed.

There was variation on the digital technologies found from the internet as some of them were more concrete and already present in current global fashion system and some of them on the other hand were related to designing and manufacturing phases hidden from the normal consumer. The most relevant findings from the literature were tracking and identification technologies such as blockchain technology, RFID, and IoT, and technologies for designing the garment, which were CAD and 3D design tools. The results from example companies were mostly related to extending the use phase of the garment such as digital care guidance, platforms for secondhand trading and repairing of the garment. Other digital-aided tools were digital printing in manufacturing phase, guidance and optimization for retailing, digital printing, and the digitalization of overall business operations.

First research question was to discuss about the level of digitalization for the circular economy for Finnish fashion industry. The results of company study showed that Finnish fashion system relies on traditional and technologies and methods. Compared to the possibilities in Finland and knowledge capital related to circular economy, the level if digitalization for the circular economy could be higher. The lower level of digitalization can be viewed as an advantage as Finland can create the system by designing it for the digitalized circular economy from the beginning.

To create digitalized circular fashion system, the integration of broadly used circular economy principles and digital technologies are needed. Circular design concepts should be applied already in the design phase, in which Finnish fashion industry is already one step ahead compared to many fast fashion companies. Finnish fashion design and production is traditionally highly valued due to the quality and durability, which is a precondition for long and circular lifetime. Data storing and accessible information related to materials and their sustainability impacts enables designing for circularity in a longer perspective. Minimization of material use, and even possible zero-waste designing can be aided with CAD and 3D design tools. Circular economy principle for minimization of material use can also be implemented in manufacturing phase, where excess production, prototyping is made resource-efficiently, and high-quality manufacturing enables long-lasting lifecycle for the garment. Smart manufacturing is a digital environment where in proposed situation the environment and its operations are monitored and through utilization of technologies such as IoT, which enables the optimization of the processes in means of quality and energy-efficiency. Digital twin created in the manufacturing phase or blockchain technology can be used for tracking the product throughout its lifecycle and collect relevant data related to it beginning with the material origin and ending up to recycling phase.

Information about the garment, its material origin and manufacturing can be provided with barcodes, RFID, QR, or on websites depending on the company resources. For online shopping, companies can provide comprehensive information on sizing and other fitting-related attributes. Digital tools can be used for creating predictions on customer demand based on collected data, but companies with less resources can utilize pre-ordering systems for manufacturing on demand and for collecting useful data for demand predictions. For extending the use phase of the garment, companies and other services can create platforms for secondhand trading, maintenance, and alteration of clothing. Technologies used for tracking can also provide origin and authenticity information for secondhand buyers.

The challenges related to implementing digital technologies for the circular economy of Finnish fashion industry are related to technicalities, lack of resources such as skills and finances, consumer behavior and domination of current fast fashion industry. Finnish fashion system is in an advantageous position to avoid described challenges as the smaller scale of the industry enables faster implementation of digital technologies and existing collaboration between the companies can be beneficial for overcoming the issues related to lack of resources.

References

Akhtar, W.H., Watanabe, C., Tou, Y., et al. 2022.A New Perspective on the Textile and Apparel Industry in the Digital Transformation Era. Textiles, vol. 2, no. 4, pp. 633-656.

Alves, L., et al. 2022. Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: A review, SAGE Publications, London, England.

Armstrong, C.M., Niinimäki, K., Kujala, S., et al. 2015.Sustainable product-service systems for clothing: exploring consumer perceptions of consumption alternatives in Finland. Journal of cleaner production, vol. 97, pp. 30-39.

Balasaraswathi, S.R. & Rathinamoorthy, R. 2022.Synthetic Textile and Microplastic Pollution: An Analysis on Environmental and Health Impact in Sustainable Approaches in Textiles and Fashion, ed. S.S. Muthu, Springer Singapore, Singapore, pp. 1-20.

Berg, A., et al. 2022.Handbook for a Data-Driven Circular Economy in Finland: Data Sources, Tools, and Governance for Circular Design, VTT Technical Research Centre of Finland.

Brydges, T. 2021.Closing the loop on take, make, waste: Investigating circular economy practices in the Swedish fashion industry. Journal of cleaner production, vol. 293, pp. 126245.

Chen, X., Memon, H.A., Wang, Y., et al. 2021.Circular Economy and Sustainability of the Clothing and Textile Industry. Materials Circular Economy, vol. 3, no. 1.

Cramer, J. 2021.Use Forecasting: Designing Fashion Garments for Extended Use in Sustainable Design in Textiles and Fashion, eds. S.S. Muthu & M.A. Gardetti, Springer Singapore, Singapore, pp. 85-104.

Dissanayake, D.G.K. 2022.Enabling Circular Fashion Through Product Life Extension in Sustainable Approaches in Textiles and Fashion, ed. S.S. Muthu, Springer Singapore, Singapore, pp. 21-40.

Ellen McArthur Foundation 2017.A New Textiles Economy: redesigning Fashion's future.

European Commission 2022. Communication From the Commission to The European Parliament, The Council, The European Economic and Social
Committee and the Committee of The Region: EU Strategy for Sustainable and Circular Textiles, Brussels.

Faria, R., Lopes, I., Pires, I.M., et al. 2020.Circular Economy for Clothes Using Web and Mobile Technologies—A Systematic Review and a Taxonomy Proposal. Information, vol. 11, no. 3, pp. 161.

Flick, U. 2010.Designing qualitative research, repr. edn, SAGE, London[u.a.].

Fu, B., Shu, Z. & Liu, X. 2018.Blockchain Enhanced Emission Trading Framework in Fashion Apparel Manufacturing Industry. Sustainability, vol. 10, no. 4, pp. 1105.

Ghoreishi, M. & Happonen, A. 2020.Key enablers for deploying artificial intelligence for circular economy embracing sustainable product design: Three case studies. AIP Conference Proceedings, vol. 2233, no. 1.

Ghoreishi, M. & Happonen, A. 2021.The Case of Fabric and Textile Industry: The Emerging Role of Digitalization, Internet-of-Things and Industry 4.0 for Circularity in Proceedings of Sixth International Congress on Information and Communication Technology Springer Singapore, Singapore, pp. 189-200.

Happonen, A. & Ghoreishi, M. 2021.A Mapping Study of the Current Literature on Digitalization and Industry 4.0 Technologies Utilization for Sustainability and Circular Economy in Textile Industries in Proceedings of Sixth International Congress on Information and Communication Technology Springer Singapore, Singapore, pp. 697-711.

Hwang, C. & Zhang, L. 2020.Innovative Sustainable Apparel Design: Application of CAD and Redesign Process in Sustainability in the Textile and Apparel Industries, eds. S.S. Muthu & M.A. Gardetti, Springer International Publishing AG, Switzerland, pp. 87-107.

Jain, G., Kamble, S.S., Ndubisi, N.O., et al. 2022.Antecedents of Blockchain-Enabled E-commerce Platforms (BEEP) adoption by customers – A study of second-hand small and medium apparel retailers. Journal of business research, vol. 149, pp. 576-588.

Jia, F., Yin, S., Chen, L., et al. 2020.The circular economy in the textile and apparel industry: A systematic literature review. Journal of cleaner production, vol. 259, pp. 120728.

Joy, A., Sherry, J.F., Venkatesh, A., et al. 2012.Fast Fashion, Sustainability, and the Ethical Appeal of Luxury Brands. Fashion theory, vol. 16, no. 3, pp. 273-295.

Karell, E. & Niinimäki, K. 2019.Deconstructing the clothing design process for a circular economy.3rd PLATE Conference, ed. N. Nissen, Berlin, Germany, September 18 – 20, 2019.

Loschek, I. 2009.When Clothes Become Fashion: Design and Innovation Systems, Berg Publishers, Oxford.

Luoma, P., Toppinen, A. & Penttinen, E. 2021.The Role and Value of Data in Realising Circular Business Models – a Systematic Literature Review. Journal of business models, vol. 9, no. 2, pp. 44-71.

Machado, C.G., Winroth, M.P. & Ribeiro da Silva, E.H.D. 2020.Sustainable manufacturing in Industry 4.0: an emerging research agenda. International journal of production research, vol. 58, no. 5, pp. 1462-1484.

Mäkelä, M., Rissanen, M. & Sixta, H. 2020.Machine vision estimates the polyester content in recyclable waste textiles. Resources, conservation and recycling, vol. 161, pp. 105007.

McKinney, E., Cho, S., Zhang, L., et al. 2020.Analysis of Zero Waste Patternmaking Approaches for Application to Apparel in Sustainability in the Textile and Apparel Industries, eds. S.S. Muthu & M.A. Gardetti, Springer International Publishing AG, Switzerland, pp. 31-51.

McQuillan, H. 2020.Digital 3D design as a tool for augmenting zero-waste fashion design practice. International journal of fashion design, technology and education, vol. 13, no. 1, pp. 89-100.

Niinimäki, K., Peters, G., Dahlbo, H., et al. 2020.The environmental price of fast fashion. Nature reviews. Earth & environment, vol. 1, no. 4, pp. 189-200.

Peter John, E. & Mishra, U. 2023.A sustainable three-layer circular economic model with controllable waste, emission, and wastewater from the textile and fashion industry. Journal of cleaner production, vol. 388, pp. 135642.

Quantis 2018.Measuring fashion: Environmental Impact of the Global Apparel and Footwear Industries. Full report and methodological considerations, Quantis.

Ramchandani, M., Coste-Manière, I., Walia, I., et al. 2022.Global Textiles and Its Alignment with Sustainability in Sustainable Approaches in Textiles and Fashion, ed. S.S. Muthu, Springer Nature Singapore, Singapore, pp. 1-12.

Rantala, T., et al. 2023.Digital technologies for circular manufacturing, VTT Technical Research Centre of Finland.

Rathinamoorthy, R. 2020.Sustainable Clothing Designs for Fashion: Design Strategies and Its Implementation Possibilities in Sustainability in the Textile and Apparel Industries, eds. S.S. Muthu & M.A. Gardetti, Springer International Publishing AG, Switzerland, pp. 127-161.

Senthil Kumar, P., Yaashikaa, P.R. & Femina Carolin, C. 2021.Sustainability in Textile Design in Sustainable Design in Textiles and Fashion, eds. S.S. Muthu & M.A. Gardetti, Springer Singapore, Singapore, pp. 39-51.

Sisodia, N. & Parmar, M.S. 2022.Converting Textile Waste into Designer Wall and Floor Tiles: A New Approach to Recycle Textile Waste in Sustainable Approaches in Textiles and Fashion, ed. S.S. Muthu, Springer Singapore, Singapore, pp. 149-164.

Suomen Tekstiili & Muoti 2022, , *Circular Economy in the Finnish Textile Business*. Available: https://www.stjm.fi/en/textile-innovations-design-excellence/circular-economy-in-the-finnish-textile-business/ [2023, 31.3.].

Teona, G., Ko, E. & Kim, S.J. 2020.Environmental claims in online video advertising: effects for fast-fashion and luxury brands. International journal of advertising, vol. 39, no. 6, pp. 858-887.

Työ- ja elinkeinoministeriö 2022. Kiertotalouden digitalisaatio ja ekosysteemit: Nykytila, tavoitearkkitehtuuri ja toimenpiteet, Helsinki.

van der Ven, C. & TULIP Consulting 2022. Circular innovation and ecodesign in the textiles sector, Sitra, Helsinki.

Welters, L. & Lillethun, A. 2018.Fashion History: A Global View, Bloomsbury Academic, London. UK.

Whitty, J. 2021.Fashion Design for Holistic Systems in Sustainable Design in Textiles and Fashion, eds. S.S. Muthu & M.A. Gardetti, Springer Singapore, Singapore, pp. 1-22.

Yadlapalli, A. & Rahman, S. 2022.Blockchain Technology in Apparel Supply Chains in Sustainable Approaches in Textiles and Fashion, ed. S.S. Muthu, Springer Nature Singapore, Singapore, pp. 63-83.

Appendix 1. Results from company examples gathered in a table.

Company	Field	Care guide	Digital return form	Digital form or webshop for repair or maintenance service	Menddie	Ninyes	Emmy	Fitting videos or digital guide	Digital print	Other digital tools or digital-aided practices pursuing circularity or sustainability	Circular economy practices	Digitalization	Source website
Aarre	Clothing for women, men, children, and home textiles	X	X		X	X	X	X		3D knit pantyhose from leftover recycled polyamide			https://aarrelabel.com/
Alpa	Knitwear for women, men, accessories, and home textiles			X						Secondhand webshop, computer aided design and patternmaking	X		https://alpa.fi/
Archetype	Womenswear	X											
Blaa	Clothing for women, unisex collection, accessories	X				X				Chatbot for helping to choose a product and size			https://www.blaa.fi/
Bypias	Clothing for women and men, accessories, and home textiles	X										X	https://www.bypias.com/
Ekta Helsinki	Knitwear for women, men, and children, accessories, home textiles	X											https://www.ektahelsinki.fi/fi
Globe Hope	Recycled clothing for women and men, accessories, and lifestyle	X				X	X				X		https://globehope.fi/
Halti	Outdoor wear for women, men, and children	X		X				X		3D design tools		X	https://www.halti.fi/
Kaiko	Clothing for women and children, home textiles				X	X							https://kaikoshop.com/
Kaino	Knitwear for women, accessories, and fabrics	X		X						Programming zero-waste knits, Facebook group for secondhand clothing	X		https://shop.kaino.fi/
Kude Design	Womenswear and accessories	X											https://www.kude.fi/
Lilja the Label	Swimwear for women	X	X							Pre-order, calculator for helping to choose a size	X		https://liljathelabel.com/
Lille	Womenswear and accessories	X								Pre-order			https://lilleclothing.com/
Mari-mekko	Clothing for women, men and children, accessories, and home textiles	X								Digital tool for quality assurance, secondhand marketplace	X		https://www.marimekko.com/fi_fi/
MIAM	Clothing for women, home textiles and accessories	X				X							https://miamclothing.com/pages/vastuullisuus

Moonah Wear	Yoga wear for women										X		https://moonahwear.com/
Morico	Clothing for women, including swimwear and sportswear	X				X				Zero waste design	X		https://morico.fi/
Nanso	Clothing for women and children, accessories	X			X		X				X		https://nanso.com/
Népra	Sportswear for women and men, and accessories	X								Repair patches from webshop			https://www.wearnepra.com/
NOSH	Womenswear	X								IT Innovation (not specified)	X		https://nosh.fi/
NOUKI	Womenswear and accessories									Pre-order			https://www.nouki.fi/
NP Housu-kauppa	Pants for women	X		X				X		Digital wardrobe with information about previous order			https://housukauppa.fi/
PaaPii	Clothing for women and children, fabrics, and lifestyle	X								Facebook group for secondhand clothing			https://www.paapiidesign.com/fi
Papu	Clothing for women and children, accessories	X			X	X							https://papudesign.fi/
PURA Finland	Clothing for women, accessories	X											https://www.purafinland.com/
Pure Waste	Recycled clothing for women, men and children, fabrics	X							X		X		https://purewaste.com
R-Collection	Clothing for women, men, children, and accessories				X				X				https://www.r-collection.fi/
Revoel	Activewear and swimwear for women	X									X		https://revoel.com/fi
Riva	Unisex clothing, home textiles	X											https://rivaclothing.com/
Uhana	Clothing for women and accessories	X							X				https://uhanadesign.com/
Very Nice	Jeans for women	X						X		Automatized cutting technology (not specified)	X		https://www.verynice.fi/
Viljava	Clothing for women and children, accessories, fabrics	X											https://viljavadesign.fi/
Vimma	Clothing for women and children	X					X			Computer aided design and patternmaking	X		https://www.vimmacompany.com/
Voglia	Clothing for women, unisex collection, accessories	X		X						3D design tools		X	https://www.voglia.fi/
YO ZEN	Womenswear, jewellery					X				Digital tools in company operations		X	https://www.yozendesign.com/