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Industry 4.0 as an Enabler of Circular Business Models

Within the clothing industry

by

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Abstract

This study investigates the role of Industry 4.0 as an enabler of circular business models within the clothing industry. The research was conducted based on a thorough investigation of the clothing industry through both an ethnographic content analysis and two interviews. Both the concepts of circular business models and Industry 4.0 are relatively new and more importantly, Industry 4.0 is a concept that is not fully developed as it is still underway. The research was, therefore, meaningful in order to contribute to a more complete understanding of what the current status of development is and where there is yet unrealized potential. The findings suggest that clothing companies are aware of the role of Industry 4.0 technologies as enablers of the circular economy. However, the implementation of the technologies is not very widespread yet in the industry. Consumer behavior, financial limits and company perception and knowledge of the technologies are important factors currently hindering the implementation. Meanwhile, circular business models are associated with high cost savings as they will imply that the companies no longer need to extract resources. For this reason, the circular business models are also desirable for companies as it will likely be a solution to urgent environmental issues. While many clothing companies are currently developing circular business models and implementing Industry 4.0 technologies, there is still unrealized potential in how the technologies are used to facilitate and define the development of circular business models.

Keywords: Circular Economy, Circular Business Models, Circularity, Industry 4.0, 4th Industrial Revolution, Artificial Intelligence, Machine Learning, Internet of Things, Additive Manufacturing, ReSOLVE Framework, Product-Service Systems, Cyberphysical Systems, Rs Principles

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List of abbreviations

AI	Artificial Intelligence
AM	Additive Manufacturing
BDA	Big Data Analytics
BM	Business Model
CB	Cloud-based
CE	Circular Economy
CBM	Circular Business Model
CPS	Cyber-physical System
CSC	Circular Supply Chain
ECA	Ethnographic Content Analysis
EMF	Ellen MacArthur Foundation
I4.0	Industry 4.0
IoT	Internet of Things
LLF	Long-life fashion
ML	Machine Learning
PSS	Product-Service Systems
SLF	Short-life fashion
TC	Textile & Clothing

1 Introduction

Over the past few decades, the world has undergone profound changes, predominantly resulting from rapid globalization and industrialization. This has had significant implications for global sustainable development. In parallel to these developments, the world has become more interconnected than ever before, primarily due to drastic technological developments and the increased mobility of goods, services, capital and labour in the past few decades (United Nations, 2017). This has generated various economic opportunities and has contributed to impressive economic growth, whereby worldwide gross domestic product has increased from approximately 50 trillion USD to 75 trillion USD between 2000 and 2016 (United Nations, 2017). Globalization has, however, also negatively impacted the environment, and as a result, may directly or indirectly have the potential to impede sustainable development on a global level. The United Nations (UN) highlights three globalization mega-trends, which relate to the "[s]hifts in production and labor markets; rapid advances in technology; and climate change" (2017). The latter two are of major interest in this paper; changes in technology and the environment. Technology has been a key consideration in sustainability throughout history, whereby its growth resulted in the Industrial Revolution through the evolution of machines and technology which enabled dramatic increases in production worldwide (Henderson, Persson & Sprei, 2018). This led to advanced economic activity, but at the expense of the environment. Technological advancement remains meaningful to the environment, whereby recent technological inventions may now have the ability to instead support environmental sustainability. This includes the various technologies associated with Industry 4.0 which have the potential to revolutionize manufacturing processes. Countries, as well as independent organizations including companies, should focus on how to implement these new technologies in alignment with the needs of the environment, in order to achieve sustainable development which is vital for the long term success of humanity.

1.1 Background

Sustainability has become a leading concern globally as human activity has aggravated various environmental challenges which now threaten global sustainable development. Rapid globalization has led to drastic changes in all aspects of our lives, including the environment and technology which both have a strong correlation to sustainability. Technology has both contributed to current environmental issues but may also have the ability to resolve them. These challenges have significant implications to business, whereby many existing environmental issues are a result of unsustainable business activity. At the same time, however, increased attention to sustainability within the context of business has, since the 1950s, resulted in the formulation of various sustainability theories (Henderson, Persson & Sprei, 2018). One prominent theory is the Circular Economy (CE) which focuses on decoupling economic growth from consumption through closing the loop of the use of resources (Ghisellini, Cialani, & Ulgiati 2016). The CE theory will be the focus of this paper and, more specifically, the CE's relationship to Industry 4.0 (I4.0) technologies.

1.1.1 The Circular Economy

1.1.1.1 Sustainability and Business

The UN now classifies current environmental issues as one of greatest challenges that exist today and state it is a central threat to worldwide sustainable development (2020). Sustainability entails "creating and maintaining the conditions under which humans and nature can exist in productive harmony to support the present and future generations," says the Environmental Protection Agency (EPA, 2021). There are three main dimensions of sustainability which include environmental, societal and economic aspects. Strong sustainability acknowledges that the environment is the fundamental dimension which society and economy rely on, meaning both would ultimately be unable to advance without a functioning environment (Henderson, Persson & Sprei, 2018). It is therefore crucial that human activities, including business activity, align with environmental success as it is essential to uphold this for the success of all including for businesses.

As these environmental challenges will ultimately affect all economies and societies, there is a strong relationship between business and sustainability. The environmental challenges that exist today will pose a threat to all companies, particularly the long run. Thus, integrating sustainability efforts in all fields and businesses is not only vital for the environment, but also for their own success. Corporations have the ability to aid in environmental restoration through refining their practices to support the environment. This can be enabled through the use of smart technologies within business processes, such as those associated with I4.0 (Cagno et al, 2021). Previously, sustainability within businesses was mainly used as a marketing technique, but due to stricter environmental regulations and increased awareness amongst consumers and employees, has now become a part of effective business strategy (Henderson, Persson & Sprei, 2018). Recognizing the potential role of new technologies in advancing sustainable practices, has further promoted sustainable business activity as a way to gain a competitive advantage in the long term (Varadarajan, 2015).

1.1.1.2 The Circular Economy, Circular Business Models & the Clothing Industry

The circular economy (CE) is a modern sustainability theory which advocates for the abandonment of traditional linear ('take-make-dispose') economic models in favor of circular models which, optimally, loop the use of resources indefinitely (Ellen MacArthur Foundation, EMF, 2013). The CE is commonly known for its association with the so-called 3Rs principles (reuse, reduce, recycle). These principles have become very popular in the clothing industry, particularly in recent years with the increased interest in second-hand clothing among consumers. The increased efforts made by companies in the clothing industry to associate themselves with sustainability, have also resulted from the extensive criticism that the industry has received regarding its devastating impact on the environment, as well as the fact that resources are finite and that companies may not be able to sustain their operations in the long-run if solutions are not found. The production of textiles, for example, accounts for 1.2 billion tonnes of greenhouse gas emissions annually, and a loss of over 500 million USD in potential value (EMF, 2017).

Efforts towards achieving a CE will likely generate immense profits through increased optimization of operations and a significant reduction in the use of resources. A solution for clothing companies may, therefore, be to tap into the opportunities associated with the CE through developing circular business models (CBMs). These efforts are urgently needed as Koszewska (2018) mentions that there will be an 84% increase in demand for textile fibers predicted within the next 20 years which will increase the need for resources "to their breaking point," and result in extensive amounts of waste (Koszewska, 2018, p.339). However, adopting CBMs is also associated with challenges, specifically for already established companies. The solution to these challenges may be a strategic implementation of cyber-physical systems, involving the connection between the virtual and physical world through advanced technologies. These technologies are associated with a new industrial revolution, Industry 4.0 (I4.0), which is predicted to dramatically transform the manufacturing industry.

1.1.2 Industry 4.0

The fourth industrial revolution, also referred to as I4.0, is a transition that is currently underway (Demestichas & Daskalakis, 2020). The full effects and characteristics of I4.0, are therefore, still unknown. However, what is unique about I4.0 is the ways in which new technologies are used in innovative ways to advance manufacturing. In I4.0, the virtual world is connected to physical objects in so-called cyber-physical systems (CPS). This makes the products 'smart' which enables vast opportunities, including decentralized and autonomous decision making by artificially intelligent systems, accurate balancing of supply and demand based on data generated in real-time, and advanced production capabilities. I4.0 is commonly associated with technologies and technological capabilities such as: artificial intelligence (AI), machine learning (ML), big data analytics (BDA), Internet of Things (IoT), additive manufacturing (AM), nanotechnology, biotechnology, autonomous robots and vehicles, and virtual simulators. However, this is not an exhaustive list and new technologies are constantly being developed. The concept of I4.0 will, ultimately, be decided by the ways in which businesses implement the technologies and how they are received and used by society. However, there is significant potential associated with the transformation of manufacturing into smart manufacturing. While the technologies may negatively impact the environment through accelerating the speed and efficiency of production, the hope is that the new ways in which businesses can create value will enable a large-scale transition into a CE.

1.2 Aim and Objectives

Sustainability, and more specifically its implications for business activity, in relation to the CE, is clearly a relevant topic today as environmental challenges pose a threat to global sustainable development. The rise of I4.0 technologies, and their involvement in promoting CBMs, is of particular interest as it may be revolutionary for industries worldwide. Thus, we aim to investigate how the rapid technological developments and their associated opportunities are received and implemented by different firms in the clothing industry to advance their efforts in achieving CBMs.

Choosing to focus on a single industry (the clothing industry) is a more attainable method for this study due to the time length and scope of this project and will also allow for a deeper understanding of the situation within the particular industry as opposed to a shallow analysis of various industries. We hope that our investigation of the clothing industry may reveal insights that can be applied on a more general level to the business sphere as well. Such an investigation may lead to important suggestions for future research, which is of great value to the development of the next industrial revolution, also known as I4.0, as well as the progression into a CE.

Our research question is as follows:

How can clothing companies integrate I4.0 technologies into their value creation chain to achieve a circular business model?

In order to identify theoretical gaps within existing research about this topic, an extensive investigation of previous literature was conducted. This formulated the theoretical framework which guided the remainder of the study including the data collection and analysis which will be based on observations of the clothing industry. The theoretical framework involves a detailed exploration of the previous research regarding I4.0 technology utilization for achieving a CBM. Following a detailed literature review about CBMs, I4.0, and the correlation between them, the proposed relationship will be explored by investigating the clothing companies' interaction with I4.0 for achieving circularity within their operations. The research will comprise two data collection methods, which include an ethnographic content analysis (ECA) of various virtual documents, as well as interviews with two clothing companies. Thereafter, the data will be analysed in a thematic manner to reveal common patterns within the industry, while keeping the theoretical framework in mind. Our hope is that this research will reveal valuable information of how I4.0 technologies are employed in the clothing industry to achieve CBMs, and thus answer the research question.

1.3 Research Purpose

In the process of investigating the previous research made, it was revealed that there is a substantial amount of literature suggesting that I4.0 technologies can be used for achieving the CE (Cagno et al 2021; Modgil et al 2021; Rajput & Singh 2019; Rosa et al 2020; Uçar, Le

Dain & Joly, 2020). However, this theory is more a proposed idea rather than fact-based theory based on case evidence. The reason may be that the research is still relatively new, partly because I4.0 is still underway and partly because companies are still trying to find ways to transition into a CE. The literature is also rather vague in terms of how the proposed connections between I4.0 and the CE will actually be implemented in reality. Furthermore, there has not been sufficient research into how industries may differ in being able to utilize the technologies for the purposes of circularity. In other words, the theoretical gap lies in being able to explain the current status of development, as well as how the connection between I4.0 and CE will be made in the clothing industry specifically. In addition to this, there are few previous studies that have investigated I4.0 usage in companies for the purpose of achieving CBMs within a particular industry. Although some literature exists that explains how clothing companies can use I4.0 technologies to achieve CBMs, this is still mostly within the realms of grey literature. Furthermore, these are not studies based on observations of clothing companies aimed at representing the industry in its entirety.

To fill the theoretical gap, we aim to expand CBM theories by adding a technological dimension to it, and doing so in a way that will reveal how companies are applying these concepts to their businesses. Our study will build on literature about I4.0 which is of particular importance, as I4.0 is still in its infancy and moreover, a concept that is not fully developed as it is still underway. This means that any recent investigation into this technological era is relevant as it will provide a more recent insight of its evolution. From a more practical perspective, this study can provide managerial insights by revealing how firms can implement I4.0 technologies to support the development of CBMs.

1.4 Delimitations

There are various conceptual boundaries and delimitations that have been set by the researchers, and should therefore be outlined prior to beginning this study. Initially we aimed to investigate how technologies could be employed in order to improve environmental sustainability. To narrow the scope and to explore this in a business setting, the circular economy theory was discovered which is concerned with eliminating waste and moving from a linear business model. Investigating the CE in relation to business activity, the concept of a circular business model (CBM) was revealed and chosen as the dependent variable. CBMs involve various frameworks, of which we identified the ReSOLVE, Rs, and product-service systems (PSS) framework as the most important, and thus these will be involved when evaluating CBMs.

The independent variable, which was initially technology, was also narrowed down to only include those technologies associated with Industry 4.0 which is a very relevant concept and is currently developing. I4.0 is also a relatively broad term that involves various different technologies that are still in the process of evolving, so we further had to decide upon a concrete definition to ensure consistency throughout our study. In simple terms, we define I4.0 as a revolution of the manufacturing industry which is currently underway and which builds on the interconnectivity of new and advanced technologies and innovative ways of using them, thereby having far-reaching implications for the economy, environment and society at large.

There are various different industries that could have been analysed to investigate the potential use of I4.0 in achieving a CBM. Due to the scope of this project, we chose to focus on a single industry whereby we chose the clothing sector.

1.5 Outline of the Thesis

The previous Introductory section has laid the foundation of this paper and has revealed the importance of sustainability, circularity and Industry 4.0 technology in today's world. The brief Background introduced key concepts and relevant themes that are important to the remainder of this study. We began by highlighting the importance of sustainability for businesses, including using circularity as a way to promote sustainability of a firm. Thereafter, the CE in the clothing industry was introduced and following this, Industry 4.0 and the implications for CBMs were outlined. The Aims & Objectives were also explained, including the research question, as well as the Research Purpose which explained this study's problematization. Finally, the Delimitations were outlined to highlight the conceptual boundaries of the study.

This connection between I4.0 and the CBMs is the focus of this paper, and previous research regarding these will be explained extensively in the literature review. Thereafter, we will explain how we plan to undergo the data collection for the investigation, which is presented in the Ch.3. This includes a content analysis and interviews. Thereafter, the data collected are presented, analysed and discussed in Ch.4. Finally, the implications of the study and conclusions are discussed in Ch.5.

2 Literature/Theoretical Review

2.1 The Circular Economy

2.1.1. Evolution of Sustainability

Sustainability has in the last few decades become a central part of all economic activity, including for all business activity. Discussions surrounding 'sustainable development' began when environmental issues arose as a result of human activity in the 1800s (Henderson, Persson & Sprei, 2018). Focus on this topic has continued to grow since then as these environmental challenges have accelerated extensively and at a rapid pace. The technological and social advancement that took place in the 1900s was coupled with impressive exponential population growth which has continued since then and is now expected to reach 12 billion by the end of the 21st century (Henderson, Persson & Sprei, 2018). This has important implications for sustainability and the environment as more people means more demands for natural resources.

It was between 1950 and 2000 that the consequences that human activity had on the environment became most apparent, primarily a result of the immense population growth and technological development which allowed for mass production. This *Great Acceleration* period involved extreme upward trends in the extinction of species, GHG emissions, ozone depletion, consumption and deforestation all demonstrated upward trends, and coincided with economic and social development (Henderson, Persson & Sprei, 2018). In this period discussions about 'sustainable development' began to take place and since then continuous movements have taken place to try to address and alleviate these environmental challenges.

One of the first remarkable movements was created by the UN in 1983 which involved representatives from 21 countries who pledged to find solutions to these pressing environmental issues. They established Brundtland Report (1987) whereby the most common definition for sustainable development arose, being “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (UNESCO, 2021). This movement also made discussions about sustainability more mainstream and recognized the relationship between various issues that had previously been studied individually, including acknowledging sustainability’s two inherent concerns being the environmental and economic development movement (Henderson, Persson & Sprei, 2018). Thereafter various efforts have taken place including the UN Sustainable Development Goals which demonstrate the importance of all countries worldwide working together to tackle these environmental issues.

Regardless of the various efforts made to sustain the environment, human activity continues to exploit and destroy natural resources across the world. The severe environmental challenges will also extend further and have serious consequences for economic and societal success in the future. Having said this, there is a growing awareness and effort to try to alleviate these sustainability issues. If companies and people are able to shift their focus to working alongside the environment instead of against it, there is potential to restore the environment and thrive on the Earth in the long term (Henderson, Persson & Sprei, 2018).

2.1.2 Sustainability Theories in Business

The relationship between businesses and sustainability first appeared in the 1930s whereby firms began to implement sustainable thinking and recognize their responsibility in it (Chang, Zuo, Zhao, Zillante, Gan & Soebarto, 2017). The relationship between firms and society was first theorized by Howard Bowen who brought rise to the term that has gradually evolved into“corporate social responsibility” (CSR) which is a term commonly used today to describe firms’ role in sustainability. The Brundtland Report (1987) also founded the ‘triple bottom line’ (TML) whereby corporate performance should consider stakeholders’ needs, at the same time as balancing economic, environmental and social aspects. Sustainable Business Models are those that consider the TML proposal along with all different stakeholder interests within their business strategies which “helps firms to embed sustainability into their business purpose and process, to gain competitiveness through promoting sustainability” (Chang Zuo, Zhao, Zillante, Gan & Soebarto, 2017). These theories are still evolving, with the CE being one recent theory that aligns with the view that business activity should align with the environment.

2.1.3 Defining the Circular Economy

The CE can be regarded as a tool for achieving sustainability, in particular on an environmental level. This is supported by Kirchherr, Reike and Hekkert (2017) who explain that the CE can be regarded as a way for businesses to operationalize and implement sustainable development. In somewhat vague terms, the Circular Economy (CE) involves closing the loop of the value creation chain (Ghisellini, Cialani, & Ulgiati, 2016; Geng & Doberstein, 2008). According to the research conducted by Kirchherr, Reike and Hekkert (2017), the most common definition of the CE has been formulated by the Ellen MacArthur Foundation (EMF, 2013, p.7):

> "A circular economy is an industrial system that is restorative or regenerative by intention and design [...]. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models."

In this definition, the objective of the CE ultimately concerns the "decoupling of environmental pressure from economic growth" (Ghisellini, Cialani, & Ulgiati 2016, p.11). In the CE, the decoupling is pursued through maximizing the value of the resources used for each process, product or service, by finding ways to prolong the use of already extracted resources. Through extending the amount of time a product, component or material is used, energy-efficiency will increase and redundant consumption can be avoided (Sihvonen & Partanen, 2017). Accordingly, the CE provides a more sustainable alternative to the currently widespread economic growth model, which focuses on rapid economic growth through an open-ended process of resource exploitation and disposal (Ghisellini, Cialani & Ulgiati, 2016). Furthermore, the CE builds on established theories such as Performance Economy (Stahel, 2010), Cradle to Cradle (McDonough & Braungart, 2002), biomimicry (Benyus, 2002), industrial ecology, natural capitalism, and the blue economy (EMF, 2017; Bressanelli et al. 2018).

Three assumptions are central to the CE: the preservation and improvement of natural capital, the optimization of output from resources, and the streamlining of value chains in order to eliminate negative externalities (EMF, 2015). Additionally, the CE encompasses a technical cycle and a biological cycle (Jabbour, Jabbour, Filho, & Roubaud, 2018). The former focuses on the prolongation and enhancement of the product life cycle, in particular, through the so-called Rs principles, which will be explained further in the subsequent section. Meanwhile, the biological cycle is centered on the use of renewable resources and energy and the circular processes of managing waste (EMF 2015; Jabbour et al. 2018). This has implications for how companies work to achieve the CE and also highlights the fact that all materials must be treated differently in order to achieve circularity.

The CE can also be compared to previously developed sustainability concepts of degrowth- and the steady state (Ghisellini, Cialani & Ulgiati, 2016). The concepts involve redesigning economy and society to reduce throughput in the case of degrowth and, alternatively, to maintain stable levels of throughput in the case of the steady state (Krpan & Basso, 2021; Sol, 2019)**.** While the models have different aims, they all advocate for a human society and economy which adhere to the Earth's ecological limits. The large-scale redesign of the economy and society poses major challenges for decision makers, company executives, as well as for members of society in general who act as consumers. The benefits of the CE, however, can be assumed to notably outweigh the short-term costs of structural-, economic- and social changes. They include, but are not limited to, a significant reduction of human-led negative environmental impact, positive macro-, industry- and firm-level economic growth, as well as societal benefits such as the creation of new job opportunities (EMF, 2013.; Ghisellini, Cialani, & Ulgiati 2016; Korhonen, Honkasalo & Seppälä, 2018).

2.1.4 Rs Framework/ Principles

From a more practical perspective, CE implementation takes place on micro-, meso- and macro levels (Bressanelli et al. 2018). The CE approach is strongly connected to the "3-R Principles": Reuse, Reduce and Recycle. These principles, as well as the aims of the CE in general, are currently in use to varying extents and in different industries globally, mainly through laws and regulations set by governments, international organizations and unions. Examples include the European Union's new Circular Economy Action Plan (2020) and the Chinese Circular Economy Promotion Law (2009). More recently, additional "Rs" have been added to the principles, including "Recover", "Repair", "Redesign", "Refuse", "Remanufacture", "Repurpose" and "Refurbish" (Reike, Vermeulen & Witjes, 2018). Furthermore, a hierarchy has been suggested wherein reducing waste and reusing goods are usually ranked as the most optimal sustainability solution, however, this may depend on the industry (Ghisellini, Cialani, & Ulgiati 2016; Song, Li & Zeng, 2015). On the other hand, Kirchherr, Reike and Hekkert (2017) note that the hierarchy of waste has not been included as frequently in the more recent definitions of the CE.

2.2 Circular Business Models

2.2.1 Defining Circular Business Models

The benefits associated with the CE are mainly experienced by those implementing CE processes but also indirectly to other members of society through improved environmental conditions (Ghisellini, Cialani, & Ulgiati 2016). The focus on environmental- and economic aspects is supported by Kircherr, Reike and Hekkert as they mention that "[t]he most prominent aim of CE is economic prosperity (46% of definitions), followed by environmental quality (37–38% of definitions)" (2017, p.227). Therefore, companies may have much to gain from pursuing activities that promote the CE. Accordingly, connected to the concept of the CE, is that of Circular Business Models (CBM). To begin with, a business model (BM) can simply be understood as the ways in which a firm creates, allocates and holds (economic) value (Osterwalder & Pigneur, 2010). Building on this conceptualization, Geissdoerfer et al (2018, p.713) define the term CBM as describing:

> "[B]usiness models that are suited for the Circular Economy by incorporating elements that slow, narrow, and close resource loops, so that the resource input into the organisation and its value network is decreased and waste and emission leakage out of the system is minimised"

This suggests that businesses should adjust their value propositions to better align with the goals of the CE. Anticipated benefits for companies pursuing these business models not only involves reducing negative environmental impacts, but also significant economic gains (Honkasalo, Korhonen & Seppälä, 2018). Within European manufacturing, for example, predicted annual net savings of transitions towards the circular economy are approximated to €600 billion (European Commission, 2017). Additionally, it has been suggested that customer's willingness to pay (WTP) will be higher for remanufactured products that provide information about its reduced environmental impact than for conventional products (Michaud and Llerena, 2011).

Chen, Hung and Ma (2019) further explain that the concept of CBM is a collection of multiple BMs with the common aim of achieving the CE. Commonly researched BMs with clear connections to the CE include, but are not limited to: product-service systems (PSS) and the six BMs associated with the ReSOLVE framework.

2.2.2 Product-Service Systems

Linder and Williander (2017) suggest that CBMs often assume a format in which product ownership is retained by the producer in order to simplify the future return of the product, ultimately enabling activities associated with the CE. This type of BM is commonly referred to as a "product-service" (PS) offering and is included in the broader concept of "product-service systems" (PSS) which extends to include BMs which offer additional services to the sold products (Linder & Williander, 2017). Both PS and PSS build on the idea of creating value from combining tangible and intangible goods to satisfy customer needs (Tukker 2004; Linder & Williander, 2017). PSS are considered fundamental BMs in the CE (Chen, Hung & Ma, 2019). Tukker (2004, p.248-249) suggests three categories of PSS: "product-oriented services", "use-oriented services", and "result-oriented services".

Product-oriented services refer to BMs which focus on the, often linear, production and sale of goods, but with add-on services aiming to upgrade or restore the product function (Tukker 2004; Bressanelli et al. 2018). Product-oriented services rarely hold the producing company responsible for the lifecycle of the product, which often results in a negative environmental impact as the company derives value from increasing sales, such as in linear economic models (Bressanelli et al, 2018). By contrast, the company retains ownership of the product in use-oriented services, through, for example, leasing, renting, sharing or pooling (Tukker, 2004). This facilitates circularity through activities such as extended product life through services, better designed products with higher quality, as well as activities at the end of the product lifecycle aimed at closing the loop. A drawback of the use-oriented services is more rapid depreciation of the product as customers are less incentivized to handle it with care (Bressanelli et al, 2018). Result-oriented services aim at providing the customer with an agreed-upon result for which the customer is charged depending on the outcome. Examples include outsourcing activities or paying for the product output (Tukker, 2004). Result-oriented services have similar benefits as use-oriented services, but with the elimination of the problems regarding wear-and-tear. However, results may be difficult to measure and thus problems with the agreement may arise (Bressanelli et al, 2018).

2.2.3 The ReSOLVE Framework

Another way for businesses to transition from a linear BM to a CBM is to apply the so-called ReSOLVE framework. The framework comprises six BMs involving areas of action aimed towards achieving circularity (Lewandowski, 2016). These include: Regenerate, Share, Optimize, Loop, Virtualize, and Exchange (EMF, 2015). They are derived from the three assumptions of the CE and represent valuable opportunities for businesses pursuing CBMs. On a meso- and macro-level, industries and countries can achieve CEs using this framework as well by pursuing the actions on a larger scale. The ReSOLVE framework has specific connections to digitalization and I4.0 and is, therefore, central to the connection between I4.0 technologies and the CE. The components of the ReSOLVE framework are described below and their connections to I4.0 technologies are examined later in the chapter.

Regenerate: Encompasses the transition to the use of renewable energy and resources. It mainly focuses on the biological cycle of the CE and how organic waste can be turned into energy and raw materials (EMF 2015; Jabbour et al. 2018; Lewandowski, 2016). The *Regenerate* BM also includes the variable "material leasing", wherein the company can sell the function of the product (similar to PSS), thereby reducing negative environmental impact (Ceptureanu, Ceptureanu & Murswieck, 2018). The authors also explain that *Regenerate* extends to include optimal localization of business activities so as to increase sustainability.

Share: Involves the maximization of the product utilization through distributing the product between different customers throughout the product's useful life. This can be done through, for example, sharing or pooling activities or through reselling the products in the second-hand market. Accordingly, the *Share* component of the framework also pertains to the prolongation of the product lifetime through end-of-life activities such as repair and redesign as well as designing the product to last (EMF, 2015; Lewandowski, 2016). These can be connected to the PSS explained above. *Share* activities include end-of-life services, product leasing, and upgrading-services (Ceptureanu, Ceptureanu & Murswieck, 2018)

Optimize: Focuses on the development and enhancement of the product with the aim to improve efficiency and performance as well as minimize waste from the production chain. Technologies, including big data, automation, radio frequency identification technologies (RFID) and remote steering, are central to this activity (EMF, 2015; Jabbour et al, 2018). The ability to produce according to real-time consumer demand is also central to this BM (Ceptureanu, Ceptureanu & Murswieck, 2018).

Loop: Refers to the act of maintaining resources and materials in closed loops. Closing the loop of value creation can either take place through biological cycles or technical cycles, as explained above and depends on which type of material is being handled (EMF, 2015). Lewandowski (2016) notes that inner loops are more prioritized than others. This is because the inner loops are more effective in reducing negative environmental impacts and costs associated with material, labor, energy and emissions (EMF, 2013). The inner loops are connected to activities such as replacement, repair and reuse and are preferred to outer-loop activities such as recycling and remanufacturing (Wieser & Tröger, 2018). However, it is suggested that consumers generally disfavor inner-loop activities in relation to, for example, replacing products for newer ones, thereby complicating the adoption of CBMs focused on Looping (Wieser & Tröger, 2018).

Virtualize: Involves the digitalization and dematerialization of products, thereby, replacing finite and physical materials. The *Virtualize* activity instead creates value and utility by virtual means either directly through, for example, digital media, or indirectly through, for example, e-commerce (EMF, 2015; Jabbour et al. 2018; Ceptureanu, Ceptureanu & Murswieck, 2018).

Exchange: Involves replacing outdated and finite materials and goods with advanced, renewable materials and goods (Jabbour et al, 2018; Ceptureanu, Ceptureanu & Murswieck, 2018). Technology, such as 3D printing and electric engines, plays a central role in this activity (EMF, 2015).

2.3 Industry 4.0

2.3.1 Defining Industry 4.0

Mavropoulos and Nilsen write that "Industry 4.0 is not a historical fact. It is a possible outcome, an invention in the making, something that is still ahead of us." (2020, p.36). The concept, formulated in a research project by the German government in 2011, is often referred to as the Fourth Industrial Revolution (4IR) and is ongoing and shaped by innovations and advanced technologies which are redefining manufacturing processes (Mavropoulos & Nilsen, 2020; Monostori, 2014). The 4IR concerns the ways emerging technologies fundamentally shape and change human society (Philbeck & Davis, 2018). These emerging technologies comprise I4.0 and include, but are not limited to, artificial intelligence (AI), machine learning (ML), the Internet of Things (IoT), big data analytics (BDA), autonomous robots, additive manufacturing, virtual simulators, cloud and application programming interfaces (APIs), and advanced materials (Dantas et al. 2021; Mavropoulos & Nilsen, 2020; Modgil et al. 2021). Mavropoulos and Nilsen (2020) explain that various innovations, such as those identified above, have the potential to cause a technological revolution through synergy effects. Here, it is important to understand that it is not the new technologies themselves that are driving the transition into I4.0, but the new and innovative ways they are combined, in particular with bulk data, in order to achieve results beyond what humans are capable of themselves (Drath & Horch, 2014). Notably, Lasi, Fettke, Kemper, Feld and Hoffman (2014) stress that I4.0 is characterized by manufacturing systems capable of controlling themselves and making decentralized decisions. The authors point out that the advantage of these autonomous systems will be that manufacturing of single, perhaps even customized products, will have similar economic benefits as that of mass production (i.e. economies of scale).

More specifically, I4.0 focuses on the connection between highly advanced digital and innovative technologies and increased efficiency in manufacturing and production systems (Philbeck & Davis, 2018). Lasi et al. (2014) state that in I4.0, factories will be equipped with smart technologies, thereby making the manufacturing facilities into 'Smart Factories'. More simply, Drath and Horch (2014, p.56) define I4.0 as the following:

> "The term Industrie 4.0 refers to the fourth industrial revolution and is often understood as the application of the generic concept of cyberphysical systems (CPSs) to industrial production systems (cyberphysical production systems)"

The CPS, in turn, involves the application of new technologies for managing the interconnection between physical objects and computational processes (Lee, Bagheri & Kao, 2015). I4.0, thus, has effects which reach far beyond the limits of manufacturing. This is where its connection to the CE becomes prominent. In regards to the environment, I4.0 technology may lead to so-called "dematerialization effects" which involves the ability to produce a greater value with fewer raw materials (Petrides et al. 2018). On the other hand, Petrides et al. (2018) highlight so-called "rebound effects," stemming from consumer behavior, which may counteract the benefits generated from dematerialization as they have a negative environmental impact .

Lasi et al. (2014) provide additional detail to the definition of I4.0 as they describe that the direction of I4.0 will be shaped by two directions of development: "application pull" and "technology push." The application pull signifies a need to adapt to changing conditions of the operative environment of firms. Examples of these changing conditions include: "short development periods," "high innovation capability", "individualization on demand," a call for higher flexibility of production, as well as a need for decentralized and automated decision-making (2014, p.239). Meanwhile, the technology push is characterized by companies developing new technologies which shape the industrial and consumer contexts.

2.3.2 Artificial Intelligence & Machine Learning

AI, while relatively diffuse as a concept, can be understood as "a branch of Computer Science, which is mainly concerned with automation of intelligent behavior" (Chowdhary 2020, p.1). The author further notes that, in simple terms, the components of intelligence are the abilities to perceive, analyze and react. AI also includes the ability to learn and develop and is, therefore, connected to the concept of ML which is able to learn from new information and adapt its output accordingly. There are different types of ML, including the main classifications of supervised and unsupervised learning as well as more specific techniques of learning such as reinforcement learning and discovery-based learning (Chowdhary, 2020).

Currently, AI systems are rather limited and may only be able to outperform humans in narrow tasks. By contrast, artificial general intelligence (AGI) is a form of AI that can completely mimic human intelligence. This level has not yet been reached and the common understanding is that it will entail serious consequences if AGI is reached before society has carefully prepared and considered unforeseen scenarios (Mitchell, 2019). The problems relate to the concerns of what will happen when AI is able to improve itself to the point that it will surpass humans in all regards. On the other hand, if developed properly, the technology may have the ability to provide solutions to the urgent environmental challenges that exist today. AI and ML are currently being developed to tackle problems pertaining to waste management, defending ecosystems, as well as conducting its own sustainable development research (Dauvergne, 2020; Hackl, 2020).

2.3.3 Internet of Things

IoT involves embedding technology into physical products, thereby, allowing them to become interconnected and smart (Mavropoulos & Nilsen, 2020; Bresanelli et al. 2018). The data generated through the IoT technology can thereafter be used as input into, for example, ML systems. IoT includes RFID technology which is increasingly being used within retail to track products (ed. Ustundag, 2013). IoT can be applied to monitor products remotely and in real-time (Bresanelli et al. 2018). The authors also explain that this can help companies gain an insight into consumer usage of the products, thereby improving communication between the buyers and sellers. Furthermore, Bresanelli et al. (2018) explain that IoT products are upgradable, which can prolong their useful life.

2.3.4 Additive Manufacturing

Additive Manufacturing (AM) is an alternative to the more traditional 'subtractive manufacturing' and 'formative manufacturing' approaches. Based on a virtual 3D depiction of objects, expressed in data figures, the AM technology will model the physical object using chosen material (Popescu & Amza, 2017). Therefore, AM mainly involves the use of 3D printing technology, however also includes other modelling techniques (Popescu & Amza, 2017). Mavropoulos and Nilsen (2020) explain that, while AM is mostly being used for prototypes and specific components, they will be used on a wider scale for production in I4.0. This will enable improved capabilities for adapting each individual product to specific consumer preferences (Mavropoulos & Nilsen, 2020). The authors also mention that 3D printing allows for more complex design capabilities and less use of materials.

2.3.5 Virtual Simulators & Digital Twins

Virtual Simulators and Digital Twins are essentially virtual models that mimic the real world. The models can be used as testing environments to experiment with various scenarios and can be integrated into virtual complex situations. While Virtual Simulators do not necessarily involve real-time data from sensors in the real world, Digital Twins make use of sensors to accurately mimic physical assets and situations (Mavropoulos & Nilsen, 2020).

2.3.6 Cloud Technology & Manufacturing

Cloud technology is a solution to handling data and is an alternative to local servers (Mavropoulos & Nilsen, 2020). It enables large-scale data sharing between multiple users, in various locations, and has thus become the new standard for managing data. Zhong, Xu, Klotz and Newman (2017, p.618) explain that cloud manufacturing, which makes use of cloud computing and other I4.0 technologies, can transform "manufacturing resources into services that can be comprehensively shared and circulated." They further clarify that cloud manufacturing thereby involves and considers the entire lifecycle of the asset, including its "design, simulation, manufacturing, testing, and maintenance" (p.618).

2.4 Utilizing I4.0 Technologies to Achieve a CBM

2.4.1 Connection between I4.0 & CE

There is a clear link between I4.0 and the CE (Modgil et al 2021; Rajput & Singh 2019; Cagno et al 2021; Rosa et al 2020). Jabbour et al. (2018), explicitly mention that "it may now be feasible to overcome barriers to the CE by adopting emerging technologies related to smart manufacturing" (p.274). Together, the concepts of CE and I4.0 have the potential to contribute to the achievement of the 17 UN Sustainable Development Goals (Dantas et al, 2021). There are also more specific connections between I4.0 and the CE which are, for example, based on the view of AI as an enabling technology (Uçar, Le Dain & Joly, 2020; Rajput & Singh 2019; Wilts et al 2021). However, the majority of the literature on the CE and its connection to digital technologies (DTs) discusses the value of I4.0 technologies in broader terms (Cagno et al 2021). This is due to the notion that the technologies associated with I4.0 are highly interconnected and do not reach their full potential in isolation of one another (Ivanov, Tang, Dolgui, Battini, & Das, 2021). This is further supported by Bressanelli et al. (2018) as they note that companies will benefit from investments into multiple I4.0 technologies as they will more efficiently allow for closing the loop of resources.

In general, AI and other I4.0 technologies are seen as *enablers* of the CE (Wilts et al, 2021; Modgil et al, 2021; Rajput & Singh, 2019; Cagno et al, 2021; Uçar, Le Dain & Joly, 2020). In the report *Artificial Intelligence and the Circular Economy,* provided by the EMF (2019), AI is explained as a tool for acceleration and transition into the CE. The report further explains that, across industries, AI can be used in circular design, operations and infrastructure optimizations. This can be done through, for example, ML assistance in design, prototyping and testing; AI-based predictions to balance supply and demand; and AI-enabled improvements to disassembly- remanufacturing- and recycling processes (EMF, 2019). Simulations can also be used to support decision making in remanufacturing (Rosa et al, 2020) as well as tracking products in real-time through integrating them with IoT modules, thereby, allowing for increased cooperation between companies aimed at achieving the Rs principles (Mboli, Thakker & Mishra, 2020). The arrival of 5G, associated with significant improvements to bandwidths, energy consumption and latency, is anticipated to solve many of the current issues of IoT solutions. Demestichas and Daskalakis (2020) note that ML is fundamental to advancement towards CE. Data gathered from IoT and 5G technologies can be processed and analyzed intelligently by ML to generate predictions and decisions facilitating CE activities (Mahdavinejad, Rezvan, Barekatain, Adibi, Barnaghi, Sheth, 2018).

DTs can also be viewed as having a so-called *trigger* role (Uçar, Le Dain & Joly, 2020). By contrast to *enabler* roles of DTs, which involve the ways in which DTs can facilitate CE development, *trigger* roles describe the ways in which DTs can prompt innovation that leads to the CE. The authors find that all of the cases analyzed converge on the characteristics of the enabler role being more dominant than the trigger role, and of the roles being supported by "data collection, data exchange, data storage and data analysis" (2020, p.135).

2.4.2 I4.0 & Product-Service Systems

AI can also be used in operationalizing CBMs through facilitating PSS as well as in optimizing CE infrastructure (EMF, 2019). This is supported by Jabbour et al. (2018) who note that I4.0 technologies can be used to enhance the connectivity between various aspects of the supply chain as well as in allowing companies to produce goods using decentralized decisions and autonomous systems. Bressanelli et al (2018) explain that problems with wear-and-tear associated with use-oriented services can be avoided through IoT monitoring the ways consumers use the product. The authors also point out that undesirable and unsustainable consumer behavior can be avoided through IoT by increasing communication between buyers and sellers. Additionally, service offerings can be improved through I4.0 technologies, as smart products can for instance be upgraded and end-of-life activities can be automated to a higher degree (Bressanelli et al 2018). Lastly, Bressanelli et al. (2018) note that usage-focused BMs will likely drive the shift to CBMs by companies, as long as the transitions are supported by the right DTs.

2.4.3 I4.0 & the ReSOLVE Framework

I4.0 technologies may also lead to improved cooperation between partners of the value chain (Cagno et al, 2021). This is because DTs, such as augmented reality (AR), autonomous robots (ROBs), IoT and BDA, can be used to enable the "Loop" area of the ReSOLVE framework (Cagno et al, 2021). These technologies are capable of enhancing the disassembly- and reassembly processes, tracking product history and monitoring looping activities. Cagno et al. (2021) identify similar benefits for other areas of the ReSOLVE framework, primarily regarding predictions and decisions making based on large amounts of (continuously) gathered data from users of the product as well as from the products themselves as they pass through various tiers of the value chain. Jabbour et al. (2018) also specify the ways in which I4.0 can enable each BM of the ReSOLVE framework. These include:

Regenerate: IoT technologies can be applied to improve the generation of renewable energy, as well as to manage land. Integrating the technology into decentralized decision making- and prediction systems allows for informed decision making and adaption of process according to real-time gathered data.

Share: I4.0 can be used to facilitate the optimization of sharing processes through cloud- and AI-based manufacturing and IoT. They can enable a balancing of supply and demand according to real-time data on users. Furthermore, the *Share* BM can be improved through consumer-behavior data, thereby, allowing companies to better understand consumers and design their models and offering based on the knowledge. In this sense, I4.0 allows the company to take a more proactive approach to manufacturing. IoT sensors can also be used to track how the products are being used, enabling the firm to extend their useful life through identifying the appropriate Rs principles.

Optimize: I4.0 can significantly increase optimization of manufacturing and make the following stages of the life cycle more circular. As the I4.0 technologies utilize data and work together to make decentralized decisions and predictions, manufacturing facilities can become optimized and redundant activities can be eliminated. RFID tags and IoT technologies can be used in order to optimize the movement and localization of assets, thereby reducing the amount of resources used. Real-time generated data through IoT and users integrating with the company’s platforms can further be used to make more informed decisions.

Loop: IoT technologies can be used to equip products with unique identifications containing information about how the product was made, which materials it is composed of, as well as instructions for end-of-life activities. This is commonly referred to as a ‘product passport’. Bresanelli et al (2018) also note that IoT technologies can be used to close the loop as the products become upgradeable. Additionally, cloud manufacturing can be used in order to locate new users for reused or refurbished materials.

Virtualize: Cloud manufacturing and IoT technologies can be used to connect different stakeholders, thereby enabling a service-based offering rather than a product-based one. Through collecting data on the ways in which the products are being used, the service offering could be enhanced. Additionally, AM enables customized and cloud manufacturing that can be used to improve the balance between supply and demand.

Exchange: AM and IoT can be used to replace older manufacturing machines or workers with 3D printers, for example, can aid in sustainability as AM processes are directly connected to lower levels of generated waste through the ways in which it models products.

2.4.4 Advantages & challenges of I4.0 technologies to enhance CBMs

In the context of the business sphere, utilizing I4.0 technologies for the purposes of accelerating the CE transition has many advantages (EMF 2019; Modgil et al 2021; Cagno et al 2021). Within the consumer electronics sector, this figure is approximated to USD 90 billion per year in 2030. From a general perspective, technologies can assist in the progress of adopting circular supply chains (CSC), and by extension CBMs, thereby allowing the companies to benefit from the associated advantages of the CE and improved sustainable practices (Mboli, Thakker & Mishra, 2020). Building on these advantages, digital technologies (DTs) may also allow companies to scale their CBM (Mboli, Thakker & Mishra, 2020).

Modgil et al (2021) explain that using I4.0 technologies to sort and diagnose electronics in order to offer the repaired, recycled or reused products to consumers, is mutually beneficial for the “firm, stakeholders and ecosystem” (2021, p.7). The reasons they provide for this is that the value from refurbishment is significantly greater than that of recycling; the processes may allow lower income groups to have access to higher quality products; and logistics costs can be lowered by 60-65%. The CE activities also allow the firm to expand into second-hand markets, which will further benefit the environment (Modgil et al, 2021). Similar advantages can also be observed in the waste management sector. Uçar et al (2020) find that AI-based solutions for recycling can be extended to different industries and that the development of technology can lead to partnerships between recycling firms and companies in other industries which can ultimately benefit the CE. These partnerships are essential to the advancement into a CE as a large-scale and industry-crossing transition is crucial for the sustainability benefits of the CE to be realized (EMF, 2019).

While the research mentioned above suggests that technological solutions are invaluable to the CE, they may be difficult to actualize (Geissdoerfer et al. 2017). This is also supported by Wilts et al (2021) who researched the uses of AI in achieving a CE within municipal waste sorting. The authors mention that technological solutions in themselves are not enough to achieve circularity within waste management, but that they are an integral part of enhancing all aspects of the value chain. The difficulties of implementation may also be due to the lack of a common understanding of the nature of the relationship between CE and digital technologies (Cagno et al, 2021). Other issues hindering the implementation of CE through I4.0 include: the risk of data breaches and lack of data security; immaturity of technologies in regards to performance, security and sustainability; “consumer and business attitudes”; “economic costs”; as well as a limited knowledge and familiarity with CE and modern technologies (Demestichas & Daskalakis, 2020). To tackle these problems, it is important for businesses and individuals to stay informed about CE and its enabling technologies, as well as identifying the various connections between I4.0 and CE and matching them with the relevant stakeholders to achieve a better understanding of where certain aspects of the CE and the ReSOLVE framework will best be implemented (EMF, 2019).

2.5 The Clothing Industry, the CE and I4.0

The textile and clothing (TC) industry has significantly improved the economy and living standards in emerging economies such as Bangladesh, India and Vietnam through increased exports and new job opportunities (Saha, Dey & Papagiannaki, 2020). Meanwhile, trends such as fast fashion, low costs, rapid production and low quality have had adverse effects on the environment (Saha, Dey & Papagiannaki 2020; Han et al. 2017; Koszewska, 2018). Koszewska (2018) stresses the fact that 40% of the produced clothing during the time the article was written is either not sold or does not reach the stores. This can be connected to the three groups of textile waste: “post-industrial waste”, “pre-consumer waste”, and “post-consumer waste” (Koszewska 2018, p.340).

Circularity has notably become a focal point for fashion companies in their sustainability efforts. Problems such as waste and chemical management, and the use of water in manufacturing processes are central issues which characterize the industry, in addition to problems pertaining to energy and CO_2 emissions (de Brito, Carnone & Blanquart 2008; Rahman & Raju, 2021). Walter (2016) identifies three central drivers of innovation which will characterize the industry in the near future. These include: “(1) digitisation of products, processes, factories, workplaces, supply chains, distribution and retail, (2) sustainability, circularity and resource efficiency of materials, processes and overall business operations and (3) the proliferation of new business and consumption models based on sharing of productive resources and final products, servitisation, pay-per-use or subscription models” (Walter 2016, p.4). Additionally, Walter (2016) highlights strategic areas for innovation which are anticipated to become significant for the future development of the CT industry. The areas for innovation are all centered around the CE, advanced technology and smart materials. This supports the connection between I4.0 and developments towards the CE.

Koszewska (2018) builds on the three trends identified above through acknowledging the central challenges facing the clothing industry in regards to achieving the CE. The author notes that the success of CBMs and the rate at which they are achieved will depend on the degree of knowledge, understanding and commitment of stakeholders to the focal firm. The success of CE implementation is also dependent on the internal and external factors of the firm. The internal factors include owned resources, capabilities and competencies of the firm. The external factors pertain to those factors which are ungoverned by the company, such as legislation, market conditions, technological development, and competition (Saha, Dey & Papagiannaki, 2020). In this regard, it may be crucial for the company to have dynamic capabilities and adequate resources in order to be able to handle a transformation towards CBMs (Breznik & Lahovnik, 2016; Luo, 2000; Teece, 2014).

In order to achieve a CBM, the R's principles should be applied at each stage of the value creation chain. This will require careful and strategic consideration of how the product is designed and the materials used in order to close, slow and/or narrow the loop of resources (Bocken, Miller, Weissbrod, Holgado, & Evans, 2017; Durham, Hewitt, Bell & Russell, 2015). Earley and Goldsworthy (2015) propose two alternative approaches to design: 'short-life fashion' (SLF) and 'long-life fashion' (LLF). Both approaches promote the CE, but in opposite ways. SLF focuses on closing the loop of resources and circulating the materials quickly and efficiently. The key to SLF is that it should be designed to readily and perpetually be recycled. Quality is not the central focus, and the fast production system supports modern consumer behavior wherein disposing of relatively new garments is common (Earley & Goldsworthy, 2015; Sandvik & Stubbs, 2019). By contrast, LLF is designed with quality in mind and promotes a long single-use cycle. The focus is to slow down the resource loop through creating clothes that consumers will want to be able to use for an extended period of time (Bocken et al. 2017). The LLF alternatives also facilitate reuse and remanufacturing, more commonly referred to as upcycling in the fashion context (Earley & Goldsworthy, 2015). The authors also highlight that in deciding which approach to take, it is important that companies consider the consumer intentions and behavior and how these coincide with the product's and brand's message. This is referred to as conditional design which should be accounted for in all aspects of the design and marketing process.

LLF also supports PSS as the approach focuses on high quality and is best suited for more luxurious brands (Earley & Goldsworthy, 2015). Buy-back schemes and luxury secondhand are therefore viable options for LLF and will thereby promote the CE objectives. Tunn et al. (2019) discuss sustainable consumption (SC) and note that resource strategy, revenue model, consumer effort and the targeted consumption level are central elements enabling or limiting SC. The authors note that consumers will be more inclined to partake in SC and promote circularity if they are able to do so as effortlessly as possible. PSS should, therefore, be easy to use and preferably involve incentives for customers.

Sandvik and Stubbs (2019) observe that there are challenges of implementing advanced technologies for the purpose of facilitating the CE in the TC industry. However, they also point out that technology will be essential for the future development of the industry. 3D printing technology, for example, can be used to significantly reduce material waste from manufacturing. Additionally, digital receipts can increase transparency, thereby facilitating the activities based on the R's principles (Sandvik & Stubbs, 2019). Alternatively Saha, Dey and Papagiannaki (2020) note that the use of advanced manufacturing technologies associated with I4.0, may also have a negative impact on the environment as it may accelerate fast fashion if used in the wrong way. Nevertheless, companies should aim to invest in these technologies in order to prepare for the future which relates to the concept of effectuation which promotes the "full use of the limited resources and information available" (Bocken et al. 2017, p.6). The logic behind effectuation is that it is difficult to anticipate which investments will be profitable, but that, from an entrepreneurial perspective, they are still valuable in that they provide the firm with new knowledge, experiences and capabilities.

3 Methodology

This chapter begins by describing the research approach as well as the two different data collection methods that were involved in this study. This includes the ethnographic data collection and interviews. The research design, the data collection method, and the data analysis of both are described, as well as the validity and reliability of the study, and finally the limitations of the research.

3.1 Research Approach

3.1.1 Abductive Approach

Bryman and Bell explain that the fundamental relationship between theory and the empirical data collected in a study, is defined in the research approach (2015). There are three main approaches inducing a deductive, an inductive or a combination of the two, namely an abductive approach. All approaches provide different explorative opportunities and process the research in different ways. The deductive approach, which is often employed in quantitative studies, involves utilizing existing theories to guide the research (Bryman & Bell, 2015). The researcher starts from pre-existing concepts, assumptions, and facts which are used to direct the data that is collected. Thereafter, the data is used to explore the pre-existing concepts or the relationships between them (Byrman & Bell, 2015). The theories are first examined and clearly defined in the theoretical framework which lays the foundation for the data collection, and the following data analysis highlights connections between the collected data and the theoretical framework. Contrary to the deductive approach, an inductive approach involves first collecting the data and then using the findings to discover a new theory or concept (Byrman & Bell, 2015). A generalization or idea is drawn based on the patterns discovered in the collected data, which is usually the case for qualitative studies. The final approach is an abductive approach which involves both inductive and deductive approaches.

This study involves an abductive approach where it begins with more deductive characteristics, and thereafter employs inductive ones. To begin, the proposed theory that I4.0 technologies can aid in achieving a CBM was investigated through extensively researching previous literature about these topics. There was a clear connection between the two variables which led us to further investigate this in practical terms within the clothing industry. The relationship between I4.0 technologies and circularity laid the foundation for our study, whereby the problematization was based on the previously established correlation and the gap in the literature. This was then used to formulate the research question which guides the entire data collection and the choices made regarding our methodology and sample choice. The qualitative data collection, guided by these deductive influences, began to involve more inductive aspects as the findings of the data collection is used to draw further generalizations about these concepts within the clothing sector in particular. Therefore, beginning with a deductive approach and involving inductive features following the data collection, seemed the most appropriate as the study aims to both investigate this theory and to deepen the investigation by observing how it works in a particular industry. This abductive approach allows us to first investigate the theory and then make our own generalizations based on the observed data.

3.1.2 Qualitative Research

There are two research methods that can be used to answer research questions; a qualitative or quantitative method (Bryman & Bell, 2015). The choice between the two affects the entirety of the research study including the data collection, analysis and the findings, as well as the flexibility of the study. Qualitative research usually allows for more in-depth analyses of data whereas quantitative methods are usually employed when large data samples are involved but are analysed in less detail (Sutton & Austin, 2015).

This thesis aims to investigate how clothing companies are utilizing I4.0 technologies in order to improve their circularity as opposed to numerical data, and is therefore more suited to a qualitative data collection as it allows us to focus on the individual responses of the samples and draw connections and conclusions about the information gathered. This was deemed the most appropriate method as the topic of investigation is relatively complex and requires an understanding from both the companies and the researchers in order to gather the appropriate information. A quantitative approach was also considered, however, as a quantitative content analysis would be employed to count the number of times that terms associated with Industry 4.0 (such as “AI”) was mentioned in relation to the circular economy in companies’ sustainability reports. This was however decided against, as many clothing companies did not use different terms and technologies directly relating to I4.0 and it was also not possible to quantify the times it was used for the CE in particular without intervening and checking the context ourselves. Instead, a qualitative content analysis, complemented by semi-structured interviews, will be used for a qualitative exploratory data collection.

Bryman and Bell (2015) highlight two issues regarding generalizations that may arise within qualitative studies. Firstly, analytic generalizations should be considered which relate to making generalizations of actual theories and the credibility of the researcher’s inferences (Bryman & Bell, 2015). Secondly, ‘case-to-case transfers’ refer to those “generalizations [that] are made from one case to another that are broadly similar” (Bryman & Bell, 2015, p.438). As we were aware of these from the onset, we made sure to individually investigate each company in detail and thereafter search for potential patterns in order to assure our generalizations were accurate.

3.1.3 Primary and Secondary Data

This study includes various primary and secondary data sources to reveal a complete and overall understanding to answer the research question. Primary data refers to all data collected first-hand by the researcher in qualitative data, which in our case includes two semi-structured interviews (Bryman & Bell, 2015). This primary data was, however, only used as a complementary data collection, and the qualitative content analysis is the main source which involves secondary data such sustainability reports and websites. Secondary data refers to all data used that has been collected by someone else. This is also the data type used for literature review, however this was mainly based on academic journal articles.

3.2 Ethnographic Content Analysis (ECA)

3.2.1 Research Design

A pure content analysis is “an approach to the analysis of documents and texts that seeks to quantify content in terms of predetermined categories” (Bryman & Bell, 2015, p.300). This method is predominantly used for quantitative studies and to examine mass media items, and other texts and documents that are either produced by an organization or other business documents. It is a research tool used to determine the presence of certain words within qualitative data which is an unbiased approach as it is unobtrusive, meaning the researchers do not interfere with the subject under the study (Bryman & Bell, 2015). An extension of this traditional content analysis method, is an Ethnographic Content Analysis (ECA) approach refers to “an approach to documents that emphasizes the role of the investigator in the construction of the meaning of and in texts” (Bryman & Bell, 2015, p.300). An ECA is also referred to as a qualitative content analysis which allows the researcher to be less rigid and is a more analytical approach (Bryman & Bell, 2015) The ECA also bears its own challenges as researchers must carefully consider the documents they choose for the analysis to ensure their findings are accurate.

This study involves this more recent ECA method which “comprises searching-out underlying themes in the materials being analysed” (2015, p.569). Although an ECA is more time consuming than a quantitative content analysis as it requires the researcher to interact with the documents and constantly revise the themes or categories that are discovered from the documents examined, it also allows for a deeper investigation (Altheide, 1996). This will improve the accuracy of the findings as the researcher can assure the chosen themes are used in the context of interest (Bryman & Bell, 2015). An ECA allows the researchers to use the predetermined categories as a guide but also to constantly discover new and relevant terms (2015). As the list of different I4.0 technologies is not definite as it is constantly developing, searching for specific predetermined key terms as in a traditional content analysis, would not be feasible as that may have resulted in valuable information being unaccounted for. An ECA allows for “much more movement back and forth between the conceptualization, data collection, analysis and interpretation” (Bryman & Bell, 2015, 569), which means that it is more appropriate considering the complexity of our topic. There will be some predetermined categorization but this method will allow for adjustments throughout the process depending on our findings.

Multiple different virtual documents will be investigated for our ECA, including the clothing companies' sustainability reports, annual reports and websites. Additionally, articles published by external stakeholders that discuss their usage of I4.0 technologies in circularity will also be involved. Initially we planned to solely analyse sustainability reports as the data source, however, we found that including more documents, such as those not published by the companies themselves, was necessary to enhance the findings and to reduce bias. This will provide a more complete representation of what the company is actually doing, and thus will improve the accuracy of the investigation.

3.2.2 Sampling Method

In qualitative research, a purposive sampling method is employed, whereby researchers select units, such as organizations and documents, "with direct reference to the research question being asked" (Bryman & Bell, 2015, p.428). The research question is likely to provide guidelines as to what categories need to be focused on and it is these that are the sample of the data collection. Theoretical sampling is a method used to sample qualitative research and is "done in order to discover categories and their properties, and to suggest the interrelationships into a theory" (Bryman & Bell, 2015, p.431). In this grounded theory concept, data is collected through theoretical sampling until theoretical saturation is achieved, meaning that observations are sampled in terms of what is valuable to the chosen theory. Thus, irrelevant samples are omitted as the researcher stops sampling when they have gathered enough data to answer the research question. This is a more interactive approach that allows the researcher to move back and forth between sampling and theoretical reflection.

This study utilizes this generic purposive sampling method meaning we stop sampling when we have found enough information to answer the research question. As this study involves an abductive approach, and initially uses a theory to help guide the research and data collection, the challenges of limiting information are eradicated as we know what information is relevant and what is not. Thus the generic purposive sampling method was appropriate as the samples for the data collection are chosen on purpose.

The clothing companies chosen for analysis are those that provide information regarding their circularity efforts and use of I4.0 technologies to do so. This aligns with the generic purposive sampling approach as “the researcher establishes the criteria concerning the kinds of cases needed to address the research question, identifies the appropriate cases, and then samples from those cases that have been identified” (Bryman & Bell, 2015, p.433) This will be done in a grounded theory manner as samples that are not meaningful and do not help to answer the research question will be omitted. This means that we can sample cases (companies) that will help us to answer the research questions and to ignore those that do not mention their use of I4.0 technologies. At the same time, being able to explore and choose cases throughout the process of research, means that we will continue our data collection until we decide that we have gathered enough data to gain a full understanding of our topic and answer the research question.

Another important choice in regards to sampling, is identifying a suitable sample size. This can be challenging as when aiming to reach theoretical saturation, it is almost impossible to know beforehand how many samples are needed (Bryman & Bell, 2015) as it may become apparent as the data collection progresses. The sample size for this ECA is based on this theoretical saturation technique and therefore deciding a sample size before beginning the data collection is relatively meaningless. Instead, the sample size is dependent on the availability of information and finding enough data. This was not known prior to beginning the data collection, we instead chose to stop the data collection once we found enough information to answer the research question. We began with a list of 50 companies to search for and analyze as many as possible that mentioned I4.0 technologies for circularity. This list comprised various Swedish and international clothing companies that we were familiar with. Our aim was to analyze 15-25 companies which seemed reasonable as we wanted to have a small enough sample size to explore each company in detail, but also did not want to have too few as this would not give us an overall understanding of the industry. Qualitative studies must also avoid too large sample sizes, as it makes the depth of analysis more difficult (Bryman & Bell, 2015).

3.3.3 Data collection method

Recognizing the limited timespan of this project, we chose to focus on a single industry to investigate the relationship between I4.0 for circularity processes. We chose the clothing industry as many of these companies aim to develop CBMs. An ECA method allows us to analyze multiple companies within the industry and on a deep level.

To begin, companies in Sweden were the focus but as the research progressed it was clear that it is mainly larger, international clothing companies that utilize I4.0 technologies for circularity and thus, the scope was broadened to include clothing companies from any country. Our purposive sampling approach meant that companies were investigated and added until we reached theoretical saturation and concluded that we had gathered enough data to properly and accurately answer the research question. Theoretical saturation was reached after analysing 18 companies, of which six were parent companies to a multitude of clothing companies. Choosing which companies to analyse from the original list of 50 companies was based on whether their sustainability reports, annual reports or websites mentioned I4.0 technologies for their circularity efforts. If there was no mention of these technologies they were omitted from the analysis, however, we have included them in Appendix E.

Virtually and publically available organizational documents were the main data source used. We identified relevant themes and key terms relating to I4.0 and the CE which were identified prior to beginning our data collection. As our research question is very specific and involves quite complex topics, our thorough literature review (Ch.2) was necessary. We had to thoroughly understand the theories to identify them within the documents and examine whether I4.0 technologies were being used in particular for circularity. The data type analysed was sustainability reports or the sustainability sections of annual reports. These reports were those from the years of 2018 to 2020. This range was chosen as we wanted to investigate the most recent information available but also wanted to ensure that we did not limit our findings to a single year as it may lead to outliers and missing important information. Thereafter, websites of all companies were investigated in order to find any further information about their I4.0 utilization and circularity. Other sources were also included where we searched for the company combined with predetermined key words (i.e. "H&M artificial intelligence"). These sources included magazine articles, news reports and other academic documents. For each company, we used between 1-5 sources depending on available data. The keywords that were searched for within documents as well as for documents (internet search) are found in Appendix F.

A common criteria used to analyse data sources is John Scott's (1990) "authenticity, credibility, representativeness and meaning" criteria (Bryman & Bell, 2015, p.555). Organizational "documents that are derived by private sources such as companies can be considered meaningful and authentic as they are comprehensible" (Bryman & Bell, 2015, p.561). However, we had to be weary of their credibility as they may involve bias, especially if they are published by the organization themselves. In order to alleviate this issue, we included various different sources for each company, including those published by chosen companies as well as any other documents and articles, in order to get the full and accurate representation of the company. Assuring representativeness of the documents is another key consideration of analysis of documents published by the companies as the researchers are only aware of the information that the companies *choose* to publish, and are unaware of any facts that are omitted. Bryman and Bell (2015) point out that organizational documents are usually written by people who want to communicate a specific message or perspective and thus they "cannot be regarded as providing objective accounts of a state of affairs" (p.562). To avoid this issue, the authors suggest that organizational documents should be complemented with other sources of data. In this study, we did this and included mass media such as articles published by others in addition to the sustainability/annual reports, to reveal additional perspectives of the companies' activities. All documents used for the ECA are provided virtually so we were careful of the authenticity of the documents as we are aware that anyone can publish information on the internet. Furthermore, researchers must consider bias to ensure the credibility of the source, and regarding representativeness, virtual sources including websites are updated continuously so we made sure to record the dates they were accessed.

3.4.1 Data Analysis

An ECA entails the challenge with the richness of data involved in qualitative data regards "finding analytic paths through that richness" (Bryman & Bell, 2015, p.579). In order to arrive at a wider concept that is significant to the business community, researchers must be careful not to be overwhelmed with the vast amount of data collected.

Bryman and Bell (2015) outline two main strategies used to analyse qualitative data, which includes analytic induction and grounded theory technique. The grounded theory approach arrives at a "theory that was derived from data, systematically gathered and analysed through the research process" (Bryman & Bell, 2015, p.584). This approach involves two main characteristics being that theory is developed out of the data collected and that it is interactive, meaning the analysis and data collection occurs "concurrently" and is "referred back to each other" (Bryman & Bell, 2015). Thus, there should be a constant comparison "between the data and conceptualization" (p.585) which is employed in this study. Grounded theory includes theoretical saturation which is also involved here. In this study, each company is first investigated individually and patterns within each are identified (open coding). These findings were sorted separately and are found in Appendix A. Thereafter axial coding is involved by reorganizing the data to make connections between the companies, which involves a cross-case analysis. The findings were sorted into categories based on different I4.0 technologies. This was the most logical and clear way to organize the analysis as it aligned with the way that the data was collected. The ways that the companies interacted with the technologies was described with regard to improving circularity as well as then connecting this to the theoretical background. This also involves a thematic analysis which can be combined with, or used within, other methods including the grounded theory approach.

One key consideration in the analysis of documents for this study's qualitative content analysis, is one's perception of "reality." Some authors such as Atkinson and Coffey (2004) suggest that "documents should be viewed as a distinct level of reality in their own right" (Bryman & Bell, 2015, p.568) as they may not represent the reality of the organization in entirety. We recognize that documents have their own ontological status, we kept this in mind and also used supplementary data sources other than just those published by each company.

3.3 Semi-Structured Interviews

The second data collection method of this study were two semi-structured interviews that were used to complement the ECA. This section will outline how the interviews were approached including the research design, the sampling method, a detailed explanation of this data collection methodology, as well as how the interviews will be analysed.

3.2. Research Design

A common data collection method for both qualitative and quantitative research studies, is a research interview (Bryman & Bell, 2015). A structured interview is a standardized method whereby the same questions are asked to all interviewees, and is common for quantitative data collection methods. A semi-structured interview allows for more flexibility but at the same time involves formulating questions prior to the interview as a guide. The interviewer prepares general questions which are a frame of reference rather than being fixed as in a structured interview format. Semi-structured interviews also allow for more latitude as the interviewer is able to "ask questions in response to what are seen as significant replies" (Bryman & Bell, 2015, p.213). A qualitative interview is a term that some use for these unstructured interviews, however they tend to include both the semi-structured format and the unstructured kind. Qualitative semi-structured interviews will be employed in this study, whereby general questions will be prepared prior to the interviews but will be used as a guide meaning more flexibility and the addition of questions during the interview.

3.3.2 Sampling Method and Case Selection

The sampling method for the interviews were also done in a purposive manner as the companies we chose to request interviews with were based on our research question. We emailed approximately 30 clothing companies requesting an interview, however, we only received confirmation from two companies. We therefore decided to include this as a supplementary data collection method and combine it with the ECA. We chose to employ both methods as the interview would enhance our observational data by giving us the opportunity to ask questions that were directly based on our research question. The interviews were approximately one hour in length and we used the same interview guide for both which can be found in Appendix D.

The first interview was with Snickers Workwear (SW) which is a clothing company that produces workwear garments. Most of the companies analysed in the ECA were fashion brands which operate in a completely different way, adding another dynamic to our findings. The interviewee at SW was the head of Corporate Social Responsibility and head of their sustainability department, which suited our research as circularity has a strong correlation to sustainability. The second interviewee, Stéphane Roche, was the CEO of Devianne which is a French clothing retailer that sells high-end brands both in physical stores and online.

3.3.4 Interview Design

A semi-structured interview style was chosen as the most suitable for this study as it allows flexibility but in an organized manner (Bryman & Bell, 2015). As our research topics are quite complex and may need further clarification depending on the interviewee and their knowledge of the topics, this was an appropriate setup. Accordingly, Bryman and Bell mention that "flexibility is important in such areas as varying the order of questions, following up leads, and clearing up inconsistencies in answers" (2015, p.497).

The “focused” aspect of semi-structured interviews entails that open questions will be asked but will refer specifically to topics that the interviewers are interested in for the research (Bryman & Bell, 2015). As we combined the interviews with the qualitative content analysis that revealed fact-based data, the interviews were a great complementary source that involved an “opinion” based dimension which can deepen our understanding of how companies (or company representatives) perceive the potential use of I4.0 technologies for achieving the CE, even if they were not currently using them. The semi-structured interviews allowed respondents to elaborate on their answers which allows for a fuller understanding of their insights into these matters. In this study, the flexibility of the interviews allowed us to form a deeper understanding of the relevant topics and into responses we considered important throughout the interview.

Bryman and Bell (2015) stress that the literature review and background research of research papers should be used to construct the interview and choice of questions to assure quality of the interview guide. Our extensive literature review was used to guide us throughout the development of the interview guide and helped to choose the best structure for answering the research questions. Furthermore, we ensured that questions were clear and easy to understand, while avoiding being too specific, which is also important in qualitative interviewing (Bryman & Bell, 2015), by including an explanation of more complex matters and also by allowing follow-up questions.

Interviews were conducted digitally via Zoom and Microsoft Teams to simplify the interview process and to abide by the Covid-19 restrictions. This also allowed us to interview company representatives in different locations, which was necessary as the second company interviewed was located in France. The interviews were audio recorded, after asking for the interviewee’s permission to do so which Bryman and Bell (2015) explain the benefits of, including helping to “correct limitations of our memories and of the intuitive glosses” (p.493). The audio recordings were also used to aid in the transcription process, which was sent to interviewees, along with the analysis, so they could be approved for submission prior to publishing the thesis.

3.2.4 Interview Data Interpretation

In order to analyse the interviews, the first step was to transcribe them whereby a voice-to-text software was utilized to improve efficiency. As all interviews were audio recorded, the recordings could be transcribed into text with the automated MS transcribing software integrated into MS Word. Byrman and Bell (2015) explain that transcribing can be very time-consuming and that the automated voice-to-text transcription softwares can reduce the time needed. Both transcriptions for this analysis were completed in approximately four hours and as these speech-to-text softwares tend to misinterpret information, we edited and revised the entire transcript, thereafter.

To analyse the interviews, the most relevant parts were identified and organized into a separate document. Direct quotes from the interview are included but organized into a more logical order, as well as omitting tedious words or sentences that do not make any contribution to the findings. This process of trying to shorten the transcript was time consuming, however, it was also deemed necessary in order to make the sentences flow better and to make the findings more understandable to the reader. These summarized transcripts are included in Appendix B and C, for SW and Devianne respectively.

To analyse the results of each interview, a within-case analysis was first conducted through flexible pattern matching which “involves the iterative matching between theoretical patterns derived from the literature and observed patterns emerging from empirical data" (Sinkovics, 2018). This approach was suitable for this study as it allowed us to identify relevant information from the interviews that we could connect to our theoretical background. The patterns identified in the literature review are theoretical patterns, and those patterns found in the interviews are the observational patterns, and analysing these in combination with one another will result in overall themes within each interview (Pearse, 2019).

3.4 Combined Data Analysis

After conducting a within-case analysis of each interview as well as a cross-sectional analysis of the ECA, a combined cross-analysis is done. The data collected for the ECA and the responses from each interview are first analysed individually to reveal patterns within them in relation to the theoretical background. Thereafter, a combined analysis will reveal common themes from all different data collections, and reveal overall patterns within the clothing industry in regards to I4.0 for circularity. Due to our interactive approach and combination of various data collection methods, a flexible pattern matching is an appropriate approach as it allows us to determine patterns within the literature review, the ECA, and the findings from the interviews. This combined cross-sectional analysis will be approached interactively and combined with our discussion.

3.5 Validity and Reliability

There are various ways to assess validity and reliability of qualitative research (Bryman & Bell, 2015) whereby two are traditionally applied to quantitative research. One way of assessing these within qualitative research is to adapt their meanings to include external and internal validity, and internal and external reliability (Bryman & Bell, 2015). An alternative way of evaluating qualitative studies is to use a separate set of parameters not based on validity and reliability measures used for quantitative studies. This alternative consists of two primary criteria being *trustworthiness* and *authenticity* (Bryman & Bell, 2015).

Trustworthiness includes a study's degree of credibility, transferability, dependability and confirmability (Bryman & Bell, 2015). Credibility involves the issues regarding the true meaning of reality whereby "there can be several possible accounts of an aspect of social reality" (p.401). To alleviate this, we ensured respondent validation by confirming our interpretations with interviewees prior to publication. To check credibility, triangularity was also employed as we include an ECA based on various different sources of data, as well as interviews. Transferability is also an important consideration in qualitative research so we made sure not to transfer specific details about a particular case to other cases, as details may be unique to that particular situation. Dependability involves carefully planning, recording and continuously revising the research process to end up with the most accurate results. Confirmability relates to us trying to stay as unbiased and impersonal as possible throughout the study. The second criteria is authenticity and includes fairness, as well as ontological, educative, catalytic and tactical authenticity (Bell & Bryman 2015). Fairness accounts for whether the perspectives of all members in that social group being studied is accounted for in the research whereby we tried to include various clothing companies in order to get an overview of the industry as a whole.

Regarding our degree of realist thinking, we employ a middle ground approach (Bryman & Bell, 2015) and recognize that our research is only a single study into this topic, however, we attempt to minimize the gap between reality and our research by employing methods such as triangulation, and staying as unbiased and objective as possible throughout the entire research, and at the same time involving as many credible sources of data for our investigation in order to achieve a well-rounded representation of the reality of the situation.

3.6 Limitations

There are some limitations to this study that should be considered before the analysis and discussion. Firstly, with regards to the theoretical background and literature review, even though a majority of the sources used have been peer-reviewed journal articles, in order to fully investigate this topic in particular other sources had to be utilized. The disadvantage of this pertains to the notion that a significant portion of the discussion and ideas being developed in the areas of CE, AI and Industry 4.0 are done so in the “grey literature”, including blog posts, reports and business forums. This was also the case in some of the literature used for the ECA as I4.0 technologies is a relatively new topic, and especially in relation to clothing companies’ circularity. However, as a multitude of data sources were used, we tried to limit this issue as much as possible by cross referencing information. Another issue here is that most of the literature used for the content analysis was organizational documents and companies’ websites which may involve bias by the company that published the information.

With regards to the interviews, a single company representative for each company interview was interviewed. Their responses may involve bias and may not provide an accurate representation of the entire company as a whole. As this study only includes two interviews, it may only give a very particular insight into the topics especially if they happen to be outliers. We tried to alleviate these issues by using the interviews as a supplementary data collection method which the analysis is based on, increasing the accuracy of the findings.

The aim of the research was however not to compare each company but instead to develop an overall understanding of how I4.0 is used within the clothing industry to achieve CBMs. Therefore, the fact that there were variations in the availability of information for each company is not very concerning.

4 Findings, Analysis and Discussion

In 2018, the Head of Advanced Analytics and AI at the H&M group, Arti Zeighami, highlighted the connection between AI and circularity in stating that:

> "Circularity is ultimately about using resources sustainably, where one central aspect is to avoid over-production. With the help of advanced analytics and AI, we can be much sharper in aligning supply and demand. This could also entail less transport and warehousing, which means less energy is used. It's really a win-win situation: while creating an even more relevant offering for our customers, we are reducing the environmental impact of our operations." (H&M 2018, p.23)

This reasoning is found in companies across the fashion industry who are now beginning to acknowledge and utilize I4.0 technologies in their operations and strategic objectives. The findings from the ECA and the interviews will be presented here with the aim of identifying the ways clothing companies are utilizing I4.0 technologies within the context of the CE. The findings of the ECA are divided into groups based on the I4.0 technologies described in the literature review. Due to the semi-structured format of the interviews, these findings will instead be presented through applying the ReSOLVE Framework, PSS and Rs principles. Thereafter, the analyses from the ECA and interviews will be cross-analyzed and combined with a discussion.

4.1 Cross-Sectional ECA

4.1.1 Utilization of AI & ML

4.1.1.1 Predictive Purposes & Forecast Trends

It was found that AI and ML are used by multiple companies, with the H&M Group (H&M) and Norrøna in the lead. The main use of AI & ML was to make predictions in order to balance supply and demand, reduce excess stock and optimize production processes. This was specifically found for the parent companies PVH, H&M Group and Inditex (Appendix A). The use of AI and ML to accurately balance supply and demand can potentially be a way to minimize textile waste. With regards to post-industrial waste, for example, Inditex mentions that they are developing “prediction tools for manufacturing technologies with a greater risk of generating nonconformities" (Inditex 2019, p.158). This is directly connected to the ‘Optimize’ business model as the AI and ML technologies can identify failures in the manufacturing systems (Jabbour et al. 2018).

From the perspective of pre-consumer waste, AI and ML can be used to ensure correct product placement based on local customer preferences, thereby reducing the amount of unsold garments (Koszewska, 2018). This is exemplified by H&M in that they use AI to “analyze returns, receipts and loyalty card data to tailor the merchandise for each store” (Marr, 2018). It is also suggested by the acquisition of the AI-based company Celect by Nike with the purpose of optimizing “ inventory across an omnichannel environment through hyper-local demand predictions” (Nike News, 2019; Thomas, 2019)

Reducing waste, and ultimately the amount of resources used, through AI-based forecasting of supply and demand is very significant in the achievement of CBMs. This is due to the notion that *Reduce* is often considered higher ranked than other Rs principles and therefore more preferred in advancing towards a CE (Ghisellini, Cialani & Uligiati, 2016; Song, Li & Zeng, 2015). These AI-enabled methods of reducing waste through predictions of supply and demand can be connected to the ‘Optimize’ business model of the ReSOLVE framework (Jabbour et al, 2018).

4.1.1.2 AI for Decision Making

Furthermore, the AI- and ML technologies can facilitate decision-making, most notably through the statements made by Norrøna and the H&M. Norrøna, for example, is using a Google Cloud ML platform in order to support “business intelligence solutions” (Mikkonen & Gariel, 2019). Meanwhile, the AI department at H&M was established in 2018 with the purpose of supporting operations across their entire value chain (H&M Group 2018, p.23). This can, perhaps, be a solution to the problems facing designers in deciding which combination of materials to use (Koszewska, 2018). It may also be of use in redesigning the BM to become circular, which will require extensive planning and decision making on very complex levels. In this regard, having developed AI and ML systems to handle decision-making and predictions may allow for a better understanding of how to manage the transformation of established BM to CBMs. This is supported by Zeighami who states that “[AI] is one of the most powerful tools we have in the transition towards a circular and sustainable fashion system. With AI we can make sharper and better decisions that impact our world in a sustainable way." (cited in H&M Group 2018, p.23). Furthermore, AI-based decision making can be used to facilitate multiple areas of the ReSOLVE Framework. In particular, the 'Share' BM of the ReSOLVE framework can be facilitated by AI-based decision making processes (Jabbour et al, 2018). This is because they allow for, among other things, design processes which can be specifically adapted to meet consumer preferences whilst simultaneously considering design alternatives of various materials and what the used materials will mean for future possibilities following the Rs principles.

4.1.1.3 AI for Customer Reach

It was also found that clothing companies use AI and ML to improve their communication with their customer base. For example, Levi's is using AI to allow for personalized promotions in their loyalty program and is using an AI-driven chatbot on Facebook Messenger to facilitate customers in finding clothes (Gosselin, 2019; Preez, 2020). Similarly, VFC is using IBM Watson, powered by AI, to "replicate the personalized experience of talking with an expert" when shopping (IBM, 2015). Norrøna specifically mentioned that one of the aims in creating their Google Cloud ML platform was to improve e-commerce and communication with customers. Similar strategies are also pursued by Fast Retailing and Asos. While the direct goal of implementing the technologies may be to encourage purchases by customers, a significant side-effect is the reduction of waste, emissions and energy which result from incorrect purchases. Digital services, such as chatbots and AI voice augmentation, can be connected to the *Virtualize* BM in the sense that it decreases the need for physical stores which are associated with higher levels of energy consumption and more complicated logistics systems. Instead, e-commerce is developed to become more efficient and user-friendly, thereby enabling physical stores to be replaced by digital stores. By extension, improved communication with customers may also enable *Loop* activities as companies may gain a better understanding of their customers through increased and improved communication. A similar line of argumentation can also be applied to the adoption of the *Share* BM. Additionally, the AI-based improvements to e-commerce and communication may facilitate a transition into PSS (Bressanelli et al. 2018).

4.1.2 Utilization of Internet of Things

The findings suggest that the larger parent companies, H&M, Inditex and PVH are utilizing- or beginning to utilize IoT technology in order to improve traceability and logistics. This supports the arguments of I4.0 technologies acting as enablers of the CE (Wilts et al, 2021;

Modgil et al. 2021; Rajput & Singh, 2019; Cagno et al, 2021; Uçar, Le Dain & Joly, 2020).

PVH and H&M, among others, are collaborating with a wide range of organizations, including Microsoft and the EON Group in piloting the "CircularID Protocol." The idea behind the CircularID Protocol is to make physical products smart and interconnected, thereby, allowing information to be shared on a platform between multiple agents of the value chain (EON Group, 2020). The aim behind the innovation is to create a new industry standard for sharing information about how the product was produced and what it is composed of, thereby increasing traceability and enabling end-of-life solutions such as those described by the Rs principles (EON Group, 2020; Bressanelli et al. 2018; Mboli, Thakker & Mishra, 2020).

Furthermore, the CircularID protocol may enable BM of the ReSOLVE framework. The EON Group mentions that "CircularID™ Protocol powers item-level tracking and reverse logistics essential for rental, sharing, and subscription business models" (EON Group, 2020). This clearly supports the *Share* BM as the technology can provide companies with more knowledge about the product at each stage of the life cycle. In turn, this will enable more informed decisions in regards to how to best circulate the product between users and how to handle the product at the end of its life. Accordingly, Jabbour et al. (2018) mention that the gathering of information on consumer behavior through the IoT technology can be useful in order to improve the design of the product to better correspond to the ways in which the product is being used.

A similar logic can be applied to the PSS offerings. In these BM, the information gathered on the users as well as the improved traceability of the product can be used to counteract the risks of unnecessary wear-and-tear resulting from consumers being careless with the product as they do not own it (Bresabekki et al, 2018). Furthermore, the IoT technology may make PSS more efficient as accurate product information will "follow" the product throughout its entire life cycle. Instructions for how to dispose of the product when a user is finished with it can also improve efficiency in PSS. If the CircularID protocol becomes a new industry standard, it can potentially enable a large-scale transition into a sharing economy, thereby, promoting the objectives of the CE.

It was also found that H&M and Inditex use RFID technologies in order to improve supply chain efficiency and increase control and integration between different suppliers (Marr, 2018;

Inditex 2019). The investments into RFID and what it entails can be connected to the *Optimize* BM as resource efficiency and performance can be improved in line with increased control of the supply chain. Furthermore, the increased traceability of the location of products may allow companies to more efficiently move products between different locations (Jabbour et al. 2018). This will presumably result in reduced waste and emissions, as well as lower costs for the company implementing the technologies (Ustundag, 2013). IoT technologies can also be used to enable the 'Loop' areas of the ReSOLVE framework (Cagno et al. 2021) as the traceability can facilitate activities at the end of the product life cycle such as refurbishing, reuse, recycling and remanufacturing (also referred to as upcycling).

4.1.3 Utilization of additive manufacturing

It was found that Under Armour (UA) and Asos both use 3D printing technology, which is central to AM, in their manufacturing processes. UA, for example, has invested in a new manufacturing and innovation facility named "Under Armour Lighthouse" (Under Armour 2018, p.30). Tara (2016) explains that UA is able to 3D print products using inputs of parameters including "durability, flexibility and weight requirements." Asos (2019) explains that their use of 3D printing in the production of footwear has resulted in significantly lower lead times. The use of 3D printing technology has many applications for achieving CBMs.

One way in which 3D printing can be used is to improve the design to allow for extended future possibilities of circularity, which is one justification EMF describes for the connection between AI and the CE. Additionally, 3D printing can be used to shorten lead times of production and facilitate communication between designers, engineers and users (Jabbour et al., 2018). The challenges of communication and gaps in knowledge between the design department and the production department is a major issue hindering the implementation of CSCs (Sandvik and Stubbs, 2019). Therefore, the possibility that 3D printing may facilitate communication between these agents may be very beneficial for achieving a CSC. It may also lead to better and more desirable products as the production can make use of the gained knowledge. Furthermore, 3D printing technology can enable further reduction of waste through allowing production to adapt to the real-time demand (Sandvik & Stubbs, 2019).

In these ways, 3D printing can be connected to the ReSOLVE framework as well as PSS offerings. For example, the *Virtualize* BM can be enabled by 3D printing technologies as they allow for products to be customized to a wider extent than with traditional manufacturing techniques (Jabbour, 2018). Furthermore, 3D printing can be connected to the *Exchange* BM as they can facilitate the production using sustainable materials. In addition to this, 3D printing can reduce post-industrial waste such as fabric cutting waste (Koszewska, 2018).

4.1.4 Utilization of Virtual Simulators and Digital Twins

Burberry, H&M and UA were found to have used virtual simulators and digital twins in their manufacturing processes. Burberry, for example, notes that they use "'Digital Product Twins' to help reduce reliance upon physical sampling" (Burberry 2019, p.68). Similarly, UA uses "virtual design and virtual prototypes to eliminate pre-production waste during the development processes, lessening the introduction to the environment of garments and samples never intended for sale" (2018, p.28), a method also employed by H&M (see appendix A). These methods of replacing physical samples with digital ones can directly be connected to the *Virtualize* BM as it involves dematerialization of physical objects. In the *Virtualize* BM value is created virtually instead of through physical means (EMF, 2015; Jabbour et al. 2018). This directly reduces waste and also facilitates modifications and design decisions. Furthermore, as is noted by H&M, the virtualization of physical samples can also result in lower GHG emissions from transportation. Simulations can also be used to test different scenarios, such as decisions of materials, in order to optimize the composition of products for end-of-life solutions (Mavropoulos & Nilsen, 2020).

4.1.5 Utilization of cloud solutions

The findings further reveal that clothing companies are using cloud technology. As explained earlier, Norrøna is using a Google Cloud platform to handle data, power ML predictions and support "business intelligence solutions" (Mikkonen & Gariel, 2019). Eileen Fisher is using cloud-based (CB) solutions provided by the company Bluesign in order to improve chemical traceability (Eileen Fisher 2019, p.7). Additionally, Macy's has adopted the CB online information system 'SGS Transparency One' in order to improve traceability of their products through "direct exchange of technical information and data" between the company and its suppliers (Macy's 2018, p.11). Capri Holdings have also implemented CB solutions, but in their case to reduce GHG emissions.

These uses of technology suggest that CB solutions support and enable other I4.0 technologies and their output. This allows the entire system of I4.0 technologies to become more efficient and interconnected. Furthermore, as exemplified by Norrøna, the cloud is useful for storing large amounts of data, as supported by Mavropoulos and Nilsen (2020) who note that the cloud is important for handling data and making it accessible in real-time. This can again be connected to the *Virtualize* BM in the sense that CB platforms can be used to replace physical assets. Mavropulos and Nilsen (2020) mention that cloud and API technology can be used to innovate on an architectural level. They further explain that I4.0 technology could potentially allow parts of company operations to be replaced, through for example platform-as-a-service models enabled by the cloud. This supports multiple areas of the ReSOLVE framework as well as PSS because CB services can have supportive functions.

4.2 Interview Within-Case Analysis

4.2.1 Snickers Workwear Interview Analysis

The interview with the sustainability coordinator of Snickers Workwear (SW) gave important insights into how the concepts of the CE and I4.0 technologies are perceived and used in practical terms within clothing companies. It also provided another dynamic of the issues facing companies producing workwear garments in particular, as opposed to traditional fashion companies. A detailed summary of the interview with the sustainability coordinator of SW, Maria Schartau, is attached in Appendix B. Ms. Schartau begins by highlighting the importance of sustainability at SW whereby she acknowledges that they "*have to work with sustainability to stay relevant.*" This relates to the concept of strong sustainability (Henderson, Persson & Sprei, 2018) which recognizes that all business activity ultimately relies upon the environment. There are various parts of the interview that directly correspond to the PSS and the ReSOLVE framework, as well as the various R's principles and theories regarding the importance of using I4.0 technologies for the CE.

4.2.1.1 ReSOLVE Framework

Firstly, with regards to the *Share* aspect of the ReSOLVE framework, which is concerned with prolonging the product lifetime through end-of-life activities such as repair and redesign as well as designing the product to last (EMF, 2015; Lewandowski, 2016). Ms.Schartau stresses that SW's fundamental aim is "*get[ting] the garments to last as long as possible,*" as well as *"selling the correct product for the correct use."* She describes that this will allow "*the garment to live longer"* and adds that it will hopefully encourage consumers to care for their garments in a better way.

This relates to the *Optimize* dimension as it entails that SW focuses on the development and enhancement of the product with the aim to improve efficiency and performance (EMF, 2015; Jabbour et al, 2018). SW uses sensor technologies to measure and monitor the workers wearing the clothing, which has helped them to understand consumer behaviour and improve their garments to suit these needs. This means that they have been able to readjust their design to improve their quality based on discoveries through these sensor technologies. The design can be improved through I4.0 technologies which can facilitate product design, prototyping and testing, and predict the best functionality (EMF, 2015; Jabbour et al, 2018). Thus, there is a potential for SW to use AI technology to facilitate their design process and to increase product durability. The *Share* BM can also be aided through the use of IoT sensors to track the ways in which the products are being used, enabling the firm to extend the useful life of products through the appropriate Rs principles (Jabbour et al., 2018). This can clearly be compared to the ways in which SW used sensor technologies, as they measured the user and then used this information to improve their product.

A connection can also be made to the LLF approach which stresses product quality and promotes a long single-use cycle, as opposed to circulating the materials quickly in SLF (Earley & Goldsworth, 2015). This directly corresponds to SW's mindset as they prioritize garment quality and durability. Ms. Schartau highlights another concern for workwear being that by the end of its life cycle, the garments are usually completely worn out and often covered in chemicals**.** The aim of LLF is creating clothes that consumers will want to use longer (Bocken et al. 2017). In order to slow down the resource loop, SW enhances durability and quality, thereby limiting 'pre-' and 'post-consumer waste' (Koszewska, 2018). Quality assurance eliminates faulty garments that would be unsold, as well as ensuring that consumers can use the garments for an extended period of time. There is the potential for I4.0 technology to be involved in improving the LLF approach including both SW's sensor technology and predictive technologies which are described further below. The focus of SW on this approach is particularly important for their industry as reuse may not be a good option for their offering due to the chemicals that often cover the garments by the end of their life cycle. With regards to selling *"the correct product for the correct use"* smart technologies such as IoT could be implemented to increase data gathered on consumer behavior, which allows companies to better understand consumers and design their models and offering based on the knowledge (Jabbour et al., 2018), which again relates to the *Share* BM.

Furthermore, Ms. Schartau explains that SW must communicate with their consumers in order to encourage them to care for their garments, which could be achieved through the use of I4.0 technologies. She explains that encouraging consumers to care for the garments would make them last longer, thereby decreasing their climate footprint. Furthermore, improved communication would benefit the purchasing company financially as they would not need to purchase as many garments to replace the worn ones which also involves the potential for repair. However, Ms. Schartau explains that it is vital to make customers understand that they have an opportunity to reduce the negative environmental impact through increased care. This, she adds, it "*is something that we will need to work with from a higher perspective to try to gradually get them to change their view."* Such an effort would hopefully reduce the amounts of garments used and wasted, which relates to the *Share BM* by extending the product's lifetime through maintenance. Ms. Schartau explains that "*some setups [entail that] the end user is not paying for their workwear out of their own pocket*." This accelerates the issues of users not caring for their garments and can be connected to the drawbacks of the use-oriented services of the PSS regarding rapid depreciation of products as customers are less incentivized to handle them with care (Bressanelli et al, 2018). One of the proposed solutions is to use I4.0 technology to better monitor and incentivize consumers to sustainably use their garments (Bressanelli et al. 2018). Ms. Schartau mentions that very minor defects, such as a lost button, that could be repaired very easily, may instead be thrown away as the consumer can replace the entire garment for free. She explains that in order to solve this, they must communicate with the workers and "*promote the idea of repairing and caring for the garments and possibly also supply the solution"* which has a strong correlation to the *Loop* BM that is concerned with maintaining resources and materials in closed loops (Wieser & Tröger, 2018).

SW has a significant focus on balancing *"supply and demand"* to minimize overproduction and, thereby, minimize the amount of unsold garments produced. This will further reduce energy consumption and resource use associated with the production of the garments. More specifically, this involves a reduction in 'pre-consumer waste', whereby predictive technologies can limit overproduction (Koszewska, 2018). Ms. Schartau described SW's use of predictive technology, and that they recently *"invested in a new forecasting system"* that is more accurate and will be able to *"reduce the amount of stock they have as much as possible while [at the same time as ensuring that they are] able to supply enough."* Ms. Schartau explains that this will help them to limit their stock which will improve their finances. Using the smart predictive technology, she claims will facilitate their sustainability efforts through reducing stock and helping them to plan better. By extension, she explains, this will reduce other areas of energy consumption such as unnecessary transportation. This is part of the *Share* dimension of the ReSOLVE framework wherein technologies, such as AI and ML, can be used to balance the supply and demand according to real-time gathered data on users (Jabbour et al., 2018). SW's predictive technology also helps them with *"supply chain transparency and risk analysis which uses big data analytics."* Using digital receipts to increase transparency can facilitate the activities based on the R's principles (Sandvik & Stubbs, 2019) as it can help in understanding activities at the end of the product life cycle to ensure that the materials remain in the loop of resources.

SW also has *"a rolling assortment"* meaning that waste is eliminated as their supply department analyses the trends in the forecasting system and adjusts production levels accordingly, also relating to the *Share* BM. SW also has an outlet with their discontinued products, which further reduces waste by ensuring the garments are used through selling them at a reduced price. While this is a preferred alternative to disposing of the unsold garments in more unsustainable ways, it points to the problems that the clothing industry faces regarding excess stock (Koszewska, 2018). If I4.0 technologies were used to a wider extent, perhaps these issues could be avoided.

A major concern with the *Loop* BM for SW regards the recycling of workwear garments. Ms. Schartau mentions that this may not be an option for SW as the chemical contents end up on the clothing. Thus, it is challenging to know how to recycle, remanufacture or reuse them as the chemical content is often unknown. Here, I4.0 technologies can be used to identify the contents, for example, using IoT technologies to determine how the garment has been used which can then be communicated to facilitate activities at the end of the product's life cycle (Jabbour et al. 2018). This can directly be connected to the *Loop* BM. Alternatively, Ms.Schartau mentions that there is *"a possibility of downcycling but it would most likely need to be for products that are not sensitive to chemical content.. [for components such] as stuffing and insulation... but not for garments."* This is also a part of the *Loop* BM as the fibers could be given a *"second life"* whereby they can be used for other purposes than just for workwear. Although they may not remain in the same company, the materials are still kept in use instead of thrown away as in a linear model.

Another major part of the discussion with SW surrounded the potential of recombining fibers. Their garments contain cotton and polyesters and there is currently no commercialized way of separating them. The only way of doing so now is to mechanically separate them which results in fiber lengths that are too short to create the quality needed for workwear garments. The technology does exist to separate these fibers, however, this is only on a small scale and is also very expensive. The reason why separating and recombining fibers is important is that the materials could be used again to create new garments, thereby enabling the *Loop* dimension of the ReSOLVE framework. Ms. Schartau explains that if they were able to access these separating technologies, it would be revolutionary to the circularity of their business, especially as SW has a very streamlined production meaning that they could do this on an immense scale. Their lack of financial resources along with a lack of research, is identified as one of the main challenges with transitioning into a CBM, according to Ms. Schartau. This also relates to the *Exchange* aspect whereby "new technologies, materials or processes" could be employed in order to resolve the issues through replacing older technologies and machines with newer and more sustainable ones (Jabbour et al, 2018). Furthermore, SW is working with their supply chain management and researching the ways in which fibers can be recycled back into workwear. Here, the main concern is the durability as this tends to be an issue with the recycled fiber which is often weaker due to the shortened fiber length. AI and ML could potentially be used here in order to generate simulations on new materials as well as conduct its own research (Dauvergne, 2020; Hackl, 2020).

4.2.1.2 Rs Principles

Various parts of the discussion with SW also relate directly to the 'Rs' principles (Bressanelli et al. 2018). Firstly, with regards to *recycling* there are various issues within the workwear industry as a whole due to the chemicals that are involved throughout the garment's lifetime. Ms. Schartau discusses the more viable option of downcycling and using the garment for other purposes that do not require that they be chemical-free, such as stuffing. Furthermore there is the potential to recombine fibers, which is facilitated by advanced technologies, however, these are not available on a large scale as of today. Finding ways to commercialize these technologies, would allow for *reusing* the materials and fibers and thus would *reduce* the amount of new materials needed and improve their circularity. The *Reduce* dimension has great potential within SW and also for utilizing I4.0 technologies. For instance, when SW uses predictive technologies to match demand and supply, they *reduce* the number of unnecessary garments produced as the technology determines the correct amount of garments demanded from the start. Also relating to *reducing* both pre- and post-consumer waste, SW is aiming to convince consumers to care for their garments and to get them repaired when needed as opposed to replacing them with new ones. Through SW's attention to quality and durability of their garments, they are also *reducing* the amount of garments produced as their lifetime is increased and thus not as many garments needed. In regard to Rs principles added to the original three, SW also directly involves *repair* and *repurpose* (Reike, Vermeulen & Witjes, 2018), the latter relating to their recognition that used garments can be utilized for alternative purposes such as for stuffing. I4.0 technologies can also be utilized to advance these efforts by, for instance, facilitating traceability, forecasting, decision-making (in design for instance) and balancing demand and supply, which supports CBMs.

4.2.1.3 Product-Service Systems

PSS is another prominent CBM (Linder & Williander, 2017). SW mostly coincides with the product-oriented service category as their BM is focused on the sale of a product (workwear garments) through a somewhat linear production process. This is because after SW sells their garments, they do not interact with them or monitor what happens to them at the end of their lifecycle. This also aligns with their LLF strategy which is more suitable for high-quality brands (Earley & Goldsworthy, 2015). SW's censoring technologies have allowed them to monitor the consumers in order to determine ways to improve the durability and quality of their garments which also improves circularity as it implies that they reduce the number of garments needed. Furthermore, the ownership of the product is moved to the consumer when it is sold, which also suggests a product-oriented service. A reason why this BM is appropriate for SW is due to the issues with recycling and reusing the workwear as explained above (for instance due to chemicals). The PSS framework explains that companies can become more circular through providing add-on services that are aimed to upgrade or restore the product function (Tukker 2004; Bressanelli et al. 2018). As product-oriented services rarely hold the producing company responsible for the lifecycle of the product, the main way that companies can make the garment's lifecycle more circular is through reaching the consumer and encouraging them to care for their product or its repair, which SW tries to do. Here I4.0 technologies could be utilized to both interact with the user and monitor their behaviour to understand what happens to the garment after it is sold which would allow them to have more control in involving end-of-life solutions. Due to the fundamental issues with workwear garments, the use-oriented aspect of the PSS may not be suitable as their clothes are extremely worn out after their use. However, this dimension also involves extending the product life through better designed products with higher quality (Tukker, 2004) which is a main goal of SW. Ms. Schartau also explains that in doing so, they may be able to reduce their carbon footprint extensively through increasing the garment's lifetime. SW could apply a results-oriented service when trying to convince consumers to repair their garments as opposed to replacing them with new ones. If SW was able to give the consumers an incentive to do so, which is part of this results-oriented service approach, it could help them to reduce the number of garments produced as well as reduce waste as consumers repair the garments instead of replacing them.

4.2.2 Devianne Within-case Analysis

The interview with the CEO of Devianne, Stéphane Roche**,** revealed further information on the ways in which companies pursue CBMs and use I4.0 technologies.

4.2.2.1 ReSOLVE Framework

Devianne's operations are closely linked to various *Share* BM principles as they try to increase the product's utilization by distributing it between various customers throughout its lifetime. This includes Devianne's secondhand section in different stores as well as its app, which is currently under development, that aims to be a buy-back service which will encourage customers to sell clothes back to Devianne. They then upcycle, recycle or reuse the garment and sell it in the secondhand market. The buy-back system will mainly aim to repair, adapt or upcycle the used garments. Another option here is to recycle the clothes if they are completely worn-out, and in this case the customers would receive a voucher. In this way, Devianne will pursue a so-called C2B2C approach, wherein products are circulated between consumers with Devianne as the intermediator.

This relates to the reuse section of the *Loop* area (Wieser & Tröger, 2018), which also supports circularity as the clothes continue to be used and are not thrown away. Additionally, this approach is valuable as it promotes continued use of the original garment, which can be connected to the inner loops of the *Loop* BM. Closing the inner loops of resource use involves activities, such as reuse and repair, which lead to the product being used in the same way as it was originally intended. The idea is that this will be more resource efficient and imply more environmental benefits than what will result from the equivalent efforts of closing the outer loops (EMF, 2013; Wieser & Tröger, 2018). This can also be connected to the notion that Devianne is offering repair services in many of their stores.

With regards to their secondhand section, Devianne is focusing on modernizing this industry to make secondhand clothes more "*attractive and trendy.*" The second-hand market can also be an area where materials that will be scarce in the future (i.e. cashmere) may be found. Consumer interest in purchasing second hand garments may, therefore, increase as products become more scarce. If Devianne is successful in implementing the app and buy-back service, thereby transitioning into a CBM based on redistributing products between users, they could potentially gain first-mover advantages such as a valuable network of consumers which supply them with new materials.

In developing the app and transitioning into a CBM based on, for example, the *Loop* or *Share* BMs as suggested above, there is a potential for I4.0 technologies to facilitate the operations and enable improved capabilities. Smart technologies such as ML or product passports can, for example, be used to determine what the particular garment is composed of, how it was produced and, perhaps even, how it has been used throughout its lifetime which facilitates the technical challenge of identifying the material composition of the product with the purpose of separating materials (Sandvik & Stubbs, 2019).

The interactive app which is being developed by Devianne, also allows users to see how much money they could potentially make at a particular time if they were to return their worn garments to Devianne. Mr. Roche explains that they are working on integrating a 'gamification' aspect into the app, whereby users can receive points based on, for instance, the amount of emissions they have saved by returning their garments. This can then be used to receive a discount or special offers in their stores. Not only will this incentivize the consumer to return their clothes but it can also help Devianne to retain customers as they will want to return to their stores to use these promotions. This approach relates to the *Virtualize* area of the ReSOLVE framework which focuses on creating value through virtual means or digital media (EMF, 2015; Jabbour et al. 2018).

With regards to RFID, Mr. Roche explains that it may not be as applicable to their company as they are not designing or manufacturing their own clothing, but instead selling other brands. He adds that these technologies are also too expensive and that he does not believe that it will currently generate a sufficient ROI in their case. On the other hand, he points out that he sees benefits with implementing the IoT technology in the future to follow the movements of the garments. This can, for example, be connected to the *Optimize* BM as well as perhaps enhance their services through improved understanding of the ways in which products are used.

Mr. Roche discusses overstock issues which is a major issue for fashion retail stores (Koszewska, 2018) and is harmful for the planet and for their profit. He recognizes the potential for AI usage to predict how competitors will behave as well as predicting how quickly Devianne themselves will be able to sell their secondhand products. Thus, they could adjust their price levels for the secondhand products depending on the real-time demand. This relates to the *Share* BM whereby it has been established that cloud and AI-based manufacturing and IoT can help companies to balance their supply and demand through the use of real-time data of users (Jabbour et al., 2018). Balancing supply and demand can also help companies to design their models based on consumer behaviour and to extend the products lifetime through knowing the best suitable Rs principle the authors mention (2018). For Devianne this could help them to predict which of their circularity efforts (upcycling, adapting or recycling) are working the best.

With regards to the *Virtualize* dimension, Mr. Roche highlights the issue of the digitalization of the clothing industry and the rise of online shopping, stating that *"the issue is that you have to invest in all digital [technologies], AI, data management, and website platforms at the same time as you still have to invest in your stores."* The *Virtualize* BM explains how these alternative virtual systems can be used to create value for the company as opposed to finite or physical materials (EMF, 2015; Jabbour et al. 2018). This suggests that there may be more room for innovation which would increase sustainability. On the other hand, consumer behavior plays an important role as, Mr. Roche notes that a majority of their consumers still purchase their garments in the physical stores.

As of right now, Devianne's priority is trying to build this new business plan around this app in a way that makes it profitable. This means they must determine how many resources and personnel to allocate to each of their operations. They must also establish how much "traffic" generation is needed to their stores in order to profit from the investment. Here there is a significant potential for I4.0 technologies in relation to the *Virtualize and Optimize* BMs whereby predictive technologies can be used to provide producers with information to help them design and plan in the most effective way possible (Jabbour et al., 2018).

Notably, Devianne pursues activities directly connected to the Rs principles and, in particular, reuse, reduce, recycle, remanufacture (i.e. upcycling) and repair (Reike, Vermeulen & Witjes, 2018). Again, this connects to the *Share* BM of the ReSOLVE framework which suggests that IoT can be used to extend the useful life by tracking how products are used and thus can provide insights into the most efficient Rs principles to employ (Jabbour et al., 2018). Reaching consumers to promote both the importance of these circularity-related concerns, as well as making it obvious that these are possible with Devianne, can be assisted through I4.0 technologies as mentioned by Tunn et al. (2019) in their discussion of sustainable consumption. Devianne's extensive focus on these Rs processes as a way to quickly and efficiently close the loop of resources and circulating materials, which aligns with SLF (Earley & Goldsworthy, 2015). Here the focus is on fast product systems as opposed to quality wherein the target is instead to have strong recycling processes, which Devianne has, as well as other Rs that support circularity (as those mentioned above).

4.2.2.2 Product-Service Systems

Devianne's operations also have a strong connection to the PSS framework (Tukker, 2004). Currently, Devianne offers product-oriented services, wherein they sell the product and then offer add-on services. There is also potential that, in line with the implementation of the app, Devianne could transition into a use-oriented BM. This would, however, require that they retain ownership of the garment throughout its entire lifecycle. The benefit of the PSS offering would be to extend the product life through services as well as closing the loop through focusing on activities at the end of the product life cycle (Tukker, 2004). For Devianne, this includes their various efforts to prolong the use of their clothing such as their repair shops, second hand stores, recycling processes as well as their adaptation of used garments.

4.3 Combined Integrative Analysis & Discussion

Up until this point, the analysis has partly been focused on how each of the I4.0 technologies separately can be connected to CBMs, and partly focused on the ways in which the interviewed companies' BMs can be interpreted as circular. While this has been beneficial for providing for a more clear understanding of how each company may utilize I4.0 technologies to achieve CBMs, it has not sufficiently explained how the findings show the overarching characteristics of I4.0 and how these can be integrated into companies' value chains in order to develop CBMs. This is of interest as I4.0 is currently being shaped and the connections and overarching analysis which extends beyond the borders of the individual firm will form a more valuable understanding of the patterns of I4.0 and CBMs. Furthermore, there are overarching themes that are very influential to properly implementing CBMs, that have not appeared yet in these individual analyses. Therefore, the following combined integrated analysis is very important to reach our aim of gaining a more in-depth understanding of the clothing industry in its entirety, and the connection between the dependent and independent variables of the thesis. In order to enhance the analysis and tie it to reality as well as to clarify the unrealized potentials of I4.0, the discussion will be integrated into this chapter as well.

4.3.1 Interconnectivity between I4.0 technologies for achieving CBMs

One of the key characteristics of I4.0 is the interconnectivity between different advanced technologies and CPS (Drath & Horch, 2014; Lasi et al. 2014; Mavropoulos & Nilsen, 2020). This became apparent within this study as many of the companies use a combination of I4.0 technologies to achieve specific goals. Norrøna, for example, uses cloud services to drive their ML platform, thereby allowing for support in decision making processes based on vast amounts of generated data stored in the cloud. Similarly, H&M combines AI with data analysis and 3D visualization to increase their circularity. Additional examples can be found in Appendix A.

The interconnection of the technologies is essentially what will revolutionize the industry in I4.0 and what will particularly enable CBMs. This is due to the prospect of entire areas of operation becoming autonomous, decentralized and capable of making their own decisions, predictions, and designs based on data generated from multiple parts of the organization and its value chain. In this regard, there are notably still large areas of unrealized potential as companies are only beginning to utilize the technologies. In other words, there does not yet seem to have been a large-scale development of technological ecosystems such as those anticipated for I4.0 (Lasi et al, 2014; Mavropoulos & Nilsen, 2020).

There are also examples that were found, primarily in the ECA, which involved other uses of advanced technologies, but which were either not as widespread or not as clear in regards to the extent to which they can be categorized as I4.0 technologies. Examples include the use of big data analytics, autoboxing technology, and apps developed for shopping and loyalty systems. These technologies are important in the ecosystem of I4.0 as they have the potential to be combined with I4.0 technologies. Autonomous robots, for example, can be used together with decentralized decision making and prediction systems in order to respond to real-time supply and demand (Mavropoulos & Nilsen, 2020). Combined with additive manufacturing, the benefits associated with economies of scale may become irrelevant as machines will be able to manufacture customized products at very low costs and in an extremely efficient way. This will likely enable vast opportunities for circular design in the future as predicted by the EMF. However, it also requires that clothing companies have the appropriate capabilities to implement such systems (Breznik & Lahovnik, 2016; Luo, 2000; Teece, 2014). Dynamic capabilities, for example, have been used to explain why certain companies perform better than others when they all operate in the same industry.

The complexity of the ways in which multiple technologies need to be used in order to achieve the desired effect, could presumably be one of the reasons as to why some companies are reluctant to invest in I4.0 technologies, as suggested by the interviews. Devianne, for example, points out that the issue of the gradual transition into e-commerce and the investment decisions of to what degree the company should invest in enhancing their digital platform, is complicated by the fact that investments need to be made into multiple digital technologies, including “AI, data management, and website platforms” whilst simultaneously investing in the physical stores.

4.3.2 The importance of the customer perspective

Throughout the literature, the effects of consumer behavior and expectations are indicated. For example, the success of PSS offerings in achieving circularity requires that consumers handle the products with care and follow the instructions for how to handle the products when they are finished with them. These issues are also indicated by Devianne, as Mr. Roche discusses the potential ways to shape an incentive system for customers. In their case, they are working to develop a gamification aspect to their app as a way to encourage users to interact with it.

The effects of consumer behavior can also be connected to Devianne's efforts to improve the attractiveness of the secondhand market as a way to encourage customers to purchase more reused clothes. Furthermore, the ways that consumer behavior may determine the success of new BMs is likely one of the reasons as to why the investigated companies have made significant investments in technology to improve the communication between them and their customers. Improved communication will hopefully allow companies to understand how to align their BM with consumer needs and behavior. At the same time, improved interaction with consumers may enable companies to encourage consumers to be more sustainable.

These circumstances are described in the literature, wherein Koszewska (2018) mentions that one of the three challenges facing the clothing industry is the strong dependence on stakeholders' understanding, commitment and adherence to the firm's objectives. The challenge also relates to the notion that companies are affected by external factors, which are mostly uncontrollable from the perspective of the focal firm (Saha, Dey & Papagiannaki, 2020). The circumstances may also be complicated by the fact that consumers are often irrational, as they may act in ways that are contradictory to their beliefs. An example of this may be that consumers who perceive themselves as environmentally conscious still consume fast fashion products. This can also be connected to what SW mentions about encouraging customers to become more mindful of their workwear, in order to make them last as long as possible. Realizing the Rs principles, thereby working towards the CE, will ultimately involve efforts from both the demand-side and the supply-side. This is also logical as a major part of the product life-cycle involves the ways in which it is used by consumers and can be moved around between consumers to prolong its useful life.

The importance of consumers following the new BM, enabled by I4.0, will likely require that they are willing and capable of using products which are connected to the virtual realm. A specific example involves the fact that, in order for companies to benefit from the IoT technologies as described in the content analysis, users must be willing to share their data gathered from the simulators. One of the main benefits of IoT, monitoring use, may pose some ethical issues regarding the question of whether or not it is acceptable for companies to monitor the specific activities of users. The ethical dilemmas may lead to legislation in the future, hindering companies from having unrestricted access to the information gathered by the sensors. Furthermore, questions of data security and cybersecurity will likely become even more relevant than they are today.

4.3.3 The differences within the clothing industry

The analysis of various clothing companies made the differences within the industry very prominent. The differences will ultimately affect the success of the implementation of CBMs and I4.0 technologies in individual companies. For example, differences between the capabilities and resources of the clothing companies will likely imply that they will vary in regards to the extent to which they will be able to handle problems associated with the implementation of I4.0 technologies, such as those mentioned by Demestichas and Daskalakis (2020). In the I4.0, where manufacturing relies heavily on CPS, companies will presumably be more sensitive to data breaches and cybersecurity issues. Different companies may have different capabilities to handle such breaches and the risks should be taken into account when developing the CBM. Another relevant issue may be the financial costs associated with implementing the technologies (Demestichas & Daskalakis, 2020). This may be one of the reasons as to why H&M is apparently further ahead than smaller companies in the clothing industry in implementing the I4.0 technologies. On the other hand, smaller companies may be more flexible in redesigning their BMs and operations, an issue mentioned by SW.

The investigation also revealed that some companies may be more limited than others in pursuing CBMs. SW, for example, provides workwear which, by the end of their use, are very likely to be either covered in unknown chemicals or extremely worn out, if they are not thrown away by the customer before that. This implies that the solutions, as proposed by the Rs principles, may not be as accessible to SW as they are to companies which supply regular fashion goods. On the other hand, SW also mentioned that the nature of their business allows them to streamline their production chain to a very high degree. This may not be possible for regular clothing companies who face the pressure of having to adapt more often to local consumer preferences and changing trends. Nevertheless, in both cases, there is a significant potential enabled through I4.0 implementation.

4.3.4 Unrealized potential of I4.0 technologies in achieving CBMs

As I4.0 is still being developed and is shaped by new technologies and innovative ways of using them, failing to elaborate on the inherent potential of the technologies, would be omitting an entire dynamic of the study. Currently, clothing companies are implementing I4.0 technologies to limited and various extents in parallel to their efforts towards achieving circularity within their businesses. However, the connection between the two fields often seems to be missed. The literature reveals the enormous potential of creating an ecosystem of technologies and smart objects in order to enable the CE through design, optimization and supporting the decision making and predictions (EMF, 2019; Jabbour et al, 2018; Mboli, Thakker & Mishra, 2020; Rosa et al, 2020). Furthermore, advanced technologies may also be used to aid the research and development of new textile materials. There is a significant amount of research supporting the profitability of such investments (Mavropoulos & Nilsen, 2020). However, there are also clear challenges of implementation, mainly associated with a lack of technological competence, financial means and, perhaps, also difficulties in implementing the technologies in already established organizations. Furthermore, the increasing competition from online-based companies selling clothing at incredibly low prices means that established companies may be focusing on remaining competitive rather than redesigning their BMs.

Perhaps, there is a need for international cooperation between governments, trade organizations and businesses in order to create a new industry standard promoting the use of technology for achieving CBMs. An example could be a large-scale implementation of IoT technology and product passports, such as CircularID, which would drastically simplify the end-of-life processes regardless of which company, person or organization the product ends up with. International agreements and regulations could also pressure companies and consumers to abandon linear economic models in favor of the CE. As the problems associated with sustainable development are urgent, the opportunities associated with these types of measures are significant. The apparent need may also be filled by tech companies such as Google and Microsoft as well as innovative start-ups focusing on sustainability such as Rent the Runway, Azolla, and ThredUp.

5 Conclusion

5.1 Research Aims & Objectives

The aim of this research was to investigate how I4.0 technologies can be used to achieve and advance CBMs. To investigate this, the clothing industry was explored to reveal how and which technologies they were using and in what way these were involved in circularity-related processes. Thus, our research question was formulated as follows:

How can clothing companies integrate I4.0 (technologies) into their value creation chain to achieve a circular business model?

In order to answer the research question, a combined data collection method was used which included an ECA and two semi-structured interviews. The extensive planning and continuous refinement throughout the entire research process, allowed us to gather a multitude of data that was relevant for answering our research question. This data collection was based on the extensive theoretical background which allowed us to identify the optimal way to undertake these topics. Our integrative and thematic approach to analysing our findings, allowed us to make connections between all the collected data, and thus develop an overall understanding of the clothing industry's utilization of I4.0 technologies in regards to their CBMs.

We were able to interpret the data and identify patterns within and between the observations, which helped us to answer our research question. Thus, as explained in the previous chapter, the aim of this study was achieved as we were able to uncover how I4.0 technologies are currently being used within the clothing sector to help companies achieve CBMs. In summary, the findings suggest that I4.0 can be used to develop CBMs and that many companies are beginning to utilize the technologies for these purposes. However, the connection between I4.0 and the CE is not yet widespread in the industry. Technologies associated with I4.0 have mostly been implemented to stimulate economic growth in the companies through improved product offerings and services. Nevertheless, there are important investments being made and it is apparent that most of the investigated companies recognize the potential uses for the technologies.

The theoretical gap that was identified prior to beginning our studies was also partially filled through this investigation. Although previous literature existed that suggests the idea of using I4.0 for CBMs, there was limited literature explaining how this was used in practice, and how particular industries were employing this. There was no **evident** literature that outlined how clothing companies are currently interacting with these theories, and none (that the authors of this paper are aware of) were based on various case-studies as with this study. Our research, which was based on a multitude of clothing companies, has contributed to the theoretical gap by providing an overall understanding of how I4.0 technologies are used within the industry as a whole, to become more circular.

5.2 Practical Implications

There are various practical implications of these findings regarding how the theorized relationship between I4.0 and CBMs is taking shape in the clothing industry. The findings have shown that multiple companies are currently using I4.0 technologies in ways to aid in their circularity efforts, and that most recognize the potential of these smart technologies in the future of their business. The findings have, however, also revealed that this is a very new concept which is continuously developing, and that there are extensive gaps in both research and awareness of how to implement I4.0 in an effective way to improve CBMs. This research can help raise awareness of the potential of implementing I4.0 technologies, and also demonstrate specific ways that these technologies can be used for circularity. This will be useful to managers, executives and investors of clothing companies, but may also be useful to stakeholders of other sectors. Not only will this help managers to understand these concepts but it may also encourage other companies to implement I4.0 technologies to improve their circularity. This study may also be useful for researchers within the fields of international business, sustainability, and information systems. At the minimum, this study will bring attention to both CBMs and I4.0, and in broader terms, the importance of using technology to advance sustainable development.

5.3 Limitations and Future Research

Although this study managed to answer the research question through research from numerous companies while also attempting to provide a full representation of each company, the findings involve several limitations. As the choice of companies was based on the availability of relevant information, only companies that utilized I4.0 for their circularity in some way, were included. This may have resulted in skewed findings. For instance, when collecting data, we realized that it was predominantly large international companies that employed I4.0 technologies, perhaps because only they had the resources to invest in them. This means that smaller companies may have been completely disregarded and unaccounted for even though they could have revealed important insights into our research. Moreover, there are also various segments within the clothing industry. As our ECA primarily involves fashion companies, the findings may be misrepresented. Fashion companies may operate differently compared to other segments, as was revealed in the interview with SW whereby it became clear that the workwear segment involves additional considerations that affect their circularity, but which may be considered irrelevant for fashion companies. Future research may therefore need to be more focused in order to specifically target certain groups, or to broaden the scale of the study to include companies from all segments of the industry. Moreover, our analysis of the clothing industry may not be representative of other industries and how they are interacting with I4.0 for the CE. Thus, there is also room for further research in all fields and industries.

As I4.0 is continuously developing, there is a large potential for exploration within the field, including investigating particular technologies as an alternative approach. Here another limitation is involved, regarding the classification of I4.0 which is still evolving and involves various different technologies. As this is a rather diffuse topic, there is room for different interpretations, meaning that our findings may be skewed depending on how we chose to classify them. However, these constraints were outlined in the delimitations prior to the study. As these technologies are interconnected, it can be challenging to categorize them individually, meaning that findings may be imprecise as various of them may work together or be classified as more than one single technology. Therefore, further research should be conducted on the interconnectedness of these technologies and how these can work together in order to improve circularity within companies. Another approach would be to investigate each of the technologies separately to see how they contribute to the CE.

As highlighted in the discussion, there is also significant potential for international collaboration in order to advance the efforts towards achieving a CE through I4.0. This will require extensive research in order to persuade governments, businesses and society to take advantage of the opportunities associated with I4.0, while also avoiding the potential downsides of unplanned and incorrect implementation of the technologies, leading to an acceleration of the negative environmental impacts of the linear economy.

5.4 Conclusion

It is evident that I4.0 will have significant implications for companies and the ways in which they create value. Manufacturing will likely change radically within the near future to become autonomous and machines will be capable of making their own decisions and predictions. This will lead to optimization gains and, hopefully, be a valuable component to the large-scale transition into a CE. This revolution will not be without challenges. Established companies will need to adapt to changing circumstances and utilize the technologies. In parallel, consumers will need to change their expectations and behavior to embrace a CE. It will be interesting to see how these developments are made and whether or not companies will be able to change their business models to become more sustainable.

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Appendix A – Results from ECA

COMPANY	**USE CASES**
H&M Group (H&M, COS, Weekday, Arket, Afound, Monki, & Other Stories)	H&M Group recognize the need to "[e]xplore technological solutions to improve data quality and traceability" (H&M Group 2019, p.22) "In an effort to better stock individual stores with merchandise local clientele desires, H&M Group is using big data and Artificial Intelligence (AI) to analyze returns, receipts and loyalty card data to tailor the merchandise for each store. This is known as localization and can be trickier to execute for a global chain such as H&M Group that typically can leverage economies of scale with its global network of suppliers." (Marr, 2018) "To further secure an organization that drives innovation and optimizes business decisions which enable sustainable choices, H&M group is working with advanced analytics and artificial intelligence. Our new AI department supports various processes across our entire value chain – from design to customer experience. For example, by amplifying the decision making of our designers and buyers we can ensure that we are designing the right products. We also use advanced analytics and AI to better forecast trends, make sure the right products are in the right stores, and to give our customers even more relevant and customized recommendations and offers. Used right, AI is one of the most powerful tools we have to secure that we meet our future in a sustainable way through the lens of a circular economy." (H&M Group 2018, p. 23) In discussing the future role of AI in achieving a circular business, Zeighami highlights that: " I think it is one of the most powerful tools we have in the transition towards a circular and sustainable fashion system. With AI we can make sharper and better decisions that impact our world in a sustainable way." (cited in H&M Group 2018, p.23) In using AI, the AI department head explained that "We're actually working very specifically on being able to, for instance, calculate and quantify how many cases you're going to buy [of any item]," (Zeighami cited in Cosgrove, 2020). "Ensuring unsold products never become waste is a priority for us — we want the resources that go into producing a product to be valued, used and reused . We increasingly apply predictive artificial intelligence tools to match production to demand." (H&M Group 2020, p.49) "artificial intelligence and predictive technology have a big role to play in making all supply chains, in fashion and beyond, more sustainable," (H&M, 2019) "We need to make clever decisions that make a more sustainable impact on the world, driving the shift towards a circular fashion system. Circularity is ultimately about using resources sustainably, one central aspect of this is to produce only what we can sell. This, in turn, limits the need for transport and warehousing, which means less energy is used" (H&M, 2019)

	AI to demand planning at H&M is relatively new, and Zeighami emphasized it's important to the retailer that doing so doesn't throw out 70 years of fashion experience. Instead of artificial intelligence, he said he prefers to think of the concept as "amplified intelligence" since it heightens and refines what the business already knows. - With precisely honed demand forecasts, supply chains can use only the resources they need and no more. Without precise demand planning, the result is waste RFID technology integrated into each garment is used to provide in-store consumers with personalized recommendations generated by algorithms (Marr, 2018). "To maximize product life, we work to ensure quality and durability for everything we make, guided by the purpose of the product and always to maximise product life. Our global quality department works to improve product quality for the H&M Group, and we are updating our group wide quality and durability standards to connect them to our circular design strategy" (H&M Group 2019, p.38) COS partnered with market-leading platform Ycloset in China, offering subscriptions to rent clothes rather than buying new (H&M Group 2019, p50) **"Recycling** gives used fabrics a new life as resources rather than being destroyed or landfilled. Recycled fibres reduce consumption of virgin raw materials, and lower the use of chemicals, energy and water. We use many recycled materials including cotton, polyester, wool, nylon, plastic, down and feathers, cashmere, and silver. We are always trying to maximise the recycled content of our collections, and to invest in new technologies to accelerate progress" (H&M Group 2019, p40) "We are continuing to develop our circular design strategy. During the past few years we have been utilizing the latest technologies in 3D visualization of fabrics and products, which has lead to a reduction in sample rounds and use of resources" (H&M Group 2018, p.36) "Our designers use artificial intelligence, data analysis programmes, and 3D visualisation to reduce production waste — saving materials, time and energy throughout the design process. Our virtual showrooms enable us to assess samples remotely, shortening lead times and avoiding unnecessary transportation of goods." (H&M Group 2019, p.38) "Our circular packaging strategy — developed in collaboration with the Ellen MacArthur Foundation — guides our approach and goals in four areas: packaging reduction, circular design, material choice, and reuse and recycling. Our packaging-specific restricted substances list (RSL) for suppliers restricts the use of potentially harmful chemicals in packing materials." (H&M Group 2019, p46) "Automated warehouses fueled by RFID technology to improve efficiencies in its supply chain" (Marr, 2018)

	“The warehouses and loyalty programs are fueled by algorithms and data, and the company is rolling out RFID tech to its stores to improve efficiencies in its supply chain.” (Marr, 2018) “Accelerating our agenda to become a circular business is one of our key focuses. We don’t have all the answers ourselves, but by teaming up with – and investing in – pioneering companies that develop ground-breaking technologies, such as Re:newcell or Infinited Fiber Company, we can scale innovations and reinvent fashion together” (H&M Group 2019, p.4) “Circular design is not only about optimising resource use — it includes maximising value for our customers. These will be our two constant aims as we finalise our circular design principles and supporting guidelines. Each H&M Group brand will tailor the principles in the context of their own unique design process”. (H&M Group 2019, p.38) Moral Fiber - “Moral Fiber was among the first winners of the Global Change Award in 2016. The American innovation company focuses on chemical recycling of polyester fabrics. Our investment in Moral Fiber helps us speed up the acceleration of recycling technologies available at scale”. (H&M group 2018, p.24) “Because investing in innovation unlocks circularity, we support companies such as Moral Fiber and Colorifix”. (H&M group 2018, p.7) “Our Circular Innovation Lab ran a pilot project with Infinited Fiber Company, which led to a subsequent CO:LAB investment and to a first proof of concept of a sustainable cellulosic fibre made from recycled cotton textiles”. (H&M Group 2019, p.40) ○ new processes such as sorting and recycling technologies and facilities have to be viable at scale for us to reach our ambition of full circularity ● Scalable recycling processes and commercially viable new materials can be challenging to find. We look for innovative new materials and processes to integrate into our value chain, including through: (H&M Group 2019, p.39) ○ Engaging with the H&M Foundation’s recycling programme with the Hong Kong Research Institute of Textiles and Apparel (HKRITA) and European Union project DEMETO to accelerate improvements in recycling technology
Macy’s	Adopted SGS Transparency-One into their Private Brands section with the aim to improve the traceability of products throughout their supply chain. This is an online information system facilitating the “direct exchange of technical information and data” between Macy’s and their suppliers (Macy’s 2018, p.11). SGS Transparency-One maps the supply chain using real-time generated data coupled with cloud-based technology (SGS, 2021). “We also use auto-boxer and auto-bagger machines that can build a package that perfectly fits odd or oversized items. This fit-to-size auto-boxing technology reduces box volume up to 50% by creating the smallest parcel needed at the lowest expense, which also helps reduce shipping costs.” (Macy’s 2018, p.21) “Over the past five years, we have shifted our marketing strategies to focus more on

	digital marketing and less on traditional print mailers. Since 2013, we have reduced our annual paper tonnage by 60%." (Macy's 2018, p. 21)
Inditex (Zara, Pull&Bear, Massimo Dutti, Bershka, Stradivarius, Oysho, & Uterqüe)	In combination with Internet of Things technology in the distribution centers and Radio Frequency Identification Technology (RFID) technology in stores, the garments and stock are tracked in real-time allowing for increased control and integration between suppliers and "optimal movement between the components of the system" (Inditex 2019, p.193). This technology is implemented in all of Inditex's stores. Inditex (2019, p.190) states that: "We work continuously on the digitalisation and automation of the records and the documentation of our operations. From realtime data collection when managing our supply chain, to the development of systems that allow the digitalisation of the administrative processes of receipt and payment of invoices or customs documentation. [...] Obtaining early high-quality information is key to improving decision-making efficiency. For this reason, we are working on an innovative governance system that allows its implementation within the data life cycle. [...] Having available quality data and information, obtained in real time, enables the development of innovative applications to support decision-making and to prepare simulation models and predictive tools applicable across the value chain of the company. Both for predicting demand and for the development and organisation of our logistics and transport system, and to guarantee excellence in our products and ensure the traceability of the supply chain. These types of tools allow us to anticipate risks, enhance the sustainability and efficiency of all our processes with the ultimate goal of improving our customers' shopping experience." "We perform active listening on the messages arising from item searches both in stores and in the online channel. Then we process them using innovative analytical systems that allow us to create product coordination proposals to satisfy our customers' needs, facilitating their decision-making." (Inditex 2019, p.196). Most of all, through its analysis of 3 million images each day on social media, **Heuritech** offers a powerful market intelligence tool capable of identifying the best influencer styles and forecasting the latest upcoming trends (Heuritech, 2020) "In collaboration with the Massachusetts Institute of Technology (MIT), we have developed an analytical search engine for comparable products based on artificial intelligence that allows us to make an extremely accurate estimate of the behaviour of the demand for new products." (Inditex 2019, p.195). "Our logistics model requires accurate estimates of the transport needed, taking into account the characteristics of the products to be transported, as well as their packaging. By using technology, we can make accurate estimates of the required volume based on the mix of products that have to be transported. This ability to predict transport volumes enables better planning and optimises the load of the modes of transport." (Inditex 2019, p.195). Inditex explains that this will lead to "long-term improvement in product availability", "optimisation of transport flows", and "reduction in the carbon footprint of transport operations" (2019, p.195).

	“Within the framework of Picking, Inditex is collaborating with specialised researchers in the textile industry on the development of prediction tools for manufacturing technologies with a greater risk of generating nonconformities.” (Inditex 2019, p.158) The Inditex Open Platform (IOP) is used to run all their digital operations. “It is designed to be immediately adaptable for all types of operation, with a precision and quality that allows us to develop unique solutions for stores and online” (Inditex 2019, p.192) “Finally, the unified processing of the stock has also transferred some highly demanding capacity, speed, efficiency and scalability requirements to the logistics infrastructures of the distribution centres. For this, some significant innovations have been introduced in the different areas of the centres, such as the multi-shuttle and hyperloop systems, dynamic buffers, automated inductions, air palletising system and automatic guided vehicles (AGVs), among others. Control of these logistics infrastructures has required a change of paradigm in control systems governed by warehouse management systems (WMS), to have a unified vision and control of stock by location. It has also allowed us to prepare deliveries in an orderly, dynamic and consistent way to the various destinations where stock is to be located.” (Inditex 2019, p.193). Inditex is working with MIT to “advance in textile recycling processes and technologies that help us to meet our circular economy strategic goal” (Inditex 2019, p.177). The collaboration aims to “conduct research into the circular economy, textile recycling and data analysis” (Inditex 2019, p.34). “In order to advance in the compliance of the goals set, during 2019 we have continued to promote innovation in the development of new materials and technologies to improve the sustainability of the textile fibres used. The new lines of research consider improvements focusing both in the optimisation of the consumption of virgin materials and their subsequent recycling.” (Inditex 2019, p.85) “To close the cycle of garments that cannot be reused or the fabric cutting waste, we work with various business organisations and universities to promote the innovation and development of new more sustainable materials and technologies to help recycle textile waste.” (Inditex 2019, p.176) “To carry out all our innovation activity, we incorporate the most innovative and efficient work methodologies, combining creativity, talent, technology and an in-depth knowledge of the sector. We also collaborate with organisations, research institutions, suppliers, NGOs and other players to ensure that all our new innovative initiatives become transformational elements for us and for the industry” (Inditex 2019, p.189) “We have innovated with the establishment of our Closing the Loop programme for the collection of garments and we collaborate with prestigious entities, such as the Massachusetts Institute of Technology (MIT) and Cáritas, among others, to move forward in physical and chemical textile recycling processes and technologies that make it possible to develop a new life for our products once they are no longer useful for our customers.” (Inditex 2019, p.205).

Eileen Fisher	Uses the software "Fishbowl" to track and plan damaged inventory (Eileen Fisher 2019, p.13). The company is also using Bluesign's solutions for chemical traceability (Eileen Fisher 2019, p.7). Bluesign's solutions are based on cloud-computing and allows for "continuous traceability of products, an online risk warning if there are changes, as well as recommendations for additional risk minimization". Furthermore, the solutions allow for a "networked supplier chain" which entails that "products are manufactured with high efficiency and maximal benefit to the consumer and environment" (Bluesign, n.d.). Has developed a digital showroom called "NuOrder" which has resulted in reduced carbon emissions and expenses from customers & partners travelling to showrooms (Eileen Fisher 2019, p.19).
Norrøna	Uses Centric Software for product lifecycle management. The software can be used for "product development, sourcing, business planning, quality management and collection management" (CentricSoftware, 2014). Norrøna built a Google Cloud ML platform to improve e-commerce and communication with customers through the collection of data and ML predictions. "The majority of Norrøna's data assets are stored in Google BigQuery (yet in another [Google Cloud Platform] project). This data supports not only our ML work but also enables a number of business intelligence solutions." (Mikkonen & Gariel, 2019) "In 2029 Norrøna will be 100 years. By then (we think), machine learning (ML) will be a fundamental part of our company, contributing to better customer experiences and higher quality products." (Mikkonen & Gariel, 2019) "The immediate, short-term, ML use cases have been strongly e-commerce and customer communication related. We foresee that future use cases can be found in areas like product development, sustainability, demand prediction and logistics. The diversity of future use cases is now only up to our imagination." (Mikkonen & Gariel, 2019)
Chanel	Chanel has developed a **"Cycleapp"** with the aim to improve the reuse- and recycling process within "point-of-sale sales & promotional materials (SPM)"**.** They explain that "[t]he principle of the app is to make it easier for beauty and cosmetics retailers to arrange for the removal of old SPM displays at the end of campaigns at the point of sale. When a campaign ends, the salesperson simply posts his or her SPM on the application as ready for removal and recycling, whereupon it is then collected and sent to a designated recycling center. This ensures that more SPM material enters the correct recycling channel and remains fully monitored by the company. [...W]ith collaboration between CHANEL, Marionnaud, Le Printemps, Les Galeries Lafayette, La Poste, New Attitude, and Paprec, we believe this app could be a model for the whole beauty and cosmetics retail industry in France by 2020. This project shows our commitment to the circular economy, ensuring we can reuse old SPM materials to create new displays." (Chanel 2018, p.47)

Fast Retailing (UNIQLO, GU, PLST, Theory, Theory Luxe, Helmut Lang, Comptoir des Cotonniers, Princesse tam.tam, J Brand)	Using predictive technology in order to integrate store and e-commerce operations & optimize supply according to customer search history, etc. (Fast Retailing, 2019).
Adidas	"Motivated by the ambition to better understand stakeholders' expectations about supply chain transparency and find solutions using digital technologies, we support start-ups with our expertise so they can develop ideas and test their potential for scalability. In 2019 alone, we held three events supporting more than 30 ventures." (Adidas 2019, p.79). "We continue to invest in our analytical capabilities and technical infrastructure to become faster and more insight-driven in decision-making. Leveraging data such as cross-channel product sell-through and consumer purchasing behaviors delivers actionable insights in areas such as assortment planning and product life cycle management." (Adidas 2019, p.62) "We continuously expand our consumer analytics efforts to read and quickly react to changes in demand or trend shifts. In addition, direct touchpoints with consumers via our own digital channels and direct communication with consumers on social media platforms strengthen our understanding of consumer preferences and behavior and, as a result, help us to reduce our vulnerability to changes in demand. Through continuous monitoring of sell-through data and disciplined product lifecycle management, in particular for our major product franchises, we are able to better detect demand patterns and prevent overexposure." (Adidas 2019, p.126). "Data and analytics play a crucial role in enabling fact-based decision-making. Therefore, we have a dedicated Data & Analytics team to drive business decision-making by leveraging the power of data. The continuous enhancement of our existing capabilities to build and scale insights-driven use cases and the use of the latest technology could bring value to our business operations across the entire company. As a result, we see the opportunity to become faster and more efficient in our operations. We may increase visibility and understanding of consumer preferences, increase full-price sales, reduce discounts and optimize order book management, inventory management and purchasing. This could result in improved financial performance." (Adidas 2019, p.129) "The adidas brand was amongst the first in the industry to comprehensively bring data analytics to the athlete. With decades of continuous investment in sports science, sensor technology and digital communication platforms, adidas has already taken a leading role in terms of changing the sporting goods industry through technology. With the increasing speed of digitalization, this field will remain one of our core areas." (Adidas 2019, p.67–68) Adidas have a "digitally enabled membership program" called Creators Club in which loyal customers are provided with exclusive benefits. The company notes that "[t]he program allows us to deepen the relationship with our consumers and to gain valuable

	insights into their expectations and needs." (Adidas 2019, p.68) "The high-performance footwear produced under the adidas 4D concept features midsoles crafted with light and oxygen using Digital Light Synthesis, a unique technology developed by Carbon. The midsole pioneers a digital footwear component creation process that eliminates the necessity of traditional prototyping or molding." (Adidas 2019, p.68). "To simplify manufacturing, enable product innovation and increase speed-to-market capabilities, the company's innovation activities are also focused on new manufacturing technologies. Our goal is to combine state-of-the-art information technology with new manufacturing processes and innovative products. For this reason, we commit ourselves to long-term cooperation with innovative companies and organizations to take a leading role in manufacturing innovation." (Adidas 2019, p.67) "digitize entire value chain → they remain highly committed to maintaining a full and innovative concept pipeline, bringing new groundbreaking technologies and processes to life, investing into sustainable enablers and exploring the possibilities of digitalization across our entire value chain" (Adidas, 2020)
NIKE	Have acquired the AI-based company Celect in order to use their analytics technology to "optimize inventory across an omnichannel environment through hyper-local demand predicitons" (Nike News 2019; Thomas, 2019). Nike uses a software called "CleanChain" to improve chemical inventory management (including the traceability of chemicals) (Nike 2020, p.58) Nike has become a founding member of the "Transform to Net Zero" initiative in which leading companies of different industries are collaborating to limit global warming (Nike, 2020). This is a collaboration with Microsoft who has also introduced the cloud-based "Microsoft Sustainability Calculator" to advance these efforts (Microsoft, n.d.; Block, 2020).
Asos	"Our investments in tech allow our customers to shop in an intuitive and increasingly personalised way. We have made significant improvements to our recommendations algorithms, including the launch of a Style Profile Builder, Back in Stock and delivery status push notifications, and improved product recommendations with Fit Assistant. Our Responsible Edit and responsible filters help our customers make more informed, sustainable shopping decisions, an area we know is of increasing importance." (Asos 2019, p.17). "In addition to continuing to invest in driving acquisition of new customers we also need to maximise the loyalty and lifetime value of existing customers. We are using technology and data to optimise how we do both of these. This will involve the use of machine learning and data science to be more targeted in how we acquire and engage our customers." (Asos 2019, p.37). "3D printing technology has helped to reduce footwear lead times by up to eight weeks" (Asos 2019, p.19)

	“Key investments in efficiency this year included embedding new returns processing software and the recent development of a paperless returns process which uses a mobile QR code rather than a customer returns label, which we are now starting to pilot in the UK and will enable us to move to 100% paperless for our customers” (Asos 2019, p.7)
Under Armour	UA has entered into a strategic partnership with IBM in order to utilize the IBM Watson cognitive computing technology for the purpose of creating a health and fitness tracking app for customers (IBM, 2016; Pearson, 2017). “Our new thread texturing techniques and polymer developments eliminated the need for elastane: those products perform better, last even longer—and can be completely recyclable. This innovation is revolutionary not just for us—it’s a future game-changer for the entire athletic apparel industry at a scale we haven’t seen elsewhere. We continue to challenge ourselves to engineer more materials that are 100% recyclable”(Under Armour Inc., 2021) UA utilizes 3D printing and the cloud computing software “Autodesk Within” in their footwear production. Tara (2016) explains that “After inputting various parameters—such as durability, flexibility or weight requirements—the software will then generate internal lattice structures and surface skins with varying densities to meet these design objectives”. This allows for design optimization and minimization of material waste (Tara, 2016). “[...W]e use virtual design and virtual prototypes to eliminate pre-production waste during the development process, lessening the introduction to the environment of garments and samples never intended for sale.” (Under Armour 2018, p.28) “If Under Armour can be more efficient, we can be more effective – and more sustainable. That’s why we built the Under Armour Lighthouse, a 35,000 sq. ft., state-of the-art advanced manufacturing and product innovation center for footwear and apparel. The technology we bring to the Lighthouse is nothing short of the absolute pinnacle. Among its array of capabilities are 3D design, rapid prototyping, and 3D printing. Our Lighthouse athlete body virtualization now gives Under Armour a unique 360° perspective: it allows us to see things we’ve never seen before and to build our products to address more needs.” (Under Armour 2018, p.30).
VFC (Altra, Bulwark, Dickies, eaglecreek, Eastpak, Horace Small, Icebreaker, Jansport, kipling, Kodiak, Napapijri, Red Kap, Smartwool, Supreme, The North Face, Timberland, Vans, Walls) The North Face	“Underpinning our strategy is the transformation of our business model to make VF more consumer-minded, retail-centric and hyper-digital in everything we do. This work has entailed building better enterprise- level systems, capabilities and digital tools to enable our brands’ success. It’s also about focusing on enterprise data, analytics and insights to better understand and engage our consumers. This will take on a new level of importance as digital commerce becomes more prevalent coming out of the pandemic.” (VFC 2020, p.8). **Specifically about The North Face:** “Watson's artificially intelligent language processing to replicate the personalized

	experience of talking with an expert to provide quick, accurate, and contextually relevant product and content recommendations”. (IBM, 2015) “The North Face, the world's premier supplier of authentic, innovative and technically advanced outdoor apparel, equipment and footwear, announced today the launch of a new interactive online shopping experience powered by IBM’s Watson (NYSE: IBM). In keeping with The North Face brand’s mission of applying technology to transform the retail experience, customers can now use natural conversation as they shop online via an intuitive, dialog-based recommendation engine powered by Fluid XPS and receive outerwear recommendations that are tailored to their needs.” (IBM, 2015) “Developed in partnership with digital commerce technology agency and software solutions provider Fluid and powered by IBM's Watson cognitive computing technology, The North Face experience harnesses Fluid's Expert Personal Shopper (XPS) software to create a more engaging, personalized and relevant shopping experience” (IBM, 2015)
Gap inc.	“In 2019, we embarked on a new partnership with the Hong Kong Research Institute of Textiles and Apparel (HKRITA) to address the technology challenge of recycling certain materials. Our shared mission is to develop more sustainable production processes and technology solutions that enable the industry to advance circular models across the life cycle of textiles. We have identified two initial priorities: separating spandex from used garments and decolorizing denim for recycling” (Gap Inc. 2019, p.64)
Levi’s	“[...W]e are using AI to enable personalized benefits in our newly launched loyalty program, further cultivating loyal fans.” (Bergh, cited in du Preez, 2020) “[...T]he company has rebalanced its IT portfolio and is cutting discretionary and non-urgent projects, instead focusing on its "digital transformation to drive a better consumer and employee experience" (Bergh, cited in du Preez, 2020). In collaboration with Mode.ai, Levi’s has launched an AI-powered chatbot on Facebook Messenger and their website tasked with assisting customers in finding the correct size and style of jeans (Gosselin, 2019). Gosselin (2019) notes that “[t]hese examples might not be directly enabling sustainability but by helping customers make better buying decisions, such consumer-facing tech results in lesser returns and in turn reduces the carbon footprint”.
Capri Holdings (Michael Kors, Versace, Jimmy Choo)	“[...O]ur IT teams are actively investing in opportunities to move to cloud-based solutions, which will decrease the greenhouse gas emissions associated with our data center operations” (Capri Holdings 2020, p.11)
Burberry	“A creative approach has also been adopted by our Merchandising Computer Aided Design (CAD) team who have designed 3D runway and ready-to-wear samples, known as "Digital Product Twins," to help reduce reliance upon physical sampling” (Burberry 2019, p.68)

PVH,Inditex, H&M Group, Puma	Using ML and AI to make predictions in order to balance supply and demand, reduce excess stock, and optimize production processes (Lee 2020; Inditex, 2019; H&M Group, 2019).
PVH (Calvin Klein, TOMMY HILFIGER, Van Heusen, IZOD, ARROW, Warner's, Olga by Warner's, Geoffrey Beene, and True&Co) & H&M Group	PVH and H&M Group (among others) are collaborating with Microsoft, the EON Group and other organizations in using "Circular ID" with the aim to promote circularity within the fashion industry through the establishment of an industry standard for communicating information about products (McDowell, 2019; PVH, 2019; EON 2020). CircularID gives each garment a "unique digital identity" so that it, together with data on the material, "brand, price, dye process and recycling instructions" can be tracked throughout its lifecycle (McDowell, 2019).
Asos, Zara, Boohoo	Reduce "size sampling and returns" through the AI/ML-powered solution Fit Analytics (Roshitsh, 2019).

Appendix B - Snickers Workwear Interview

Snickers Workwear (SW) is a large clothing company established in Sweden in 1975 that specializes in workwear attire. SW became part of the parent company Hultafors Group Sverige in 2007. An interview was held with Snickers Workwear CSR-coordinator, Maria Schartau, who began by introducing SW. She explains that they produce approximately *"4 million garments every year with a turnover of 1.3 billion SEK."* Although their operations must align with the guidelines set out by their parent company, they are allowed to have their own, additional plans/processes to improve their sustainability efforts. Following this, questions were asked regarding their sustainability efforts, the Circular Economy, and to investigate whether they are utilizing technologies associated with Industry 4.0 in order to achieve these goals.

Ms. Schartau begins by explaining the importance of sustainability at SW, stating that it is *"essential to stay in business"* and that a *"massive change"* has taken place in her last three years working at SW. She claims that *"four years ago hardly no one spoke about sustainability in workwear whereas you all know the journey that sportswear and fashion has done in the last 10 years, and workwear will undergo the same journey but only in 5 years."* She continues to explain the challenge with *"the immense scale of their operations is however [which is] part of the problem because the bigger the organization the longer time it takes to actually reorganize" in order to align with more sustainable practices. It is difficult to change a huge operation when "you have your processes already set, semi carved in stone in some ways."*

Ms. Schartau continues by highlighting the importance of *"customer pull in regards to sustainability and [that] it might become mandatory for procurement in the future in Europe to actually communicate your product's footprint. In that sense workwear has higher* *demands than [typical clothing companies] that sell themselves to an individual normal end user where we're selling to [entire] companies that may require this coming type of communication power. "* Additionally, Ms. Schartau stresses that *" we have to work with sustainability to stay relevant."* She explains that they for instance have part of their production set up in Bangladesh, which will be severely affected by climate change meaning it will also disturb their production.

Ms. Schartau describes SW's main values and their priority of "*get[ting] the garments to last as long as possible because if you manage that you significantly reduce the CO2 footprint from that product, so it is the best thing you could do."* Furthermore, *"selling the correct product to the correct user will enable the garment to live longer and also to get to the point where the customer actually cares for the garments in a better way"* she explains is essential. Ms. Schartau explains that workwear customers are at times relatively careless with their garments as it does not *"cost [the user] anything as an employee if the employer is paying for your work clothes."* Getting the employee to "actually care for the garments better [and for instance] wash them a little bit more often, would make them last longer, meaning we would have a lower climate footprint and the employer would have a better financial situation because they would not have to pay for so many garments."

Ms. Schartau explains SW's economic logic behind their thinking, being that a *"great garment that lasts a long time means it will attract customers to our brand and thus expand our presence on the market. So we want to grow organically, not just buy selling massive amounts of clothing to the same customers but instead the overall plan for us is to broaden our market share."*

Ms. Schartau explains the *"apparent challenge with workwear "* and the circular economy, and in particular with regards to recycling. She says that "*if we are talking about simple workwear garments, for instance the average floor layer or Carpenter, and look at the clothes at the end of the day and at the end of their life cycle, they are completely worn out and we also don't even know what is in/on all those garments in terms of chemicals."* Ms. Schartau explains that although they *"know what is there at the start when we deliver the garment, wearers work with glue, paint, and many other materials that contain chemicals which is an issue if we were to recycle that textile." She explains that recycling may never be a viable option for workwear, "instead there is a possibility of downcycling but it would most likely need to be for products that are not sensitive to chemical content [as they] can never promise [that it does not contain chemicals, however] you can use it as stuffing, insulation and stuff like that but not for garments."*

Ms. Schartau recognizes the potential for repair of workwear garments and stresses the importance to *"move the mentality to kinda touch the user of workwear to actually fully understand their possibility to affect the climate by taking care of their garments [which is] something that we will need to work with from a higher perspective to try to gradually get them to change their view."* This would help to reduce the amounts of garments used and wasted. She explains the importance of communicating with the user to promote the idea of repairing and caring for the garments, and possibly offer the solutions to this.

Ms. Schartau points out the significance of *"recombining fibers"* and explains that SW *"works a lot with cotton and polyesters, or polyamide contents, and there is no known, or at least, no commercialized way of separating these fibers and turning them back into new fibers. The only method available right now is basically to mechanically recycle them and then the fiber link will be really short so it will not be useful for workwear because it will not be featureable enough."* She mentions that technology does exist for separating the fibers but "only on a small scale."

Ms. Schartau admits that there are various challenges regarding workwear sustainability, however also highlights the potential as they have *"such a streamlined production setup, so with that solution of actually commercializing the separation of the cotton polyesters, we will be all set in regards to actually recycling large amounts of material back into new fibers. I mean it's a lot about research at the moment but then there are different possibilities out there and I think within five years we may possibly have a commercialized situation."*

We then asked concerning potential overstock and overproduction which is a major concern for most clothing companies. Ms. Schartau responds that *"part of this problem is eliminated since SW are running rolling assortments" and thus "nothing goes to waste [and furthermore] we have the outlet that takes care of the discontinued pieces. The rolling assortment means that production just continues and we have a whole supply department checking the supply trends to ensure that we are producing the right amounts so for instance, OK so now this one is going low so we push the button for re-order"*

With regards to SW's technology usage, Ms. Schartau described their forecasting technology whereby they *" have just recently invested in a new forecasting system [which] will be able to pinpoint even better so we can reduce the amount of stock they have as much as possible but still be able to supply enough." T*his would ensure that we "don't have really high stock and a lot of garment pieces in our central warehouse because we're finding that a lot of money lies in our garments. Even though we will be able to sell them at the end of the day it's not so good for the finances of the company." This "could also be considered an AI solution as we are using intelligence for accounting systems to actually to do the work for us, which may also linked to sustainability because it helps to reduce the amount garments on stock and help us to plan better, which would for example mean we do not need to fly and transport as many goods… it's all linked to each other."

She also stressed the issue of *"garment cutaway which accounts for roughly 11-15% of the raw material of the fabric, meaning that when you cut the garment pieces, this is wasted because you can't make garment pieces out of it. Even though it is perfect material and contains no contamination or anything, it is just chucked away. If you start to consider sheer volume in the world that is actually cut weight and I am really surprised that no one actually* *talks about it on a bigger scale."*

Ms. Schartau recognizes the importance of technology in the future of their businesses, stating *"there is a lot of smart technology which we are exploring" and that SW is currently using both censoring technologies on garments that can be used to measure the person wearing the garment, and also their use of WorldFavor which is a risk analysis device. This helps them in terms of "supply chain transparency and risk analysis which uses big data analytics."* Ms. Schartau adds that *"technological use in all different aspects will only continue to go so I guess what will be the divide is whether the company has the financial resources to actually invest in them."*

We asked Ms. Schartau what she thinks the greatest challenge is with achieving the CE and using technology to do so. She responded that it is the *"lack of research, in that sense that the research is going so slow due to the types of fibers that we are using, as well as the challenge with our type of garments that we're actually dealing with."* She stated that a main aim for their circularity is to *"work a lot in our supply chain with energy usage, both with the amounts and types of energy used, and furthermore researching recycling the fibers back into workwear is number one is to get it durable which is not always easy because the recycled fiber might have an inherent weakness because of the fiber length being shorter and so forth."*

Ms. Schartau explains that SW *"would love to give the fibers that we have used a second life in one way or another but to recycle them fully back into workwear may not be feasible. We will be really happy to just be able to collect the fibers to send them somewhere for a second use, it doesn't necessarily have to go back to us. Usually that polyester is quite good in quality so it could be kind of high quality garments but maybe not to the point for workwear but definitely for fashion."*

Appendix C - Devianne Interview

The second interview was held with Devianne which is a clothing retailer that holds over 60 clothing brands and is located in France. We interviewed the CEO of the company named Stéphane Roche**.** The company was established in 1882 and they now have approximately 40 stores throughout France as well as an e-boutique. Mr.Roche begins by giving a brief background of the company and his time working there.

The conversation continues by Mr. Roche introducing how the company approaches sustainability, stating that:
"we do have one big chunk of this business plan around sustainability, and we want to differentiate on that one point… in terms of services not only product..[however]...we carefully select the product according to our sustainability guidelines… and have set something new up in terms of service…[whereby] we are actually the only retail chain in France… with a repair shop… in each of our stores"

Mr. Roche continues by describing this repair system...
"Traditionally we used this to… adapt..sizes [to fit] the customer – but now we want to use that [along with] an Internet ecosystem to [become] the first retail chain saying "buy one good from our stores and our stores will always propose one solution to take it back from you… or to help you not to throw it away. And we want to do this..in three directions…. either to fix it, to ***repair*** *it and maybe also to adapt it."* He further explains the different ways they could use these bought back clothes stating that "*"we can really we can fix it, we can personalize it, [we could] upcycle it, we can buy it back, and, if at the end of the day, it is impossible to do any of those because the product is too old and it has no value on Vinted, then we will take it back just to recycle it and then we will give the customer a voucher. But in any case we want to be the first retail chain to tell our customer base "buy something from us you were sure we will find a solution with us to give value to this old product""*

With regards to upcycling, they want to
*"****upcycle*** *it with our old stock – we want to make a new collection [through] our repair shops and we do have a partnership with stylists [who are] able to imagine a new collection range from our old stock. So you take an old product A and an old product B and you make a new product C!"*

We questioned how they plan to do this and if they were using any technologies to help with the process, whereby Mr.Roche explained that they will "*buy [the clothes] back from the customer with a system we are currently developing [being] an app which will be able to [compare alternative] Internet sites like "Vinted" .. [this will probably be ready in] September or December this year… [and] ultimately we want to make [a] sustainable strategic approach.. at the heart of the mission [being] the "why" of the company"*.

Mr.Roche further explained,*"To give you an insight, this app will be able to tell you at any moment how much money you can realize in a way you have a "worth of product" in your wardrobe ...At the same time as well each time you would sell a product back to our store you would have a system we are working on a sort of gamification idea where you would receive points, or let's say value points, where we will tell you how much CO2, how much emission you would've saved by doing that, you will attain a certain score and those points can be used to obtain promotions or obtain some special offers in our store. We would like to have that as playful and as positive and as premium [as possible]... So the idea there is to create loyalty and to increase traffic in our stores because you will be always keen to visit [if you know you* *can] buy back from [a] special new product we will upcycle from the old assortment and... we'll be doing it brand by brand we can make it more fancy and more fashionable"*

Mr.Roche discussed their Vinted which is another company in France that uses this system of shops repurchasing used clothes from customers, but states that Devianne has a different target group than that of Vinted and that their buying-back process takes a shorter time, stating *"we'll tell our customer – save some time and money sell it to [us] and you will have your money right away."*

Mr. Roche then discussed their other sustainability effort being their secondhand sections of stores, whereby he states that

"We want to maintain second hand shelves and corners in our stores and [they can be] quite dull and sad… [so] we want to commercialize it and we want to make a silhouettes, we want to make it by brand, and we want to maintain it in a way which are very trendy and for that we are creating a school for our [seamstresses]... we will make a school not only to teach our people to sew and fix the clothes but also again to personalize and upcycle it but also to maintain a second hand [section] and to commercialize… [by making it] attractive.. and trendy."

Mr. Roche also explained other benefits of these second hand sections regarding resource scarcities of certain materials in the future. He states

"when I talk to big international brands they are telling me that they are worried that in 5 years from now they will not find any cashmere on the market, they will not find any merino wool [due to] law[s] and all the associations of animal wellbeing and so on… resources will be scarce in the future… so we believe also being able to partner with the brands and say "OK in a few years from now, our retail chain will partner with you to be able to source old Kashmir, old Merino wool, old sustainable cotton and some directly from secondhand stock" – Will be also a plus on the market."

"We believe this could be competitive edge because what we see on the market everybody is doing sustainability one way or another… [however through a] secrecy approach, obviously you have Vinted which is a bigger player on the secondhand market… every retail chain is trying to do a "mini-Vinted" ... every retail chain is doing their own website where customers can upload products of that chain and sell to another customer the way Vinted does. Actually why go on a mini-vinted if you can go on a big Vinted? So that's for me not a very promising approach.What we want to do is C2B2C; we want to... be able to do the full cycle where our customers can actually sell and... buy. and we can do the full cycle ourselves and flag this offer saying "buy something from Devianne and Devianne will always propose a solution from what you purchased from us."

Following this, we specifically asked Mr. Roche whether they were using any tracing/tracking technologies..

"For us in the secondhand business, I don't see that system being helpful. ***Obviously it is a great system for… the new products, but it's quite expensive****. We are actually too small*

today in our company – we are making a turnover of €80 million.. this year, so it's quite a small company [and] we don't have the resources to pay RFID to do that. Although more RFID would be [helpful] if we were sourcing and designing our own brands, we buy the clothes from Levi's and Tommy Hilfiger … and the bestsellers, or whatever."

We replied by questioning whether they see a potential in partnering with the brands they sell and using their technologies (such as RFID). Mr.Roche reponds,
"yeah, why not?... in that aspect it could help us and help Levi's know where the product did go to – so let's say that the product would be sold to our retail chain and we would sell it to one specific customer and then the customer would resell it to us. But I don't know actually, it would mean that the RFID tag would last quite long. I am wondering whether an RFID tag could last I don't know 6/7/8 years… but if you wear a jean 2-3 years and then you resell it back, I don't know. My feeling at the moment is that it seems to be quite fancy and a bit useless for secondhand products which will actually cost much less."

We then specifically asked about possibly using smart intelligence technologies, whereby Mr.Roche stated that
"one of the big issues for all of the fashion retail stores is the overstocks… it's bad for the planet, it is bad for your profit...So if I buy back some old stocks in cash that will increase my overstock level and that's quite dangerous if I don't manage to sell it back. So maybe AI could be a way in the future to try to predict not only what Vinted is selling today but what Vinted will be selling six months from now and maybe to try to predict how quickly I can sell my secondhand product goods in the next 3-6-12 months…., I could also maybe try to prepare my reselling price or to fix my reselling price on a weekly basis or you know to adapt my prices to the speed of sales I'm making on any product.. ***maybe AI could help me with that… [snd to help me to]*** adapt my purchasing price and my assortment level"

Mr. Roche then discussed the digitalization of the shopping industry and the rise of online shopping, stating that,
"the issue is that you have to invest in all digital, AI, data management, and website platforms at the same time as you still have to invest in your stores. So [it] is quite difficult because the internet is not bringing you additional business... but still you have to invest heavily to be able to follow the race. That's just one issue which is well known for the retailers right now."

Mr. Roche goes on to describe the possibility of introducing a system similar to a *"subscription... which will make people come back every year to try to valorize its old product and get a new one, you know, for fashion freaks or fashion addicts – could be a nice opportunity."*

Finally, Mr. Roche outlines the financial considerations that must be taken into account with these sustainability efforts. He explains,
"We are building our business plan right now but my idea is that we need to figure out how much traffic we have to generate, additional traffic to make it profitable, because obviously

the apps will cost money in terms of CapEx and OpEx. The… our school of craftsmen / repair people will cost us money as well [and] we will have more people in our repair shops… so there's more people to pay more salaries...so we have to figure out how much additional traffic [is needed] to make it work,"

Mr. Roche concludes stating that *"that is the core of our sustainable strategy… would be located in that matter in that new marketing offer, we call it the "4 R/ 5R": Resell, Recycle, Repair, actually we want to make a really specific approach there using this promise"*

Appendix D – Interview Guide

Sustainability and the CE:

1. What is your company's view on sustainability? Why is sustainability important for you?
2. When did your company begin working towards the circular economy?
3. How/ in what specific ways does your company work towards the circular economy?
    a. …..And do you prioritize any of the "R's" principles over others? Why?
    - *Example: Reuse, Reduce, Recycle, Recover, Repair, Redesign, Refuse, Remanufacture, Repurpose and Refurbish.*
4. What are your future plans in achieving the goals of the CE?

Industry 4.0:

1. Do you / how do you use technology for sustainability?
2. Has your company utilized I4.0 technologies within any of your operations? *(not just within the sustainability field)*
    a. …..In what ways?

AI & the CE

1. If you are currently incorporating I4.0 technology into your sustainability efforts, in what ways are you doing this?
2. In what ways are you currently working with the design of circular products? Do you think AI and ML can aid in the decision making process of design-, material- and manufacturing choices?
3. Are you currently, or do you see any potential in using AI to power the operation of circular business models (i.e. through facilitating leasing- or product-as-a-service activities)?

4. Are you currently, or do you see potential in using I4.0 technologies to facilitate processes supporting circularity such as 1) the disassembly of products, 2) remanufacturing components, or 3) recycling materials?
5. What is your take on the future potential of I4.0 in aiding the CE?
6. Do you see any problems with implementing I4.0 technologies?

Appendix E – Extended list of investigated companies

	Companies investigated (and contacted for interviews)	Used Yes/No
1	H&M Group (H&M, COS, Weekday, Arket, Afound, Monki, & Other Stories)	
2	Macy's	
3	Inditex (Zara, Pull&Bear, Massimo Dutti, Bershka, Stradivarius, Oysho, & Uterqüe)	
4	Eileen Fisher	
5	Norrøna	
6	Chanel	
7	Fast Retailing (UNIQLO, GU, PLST, Theory, Theory Luxe, Helmut Lang, Comptoir des Cotonniers, Princesse tam.tam, J Brand)	
8	Adidas	
9	NIKE	
10	Asos	
11	Under Armour	
12	VFC (Altra, Bulwark, Dickies, eaglecreek, Eastpak, Horace Small, Icebreaker, Jansport, kipling, Kodiak, Napapijri, Red Kap, Smartwool, Supreme, The North Face, Timberland, Vans, Walls)	
13	Gap inc.	
14	Levi's	
15	Capri Holdings (Michael Kors, Versace, Jimmy Choo)	
16	Burberry	
17	Puma	

18	PVH (Calvin Klein, TOMMY HILFIGER, Van Heusen, IZOD, ARROW, Warner's, Olga by Warner's, Geoffrey Beene, and True&Co)	
19	Devianne	
20	Snickers Workwear (Hultafors Group)	
21	Patagonia	
22	Gina Tricot	
23	Kering (Gucci, Saint Laurent, Bottega Veneta, Balenciaga, Alexander McQueen, Brioni, Boucheron, Pomellato, Dodo, Qeelin, Ulysse Nardin, Girard-Perregaux)	
24	Bik Bok	
25	Wolverine	
26	Sorabel	
27	Stella McCartney	
28	Nelly	
29	Zalando	
30	Arket	
31	Asket	
32	Acne	
33	A-DSGN	
34	Björn Borg	
35	Tiger of Sweden	
36	Muji	
37	Boomerang	
38	Samsoe Samsoe	
39	Stronger	
40	ICIW	
41	Aimn	
42	Hope	
43	House of Dagmar	
44	Organic Basics	
45	Kerber	
46	Filippa K	
47	Stellar Equipment	
48	Åhlens	

49	Nakd	
50	Carlings	

Appendix F – List of search terms

1. circular economy terms	2. Industry 4.0 terms
the circular economy circular circularity circular business model reduce reuse recycle remanufacture redesign repurpose resell second hand upcycle	artificial intelligence (AI) cloud cyber-physical system data analytics smart technologies Internet of things (IoT) machine learning (ML) RFID robots technology virtual 3D