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Global Management of Innovation and Technology

MASTER'S THESIS

Assessing the Role of Artificial Intelligence in Product Design towards Circularity

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ABSTRACT

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Designing circular products with longer lifetime plays a vital role in circular economy. However, analyzing huge amount of data on the products requires more human efforts and is time consuming. Thus, digital technologies can help in data analysis. The study aims to analyze the current status of digitalization in circular economy. One focus area of the research is on role of circular product design in circular economy. The study analyses the effects and the importance of designing products with circular behavior. The second focus of the study is on the role of artificial intelligence in circular economy and in circular product design.

The main research method in this study is critical literature review and case study including three semi-structured interviews in three different industries. The informants have different roles such as head of environment, head of digital transformation and environment specialist in the companies. Qualitative content analysis was used to analyze the results of the study. According to the results, Finnish companies believe that circular economy is beneficial for them and are interested in implementing digital technologies to enhance their circular economy. A framework on the role of artificial intelligence in circular economy is introduced in the study after collecting and analyzing secondary data and data from case studies. It allows companies to decide how to implement artificial intelligence in their circular processes. Moreover, the list of key enablers will help the managers to make better decisions on how to utilize technologies.

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This Master’s Thesis provided a great opportunity for me to get familiar with academic research world. It was very interesting to see how companies collaborate with universities and academia in Finland to develop their business. Writing this Master’s Thesis helped me in learning something new day by day and was challenging as well.

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“Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution.” – Albert Einstein

Lappeenranta, 25th of June 2019

Seyedehmalahat Ghoreishi

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List of Abbreviations

3D printers: Three-dimensional printers

4IR: Fourth Industrial Revolution

AI: Artificial Intelligence

AT: Analytic Technology

BMC: Business Model Canvas

CBM: Circular Business Model

CE: Circular Economy

CPS: Cyber-physical System

DT: Data Technology

IMS: Intelligent Manufacturing System

IC: Integrated Circuit

IoT: Internet of Things

LBM: Linear Business Model

ML: Machine Learning

OT: Operations Technology

PSS: Product-Service System

PT: Platform Technology

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1. INTRODUCTION

Over the recent years, the Circular Economy (CE) approach has been considerably discussed on industrial economy development worldwide and gained attention of scholars, industries and policy makers significantly. Ellen Macarthur Foundation (2012) defines the concept of Circular Economy as a "system restorative and regenerative by design, which aims to maintain products, components and materials and their highest utility and value". However, transition towards a circular model from linear economy which is "make, use, dispose", needs huge efforts by industries in cooperation with governments and policy makers. Although circular business model has numerous economic benefits and is considered as a sustainable business model, the concept is arguable since recycling the material costs heavily to renew or restore (Macarthur Foundation, 2014). Hence, implementing CE in many cases requires certain changes in companies' business models and generates additional challenges for the industry such as asset management, supply chain novelty, organizing new logistics for unfamiliar waste products as well as designing manufacturing services and quality control (Ramadoss et al., 2018).

In addition, the design for these aspects increases the challenges and complexity of CE workflow, therefore product design development as well as business model improvements are essential to accelerate the move towards circular economy (Bocken et al., 2016). Integrating circular economy business model at the early phase in the product design process plays an important role in value creation together with the supply chain since only minor changes on the products are possible once the resources, specifications and activities are being deputed to a certain product design (Bocken et al., 2014; Saidani et al., 2019). Accordingly, companies must implement innovative product design strategies to narrow or close the resource loops. Moreover, digital technologies such as Artificial Intelligence (AI), 3D printers (three-dimensional printer), Internet of Things (IoT), and Big Data underlined by the fourth industrial revolution (Industry 4.0), can help the industries overcome the challenges in transition towards CE (Bressanelli et al., 2018). AI is subset of the technologies which asset circular economy to increase product circulation, predictive maintenance and smart management (Ellen MacArthur Foundation, 2019). In this study, AI is discussed as an accelerator of Circular Economy, enhancing the development of new products and materials by rapid prototyping and testing. This study argues AI as an accelerator of circular economy by agile data collecting and testing, helping industries towards circularity.

1.1 Background

The theoretical background of the Thesis is described in this section and consists of four subsections. The first subsection focuses on the theory of CE, existing advantages and challenges for companies. More specifically, this subsection analyses the role of product design in circular economy. The second subsection focuses on status of CE in Finland. The subsection pays attention to how product lifecycle creates value to Finnish products for CE. The section continues with identifying the role of technologies in manufacturing Finnish companies. Subsection three, addresses the current technologies enhancing CE and the final subsections illustrates the role of AI in CE, focusing on product design.

1.1.1 Circular Economy

CE has been recently one of the most promising paradigms. The aim of CE is to "design out waste and pollution" by enhancing circular products, materials and components at the highest value level and utility (Prendeville and Bocken, 2016). The benefits of such approach are sustainable, creating a net profit of EUR 1.8 trillion in Europe by 2030 (Ellen MacArthur Foundation, 2019). Cohen and Muñoz (2016) mention that pursuing of sustaining life requires transition to more sustainable consumption and production worldwide. However, despite all the advantages of CE model such as keeping materials and products in use, regenerating natural system, environmental sustainability, controlling rising of resource costs, etc., the transition towards CE for established companies sets major challenges (Alghisi and Saccani, 2015). In more concrete terms, since energy and material, product design, manufacturing processes, business models, services and distribution processes along with data management should be considered in moving towards CE, the change is of high complexity (Ritzén and Sandström, 2017). Companies should change radically and innovate their business model by transforming their existing organizational and structural conditions in order to move towards a more CE business (Moreno et al., 2016). A circular business model (CBM), indicates to what extent a company is capable to create, deliver or capture the value without or within the closed loop (Mentink, 2014). Linder and Williander (2017) identifies "circular" as a business model in which economic value is optimized after used products are used for new offerings. A system-wide innovation is needed in enhancing the transformation of the whole economies, companies and industries in adapting the application of a successful CE, to change the whole process in value creation (Stahel, 2012). Moreover, in order to move towards CE and tackle existing challenges, radical innovations as well as disruptive business models are needed (Boons et al., 2013). Five types of CBM that have been recently proposed by Accenture (Lacy and Rutqvist, 2016) are as follow:

- Circular Supply-Chain: Looking for resources which are renewable, recyclable and can be used in sequential lifecycles
- Recovery and Recycling: To recover by-products and waste out of production process
- Product Life Extension: By maintenance services, updates and repair the products
- Sharing Platform: By rent, share and exchange of non-utilized materials
- Product as a Service: By combining physical products with service components.

An interaction between all involved actors is needed in CBM as a system-level phenomenon (**Figure 1**), "including both the core-business network and other stakeholders" (Antikainen and Valkokari, 2018). More details for an overview of circular business model types is available in Appendix 1.

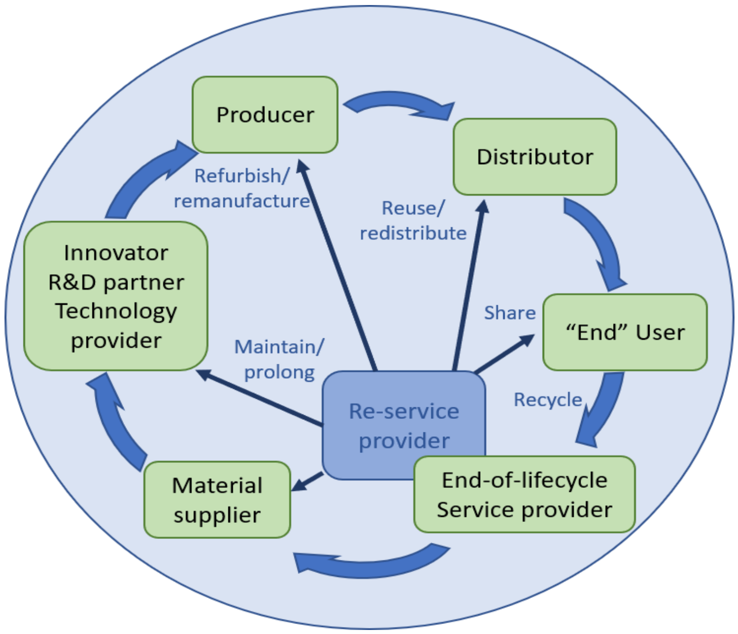

Figure 1. Interaction between actors in a CBM system (adapted from Aminoff et al., 2016)

Business model canvas (BMC) is the main tool in generating CBM innovation (Osterwalder and Pigneur, 2010). Based on the structural business models, BMCs identify and classify the product-service system characteristics (Barquet et al., 2013). Hence, it is applied in generating most of the CBMs. A framework of the circular BMC is presented in **Figure 2**.

<table>
<tr>
<td rowspan="3">Partners
• Cooperative networks
• Types of collaborations</td>
<td colspan="2">Activities
• Optimizing performance
• Product Design
• Lobbying
• Remanufacturing, recycling
• Technology Exchange</td>
<td colspan="2" rowspan="3">Key Proposition
• Pss
• Circular Product
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<td colspan="4">Cost Structure
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• Organizational Capabilities
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</table>

Figure 2. A framework of circular BMC (adaptation from Osterwalder and Pigneur, 2010)

The goal of product circularity in a CE world is to maximize the value in the products, materials and components during the longest time. Product life extension is the central economic and social model through repair, refurbishment and remanufacturing (Charter, 2018). The main challenge concerning the transition to CE is how to reduce utilization of finite natural resources and to promote positive societal and environmental impacts by rethinking of a way to maximize the value in products (Kraaijenhagen et al., 2016). Thus, product design plays the key role in creating value along with customer value proposition, supply chain, value networks of the companies and capturing the value of new offerings (Urbinati et al., 2017). According to Ellen Macarthur Foundation (2012), practices on product design allows improving the material selection, modularization of the components, standardization of the product design, purer materials flow as well as designing for the easier disassembly. Therefore, the key role of CE is that it is good for environment, but also beneficial for businesses, trades and job creation. CE is a new economic model, which promotes collaboration, removes barriers as well as free exchange of goods, ideas and services (Sitra, 2018a). The key point to achieve the future goals of CE is that all levels of society (citizens, businesses, multinational organizations and public leaders) should collaborate on all levels, in other words everyone working together. Building an ecosystem of partners is needed to achieve the full circular advantages.

1.1.2 Technologies in CE

Recent research indicates the emerging role and fast involvement of digital technologies as an accelerator of CE to overcome current challenges (Bressanelli et al., 2018). In addition, Digitalization can be discussed as an enabler of CE. Digitalization contributes to product visibility and intelligence and provides information about assets regarding their location, condition, and availability (Antikainen et al., 2018). In CBMs, one of the key roles is to lease, rent and share the durable products wherever possible rather than selling them (Bocken et al., 2016; Macarthur, 2012). Thus, digitalization is the major key in the process of shifting in the direction of product service system (PSS). It is proposed as one of the key solutions to accelerate moving towards circularity (MacArthur, DE and Waughray, 2016). Moreover, enhancing usage of digital technologies such as AI, IoT or Blockchain brings new ways of improving transparency and traceability throughout products lifetime (Stankovic et al., 2017). Smart, connected products give opportunity to the producers in monitoring, controlling, analyzing and optimizing the performance of products and collecting useful data of usage (Porter and Heppelmann, 2014). Accordingly, digital technologies as highlighted by Industry 4.0 (the fourth industrial revolution) increase the introduction of CE to the companies. Efficient reverse logistics, materials and goods that gain second life, accelerates CE concept worldwide with suitable recycling process, which uses limited resource (Macarthur Foundation, 2014). Combination of digitalization and novel business models innovation may provide significantly new opportunities towards more sustainability for industries in terms of value creation, value capturing and CE (Lanzafame, 2015). Sitra (2018b) mentions that manufacturing industries can gain tangible benefits by digital reinvention of industry to move towards CE. However, some technologies come with the risks that requires to be balanced with their benefits.

1.1.3 Artificial intelligent and CE

Artificial intelligent (AI) has gained attention of circular businesses and experts worldwide recently. AI enhances CE by monitoring automatically and remotely of the efficiency over the manufacturing process and at the end of products' lifecycle. AI can help in analyzing the massive data which is generated during the manufacturing process, use or disposal (Ramadoss et al., 2018). Ellen MacArthur Foundation (2019) suggests AI as a complement in human's skills and capabilities expansion. It can help in fast learning from feedback more efficiently by dealing with complexity as well as improve awareness of massive data amounts. Faster and rapid prototyping, learning process by repeated designing cycles and feedback collection are requirements in accelerating the transition of the complexity of redesigning key features to a better economic model. Accordingly, AI can play a significant part in enabling the systematic shift.

1.1.4 Circular economy in Finland

According to Sitra (2016), Finland is one of the pioneers in operating models for economic growth without over-consumption of natural resources. The CE innovations are expected to represent significant opportunities in Finland such as providing Finland's national economy in added value potential by 2 to 3 billion euros as well as 75,000 new jobs by 2030. Moreover, in all parts of the manufacturing value chain, substantial inefficiencies occur (product design, sourcing, manufacturing, logistics, marketing and sales, product use and end of life disposal). Sitra (2018b) defines that most Finnish products are designed for long-lasting, 50% of Finnish companies that report durability of their products are over 20 years, while another 43% manufacturer report their products' lifecycle is between 11-20 years long. The share of gained revenue from long lifecycle products is 80% for 65% of companies. Moreover, Sitra (2018b) addresses that technologies have a significant role in enabling Finnish companies to deliver CE objectives and are of fast developing. Among all technologies, AI techniques such as machine learning show an emerging and maturing role in achieving the CE goals of Finnish manufacturing industries. This study provides the results of case studies from three different large manufacturing enterprises (electronic, food, metal). Study is carried out by presenting and analyzing the current interests in implementing

AI to develop the CBMs especially in the phase of product design, lifecycle and maintenance. The results may help the companies to have a clear understanding of new opportunities in applying AI in their CE strategies and business models.

1.2 Objectives and scope

This study aims to understand how AI can enhance developing CE in industry in the product design phase, and to identify how companies employ AI in their circular strategies. The need for a CE is urgent as the percentage of non-renewable resources is decreasing significantly and the natural resource prices volatility is growing (Macarthur, 2012). Implementing CE needs an innovative business model to lessen negative impacts on environment and to produce profit in short and long-term. Geissdoerfer et al (2017) mentioned that long-lasting product design, maintenance, repair, reuse, refurbishment; remanufacturing and recycling are the solutions to achieve CE.

The need for AI technologies can be better understood by analyzing the methods and techniques that assets in product design and processes in manufacturing system and to achieve the sustainable development goals in CBMs. AI could help designers and material scientists to develop solutions that requires fundamental innovation and redesign. Furthermore, the study identifies the ways that AI techniques would help businesses to overcome the challenges that one could face in transition towards circularity. Finally, the key enablers in applying new technologies such as AI in companies is discussed in the study. Two principal research question were formulated and are presented in **Table 1**. This study will answer to the research question based on the literature review and case studies.

Table 1. The research questions of the study with the objectives

Research question	**Objective**
RQ1: How AI can help product design towards circularity?	• To understand role of AI in designing circular products, materials and components • To understand the current status of companies in implementing AI technologies in their circular business strategies
RQ2: How AI can help in maintenance services in companies towards circular economy?	• To understand role of AI in maintenance services of products towards circularity

The aim of the first main research question (RQ1) is to understand the current state of technologies in Finnish companies. The main aim is to identify to what extent companies are digitalized in their CE solutions and how they employ digitalization in their CE processes. Particularly, the way they utilize AI in circular product design towards CE. Moreover, the main research questions aim to analyze current capabilities of technologies especially AI technologies in developing products' lifecycle as well as future demands for such technologies to achieve the goals of CE. In addition, this Thesis identifies the key enablers in employing novel technologies in companies' CBMs. Finally, the study introduces a framework of the role of AI in CE in industries.

The study answers to the (RQ1) by clarifying the key factors of product design in a circular design strategy and introduces the tools for design circular products in the literature review. Additionally, the study defines the role of novel technologies in designing long-lasting products in the literature and analyses the status of the companies in the empirical part of the study. The role of AI in CE is defined in the literature and is analyzed in the case studies. The aim of the second main research question (RQ2) is first to identify the technologies that are utilizing the maintenance services in companies, and how they help and accelerate companies in delivering their CE objectives. Specifically, how AI techniques are implemented to help maintenance services. The study answers to (RQ2) based on the literature review on identifying the ways AI techniques can help in accelerating maintenance services. The study analyses the status of AI in maintenance services in manufacturing companies in the empirical section.

1.3 Execution of the study

This section describes the execution of the study. According to Saunders et al. (2009), the execution of a study consists of research strategy, time perspectives in addition to data collection and analysis strategies. The execution of the study consists of two main research phases. Research process, timetable and the purpose of each phases are summarized in **Figure 3**. The research has been conducted between January and June 2019. The first phase is the theoretical part of the study based on literature reviews and aims to get the main idea behind the concept of circular product design to identify the current CBMs and strategies. In particular, literature review helps to understand the roles of technologies in CE. In addition, how technologies can help companies to overcome the challenges towards their CE objectives are reviewed in the theoretical background in the literature review. Moreover, the literature review aims to collect theoretical background on the role of AI in CE, in the phase of product lifecycle.

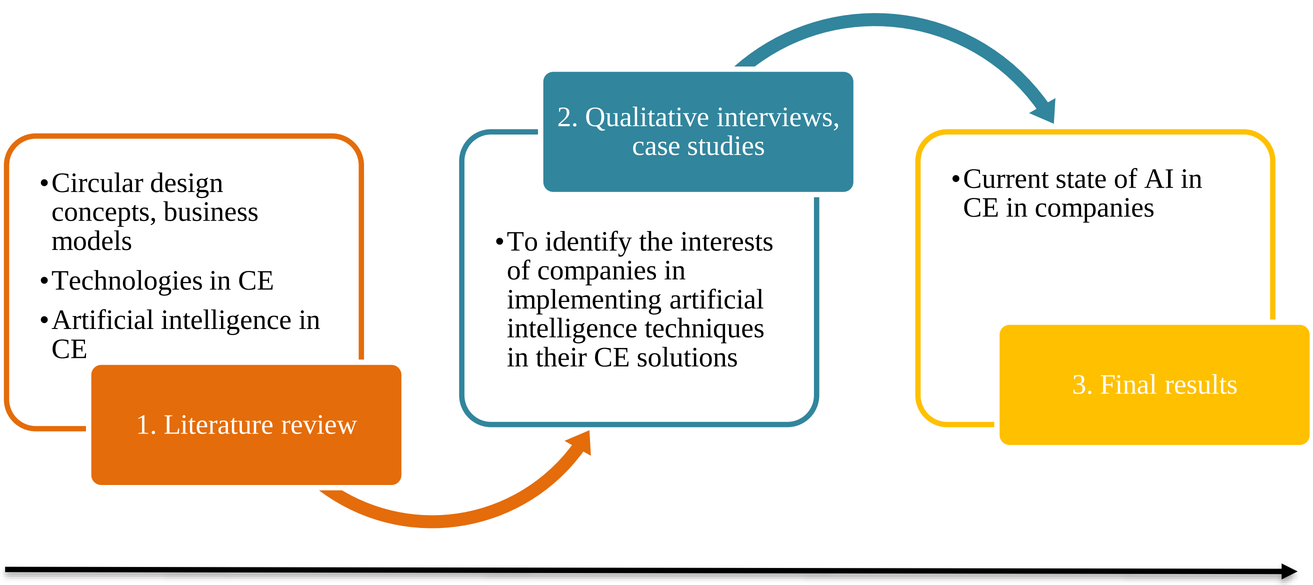

Figure 3. The execution of the study

The empirical part of the study consists of three qualitative case studies including semi-structured interviews with the experts in three different manufacturing companies. This phase aims to collect the knowledge, experiences and cognition about current CBMs in companies and to realize the gaps if there would be such. Moreover, the aim is to identify and collect the opinions of professionals about the current technologies enhancing CE, and in more detail, to figure out the role of AI in CBMs. Due to privacy policies of the companies on their strategies in product design, it was not possible to have interview with the experts in technical departments and product designers. Therefore, data collection in this era is based on the accessible data on the companies open resources and platforms. In the end, the results are conducted and analyzed based on theoretical and empirical implications. The structure of the study and methodology are introduced in more details in chapter four.

1.4 Structure of the thesis

The structure of the thesis is presented with an input-output scheme in **Figure 4**. The thesis is divided into seven sections. The introductory part gives a brief overview of the CE concept, introducing the background, scope and target of the study. The first chapter discusses the main purpose of the study, presenting the research questions as well as introducing the key concepts of the thesis. The second section analyses product design strategies in CE. The third chapter explores the roles of new technologies in CE, focusing in AI techniques and provides the clear understanding of the role of AI in products' lifecycle. Three case studies and qualitative method are presented in the methodology section (chapter four). The results are addressed in section five, which provides the main observations from the research data. In chapter six discussions are summarized and describes how to enhance circular business models by help of AI. Conclusions are drawn in the final section, summarizes theoretical and empirical implications and gives recommendation for further research areas.

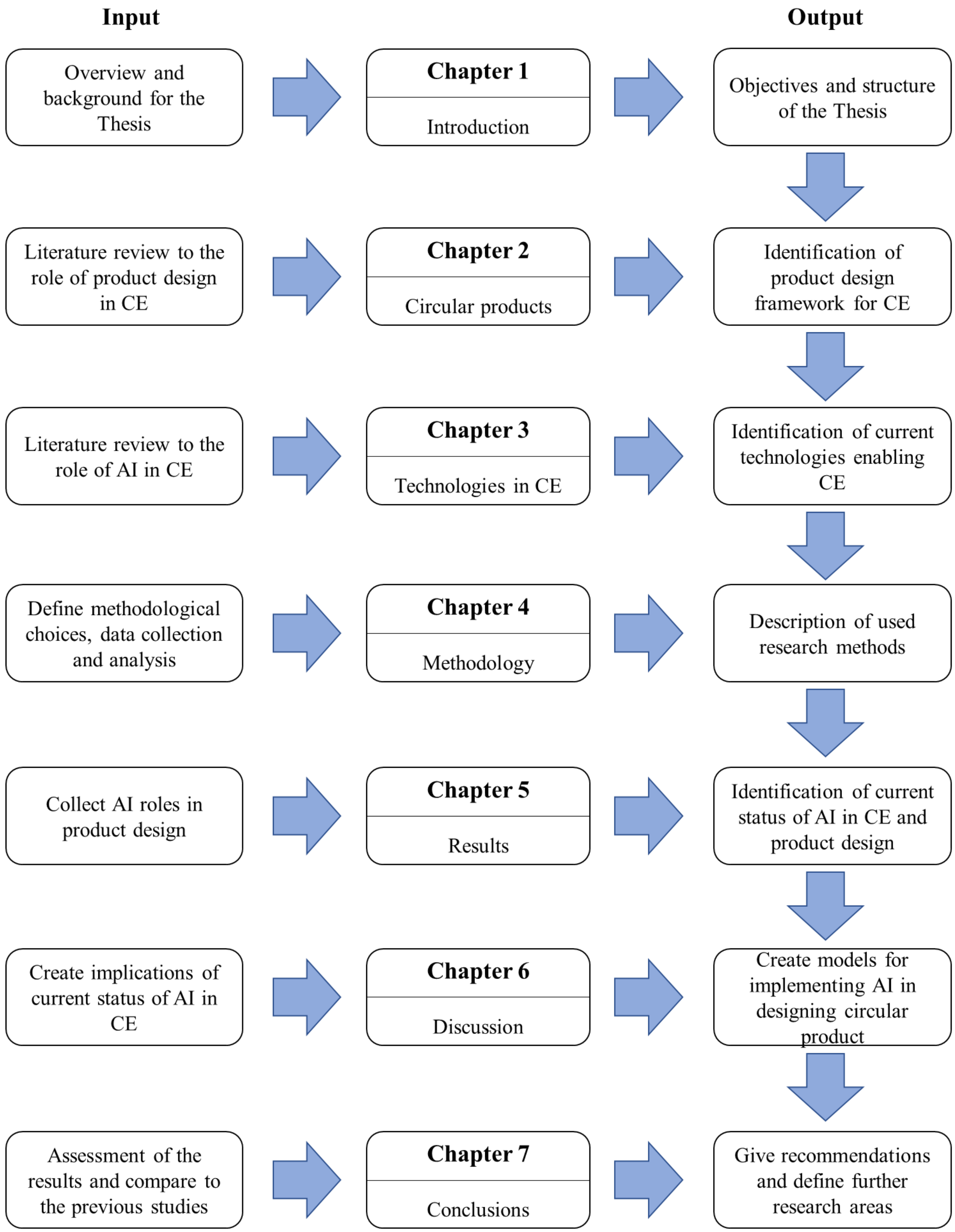

Figure 4. The structure of the Thesis

2 CIRCULAR PRODUCT DESIGN

According to European comission (2012), all the products during their lifecycle have an impact on environment in all the phases from the use of raw materials and natural resources, manufacturing, packaging, transport, disposal and recycling. The environmental impact of over 80% of the products is determined at the phase of design. Principles of CE which are shown in **Figure 5** are inspired by natural systems and are briefly identified as follow: design out waste, shift to renewable energy sources, build resilience through diversity and think in system (MacArthur, 2013). According to (Bakker et al., 2014), "circular product design: elevates design to a system level, Strives to maintain product integrity ; is about cycling at a different pace , explores new relationships and experiences with products , and is driven by different business models ". Product design plays an essential role in CBM and affects the company's competitive advantage (Lin, 2018). In this section circular product design strategies are described and a product design framework for circular design business model is presented.

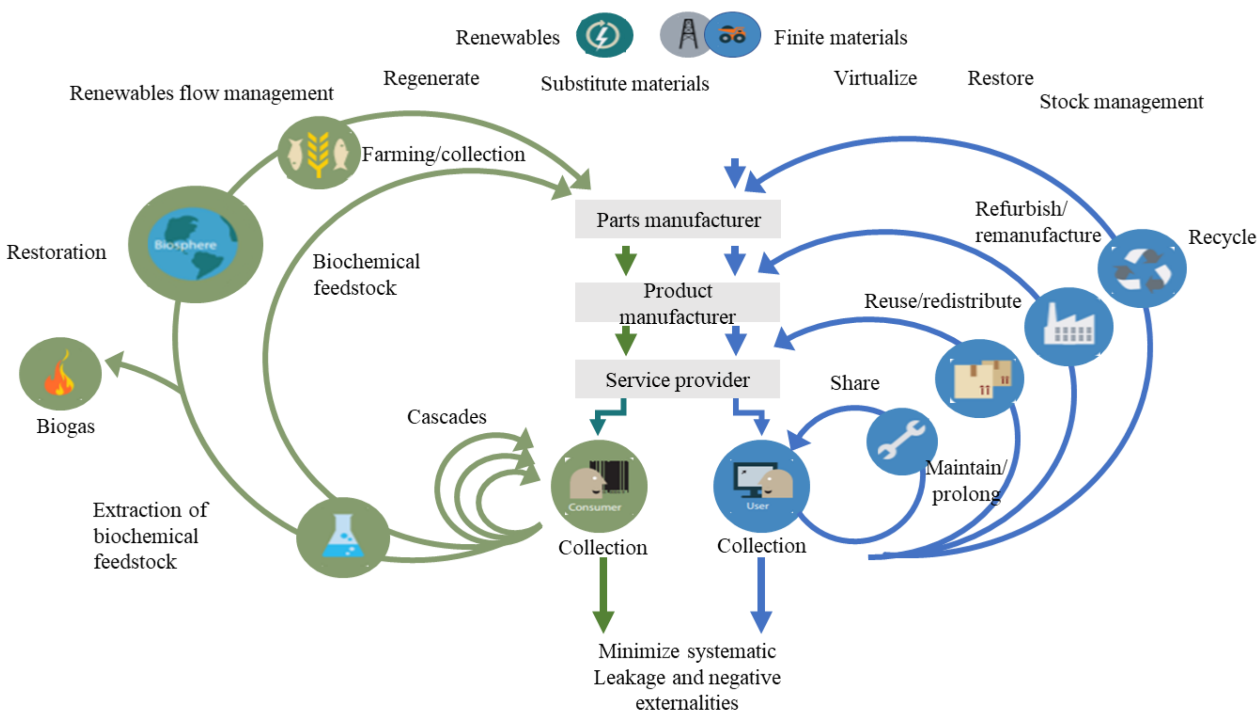

Figure 5. Circular Economy Principles (adapted from MacArthur, DE and Waughray, 2016)

As can be seen in **Figure 6**, the five main characteristics of circular products from the inner loop to the outer loop are Future proof, Disassembly, Maintenance, Remake and recycling. CE closes the loops by several circles to address the unsustainable resource. However, it only happens if the systems uses renewable energy sources to recycle the total of the resources in its entirely without inquiring in quality losses (MacArthur, 2013). If these conditions are not fulfilled, a time aspect is required to slow down the process. Reducing the needs for new products could help in this situation, manufacturing durable and functional products which can be used longer could be an example of this (Van den Berg and Bakker, 2015).

Next phase is disassembly, which is considered as the initial stage of the majority of the actions carried out on the products to elongate their lifetime or to create new materials. Optimization of products through disassembly at the design stage can be best done where 80-90% of disassembly gains are determined (Desai and Mital, 2005). However, non-destructive disassembly is prioritized for maintenance and remake, whereas for recycling destructive disassembly is more appropriate (Peeters et al., 2012). Third step is maintenance, which belongs to the aspects of delivering performance in the use phase for as long as possible. It consists of cleaning, repairing and upgrading.

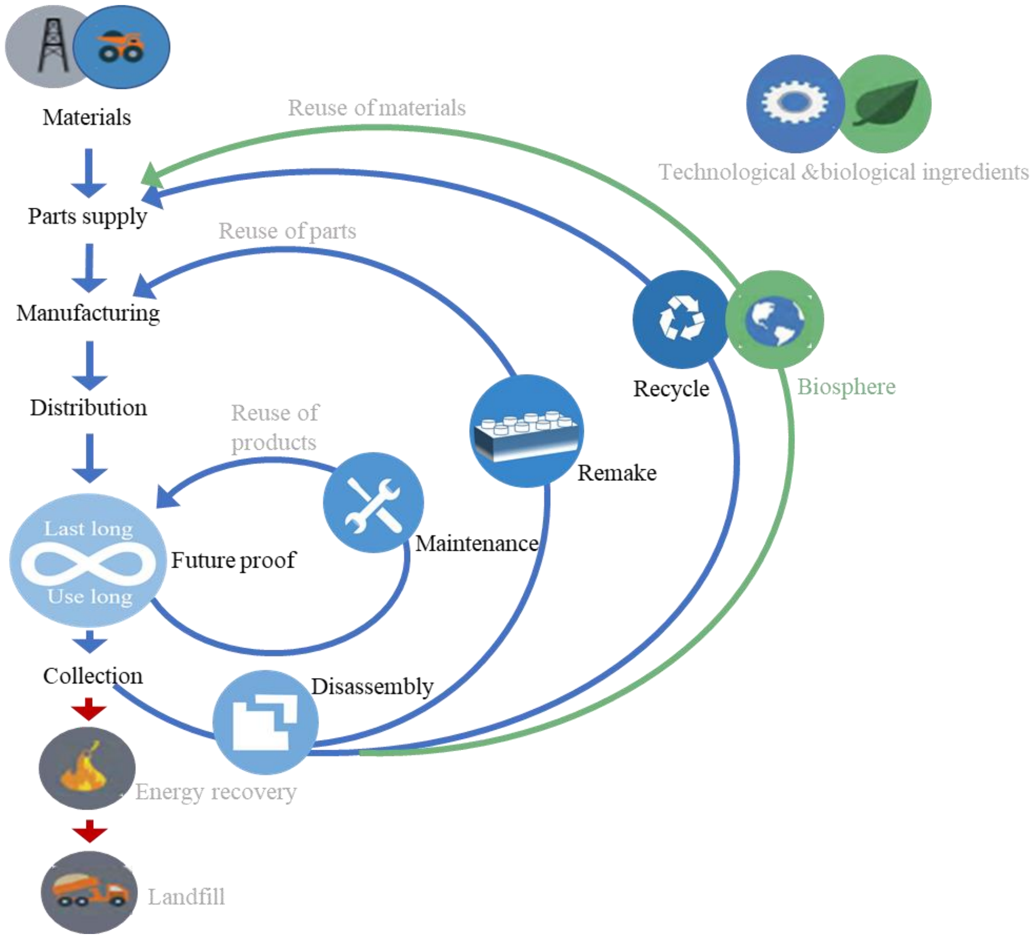

Figure 6. Circular product design model (adapted from Van den Berg and Bakker, 2015)

From a design perspective, optimal maintenance can be achieved by designing a product with lifetime prognostics, which help to predict product's functioning in the future (Van den Berg and Bakker, 2015). Fourth phase is remake, which belongs to extended use of components and includes all the actions related to returned products from buyers. Parker (2007) points out that since refurbishment, remanufacturing and reconditioning are diversely understood in each sector of industry, remake can be used as an umbrella in this term. In order to achieve affective repair and upgrading, modules should be defined precisely; therefore, modularity is a key role in remake stage (Van den Berg and Bakker, 2015). Final phase is recycling in which materials are recovered at end of-life and it is the final opportunity to recuperate remaining value of the product or component. In a CE, recycling is mandatory for all the products. Recyclability is dictated primarily with the choice of materials and the extent to which components can be separated from each other

(Bakker et al., 2014). Moreover, the bio cycle, where biological matter is added, is placed next to recycling circle. The facility to separate and recover materials is noteworthy from the design point of view (Van den Berg and Bakker, 2015)

To summarize, circular product design, designs products that last and use longer (future proof), can be disassembled, maintained, remade (components) and recycled (materials). **Figure 7** presents a circular product design vision that can be used as a tool during design process.

The figure can be briefly described as follow:

- Make the product future proof for endless performance and adaptability.
- With design for disassembly
- Easy maintenance for optional performance
- Modular design to remake products
- And optimizing for recycling at end of life

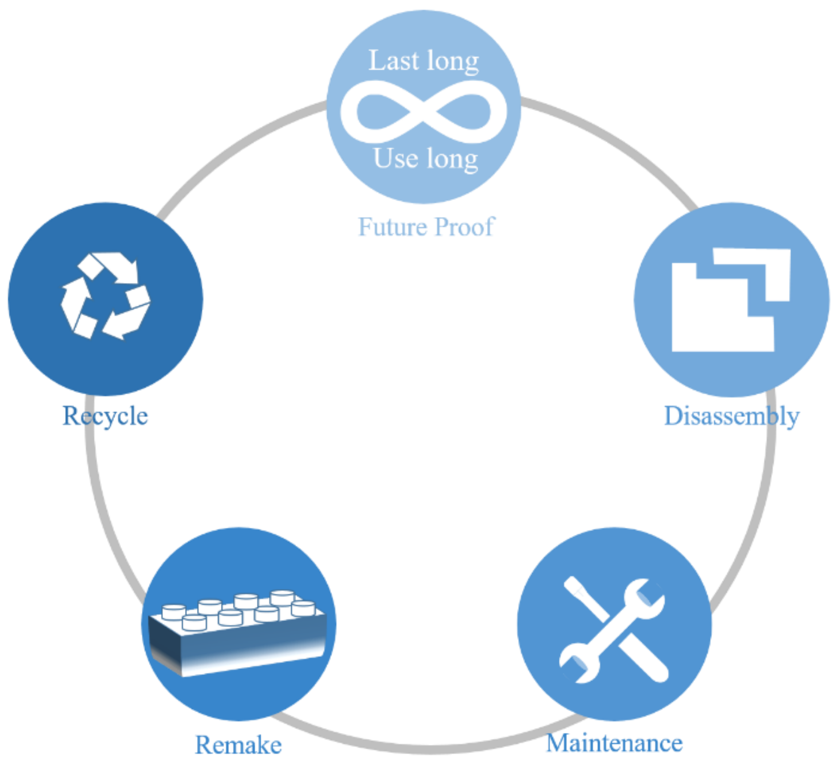

Figure 7. Circular product design vision (adapted from Van den Berg and Bakker, 2015)

A guideline list for circular product design is available in **Appendix 3**. The guideline can be used as a tool in product design process and is translated into a spider map which is presented in **Figure 8**. This tool can help in the processes where there is a lack of detailed information on the first stages of product design. The spider map can be used in discussion within a design team to define the aspects that requires consideration for CE and to realize on which area and what degree the product needs to be improved (Van den Berg and Bakker, 2015). As it is shown in the figure, the words along the axes, from center to the end, shows the increase in circularity. In this section, three tools have been introduced to help product designers in different ways. The circular design vision presents a quick-scan approach, while guidelines can be used in detailed design and the spider map can aid designers to compare products.

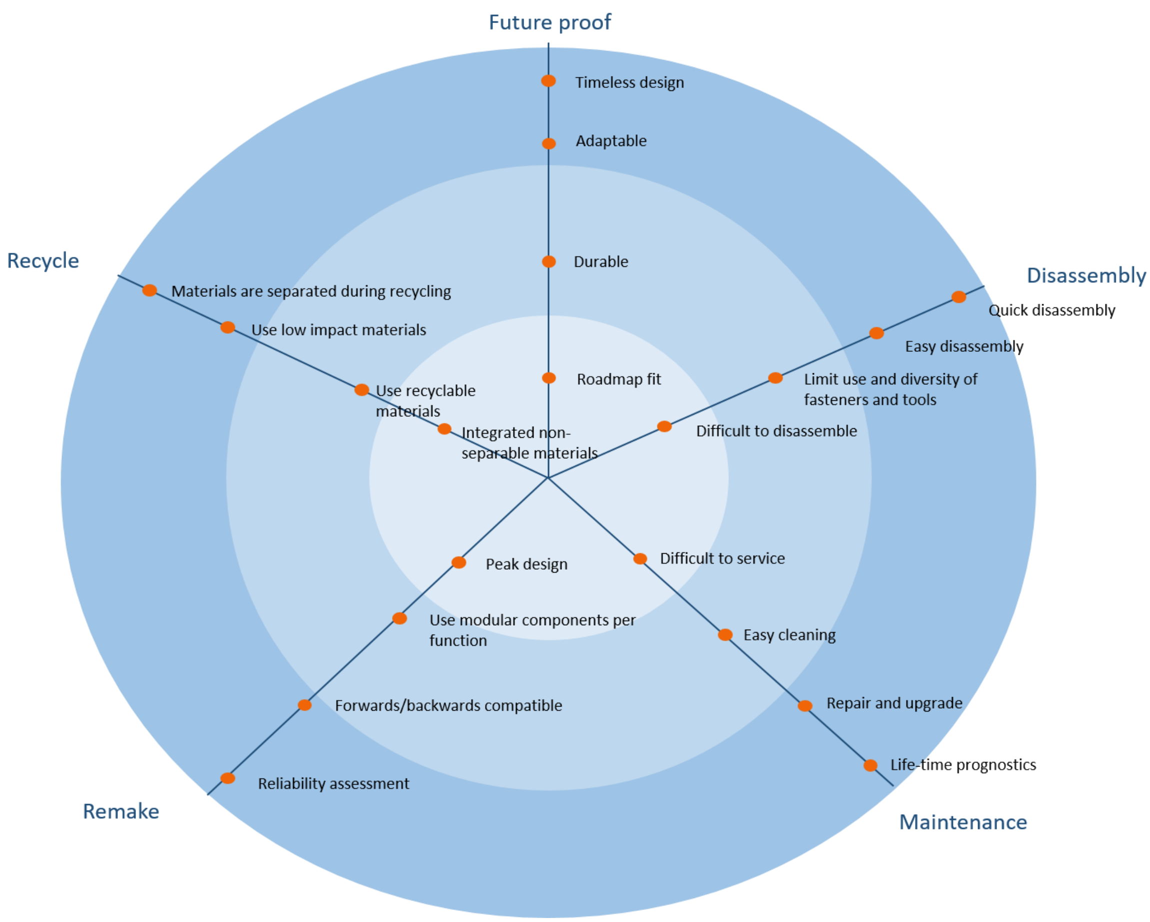

Figure 8. Spider map for designing circular products (adapted from Van den Berg and Bakker, 2015)

CE aims to circulate the products at their highest value level, thus circular design strategies and business models play a key role for the companies that want to move from a linear to a CE model. Governmental organizations together with business representatives state a significant growing in pressure on global resources as well as climate (IPCC, 2014). Since product designs in is the key factor in the early stages of product development processes, designers play an important role in providing possible changes of disposal and to make better relationship between users and products (Lofthouse, 2004). The characteristics of such a product has a direct influence on the value chain creation and the way it is managed (Bevilacqua et al., 2008), thus design has a vital role to support closing the loops in supply chains (Souza, 2013).

Figure 9 shows that since markets are changing fast and the diversity in consumer products is increasing, in order to have a better customer-driven market, the production-oriented approach shifted to market-oriented (Lin, 2018). More consideration on environmental aspects and consumer factors, strengthen product design and development (Durai Prabhakaran et al., 2006). In addition, according to Lin (2018), marginal profits of products and services will increase by utilizing CE.

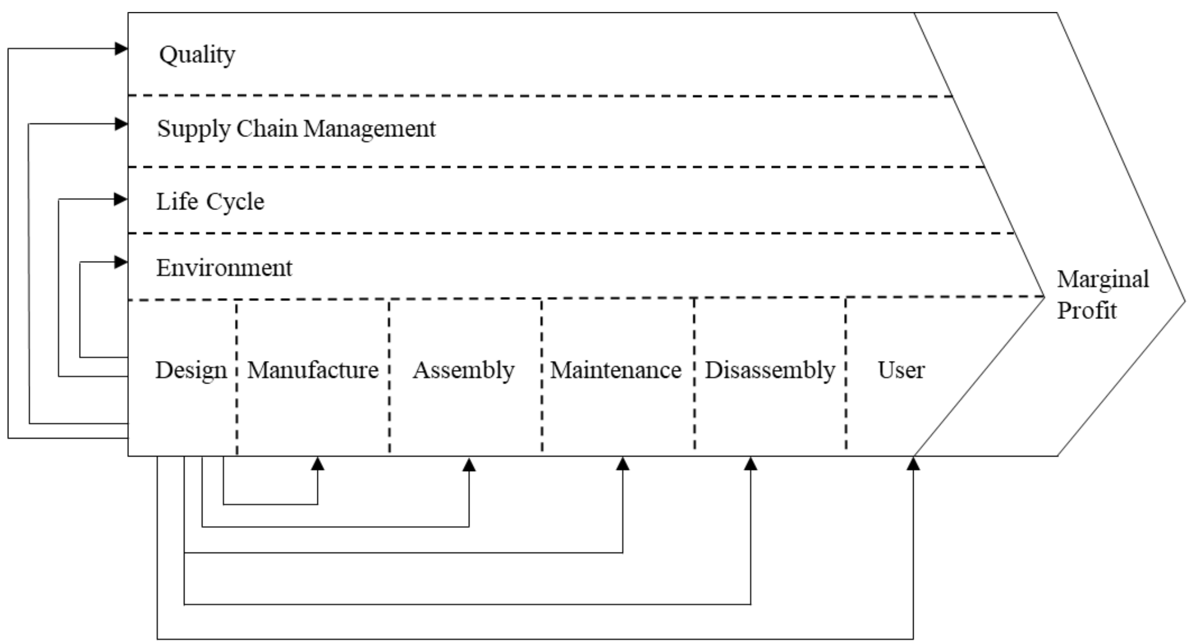

Figure 9. Value chain of product design and development (adapted from Lin, 2018)

Factors such as existing technical level, supply chain, transport, development strategies, future planning, policies and regulations and public awareness should be taken into account for a more affective practice of the CE . McDonough and Braungart (2002) discuss the importance of closing the loops both technically and biologically in a “cradle-to-cradle” or CE rather than cradle-to-grave. Next sections will provide a literature review of product design strategies and connection of Industry 4.0 and CE for businesses.

2.1 Circular design strategies

Vanegas et al.(2018) defines three product design in the vision of CE: “increasing material efficiency, product life extension, improving recycling efficiency”. Moreover, Ellen MacArthur Foundation (2019), argues features such as disassembly, upgradability or recycled content should take into consideration to design the products, components and materials towards circularity. Bocken et al.(2016) divided CE into three fundamental categories of narrowing, slowing and closing the resource loop. Narrowing loops is related to resource efficiency which aims to use fewer resources per product. Since the current strategies in narrowing the loops do not affect the speed of product flow, narrowing is not an aim of circularity, but can be used to reduce the products and processes resource usage (Bocken et al., 2016). Slowing loops focuses on designing long lifetime products and related activities to use and reuse products and materials for longer time. Moreover, circulating the materials by extending the lifetime of a product can generate revenue (Pocock et al., 2011). Closing loops is about recycling of goods and removing ‘leakages’ from the system (MacArthur, 2013). A circular flow of resources happens by recycling that closes the loop between post-use and production. **Figure 10** shows the three major strategies for design as defined by (Bocken et al., 2016) and will be illustrated in detail in the next subsections of this section.

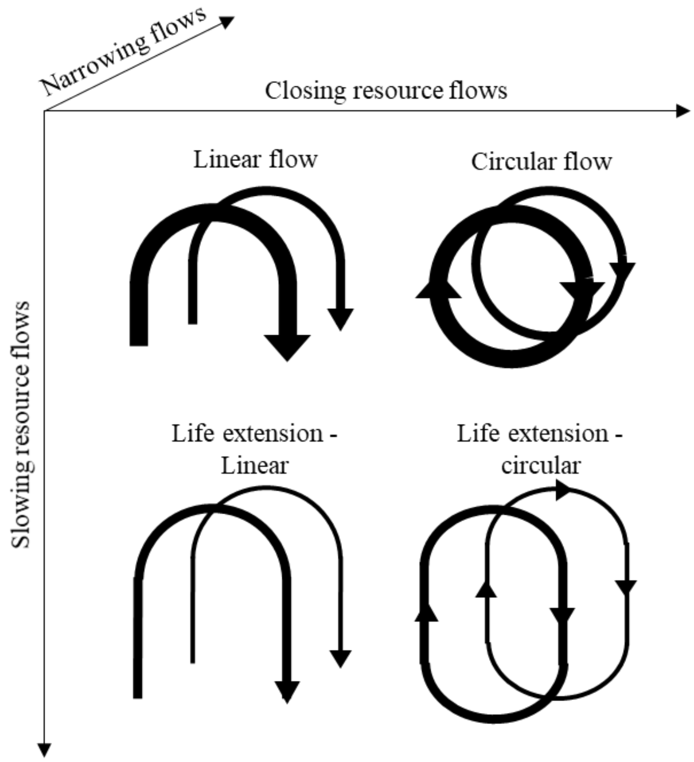

Figure 10. Strategies of slowing, closing and narrowing the loops (adapted from Bocken et al., 2016)

According to Atlason et al. (2017), in order to gain the proper function of these strategies in End-of-Life design, producers' intention should be aligned with users' handling the end use of product. If the priority for consumer is to repair and reuse the product, it is not desirable for producer to design for better recyclability. Essoussi and Linton (2010), mention the willingness of users to purchase products with reused or recycled was related to the perceived functional risk of products. Therefore, where the perceived risk is high and the margin price is low, users like to buy new products. Moreover, users' tolerance to uncertainty defines the willingness to pay for the perceived quality of refurbished product (Hazen et al., 2012).

2.1.1 Design strategies for slowing loops

In slowing resource loops strategies (**Table 2)**, slowing down the flow of resources is ensured by extending the utilization period of the product. Based on the concept of slowing loops which aims to prolong usage of materials over time, functionality is preferred than ownership. Design for attachment and trust or “design for emotional durability”, relates to producing the goods and products to be loved, liked or trusted longer. In other words, developing long-lasting partnerships (Champan, 2005). Design for durability refers to physical durability; therefore, durable material selection is one of the important parts of the design processes. Moreover, design for reliability relates to likelihood of product’s functionality without failure in a specific period of maintaining in accordance with the manufacturer’s instruction (Moss, 1985, p. 17). The second design strategy in slowing loops focuses on life-extension of the products. Design for ease of maintenance and repair concerns the services which extend product life such as reuse of products by repair, maintenance, etc. Designing the products for the purpose of repair and maintenance allows products to maintain their high quality. Products retain the functional capabilities in maintenance through inspection or service task performance (Linton and Jayaraman, 2005, p. 1814).

Table 2. Design strategies of slow down loops (adapted from Bakker et al., 2014)

Designing long-life products	Design for product-life extension
• Design for attachment and trust • Design for reliability and durability	• Design for ease of maintenance and repair • Design for upgradability and adaptability • Design for standardization and compatibility • Design for dis- and reassembly

Furthermore, repair refers to keep the products in a goo condition after a decay (Linton and Jayaraman, 2005, p. 1813). The aim of the second strategy of product life-extension design is to allow further expansion and modification. Upgradability refers to the ability of the product to remain functional under changing condition through value improvement and improving quality or effectiveness, etc. (Linton and Jayaraman 2005, p. 1814). Third strategy, design for standardization and compatibility, focuses on creating products with the parts that are usable in other products .In addition, in designing products for dis- and reassembly, the aim is to manufacture the products and parts that can be simply separated and disassembled (Bakker et al., 2014). In order to increase the future rate of reusing components and materials (Wilson, 2010).

2.1.2 Design Strategies for closing loops

The second major design strategy is for closing the resource loops. Ayres (1994) argues that there are two possible ways for materials' end of life: recycle and reuse, dissipative loss. McDonough and Braungart (2002) distinguished two different strategies for product design, technological and biological cycle. "Biological cycles" relate to dissipative losses, while the materials that fit "technological cycle" are made for recycling. **Table 3** summarizes Closing Loops Design Strategies. The first strategy suits the products that deliver a service. In technological system designing, designers aim in developing the products in a way that the recycled materials can consistently be used as new materials (Boulding, 2013). In design strategy for a biological cycle, products are made for consumption.

Table 3. Design strategies to close resources loops (Bocken et al., 2016)

Design strategies to close loops
• Design for a technological cycle • Design for a biological cycle • Design for dis- and reassembly

The third strategy is contributing to Design for a Technological and Biological cycle by ensuring the products and parts that can be disassembled and separated simply, essentially in separating materials that enter different cycles (Bakker et al., 2014). **Figure 11** shows an example of each resource cycle.

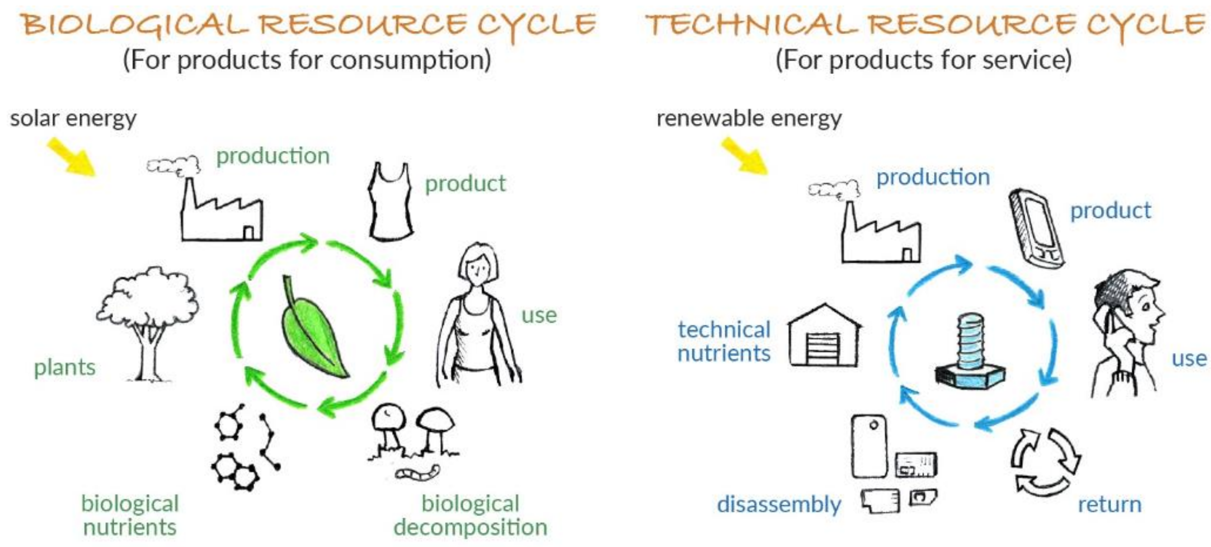

Figure 11. Resource cycles (Christian Wahl, 2016)

2.2 Circular business model innovation strategies

In a circular approach, the goal is to generate profits from the flow of products and materials instead of creating profits from selling the products (Bakker et al., 2014). Therefore, CBMs can enable feasible economical ways in reusing the products and materials constantly (Bocken et al., 2016). Business models define the way organizations do businesses and are considered as an important driver for innovation (Margetta, 2002). Business models innovation describe the organizational structure of a company (Wirtz et al., 2016) which refers to the way a firm makes value out of resources (Teece, 2010). Chesbrough (2010) distinguishes that while companies allocate vast investment on commercializing for innovative products and technologies through their business models, the capability of making business model innovation through which these innovations will pass is limited.

According to Teece (2010), as technologies or products do not guarantee the business success by themselves, each product development effort requires developing business models which defines the strategies of “go to market” and “capturing value”. Transition to a CBM requires a new way of thinking and doing business, therefore it is a radical change for companies. CBM aims to create, deliver, and capture value by implementing circular strategies which be useful in prolonging products and components lifecycle and to close the material loops (Nußholz, 2017). Business model design requires the focus on business models that can create and recreate value with less environmental impact along the product lifecycle. Schenkel et al. (2015) mention that organizations can capture revenue stream multiple time through the lifecycle, for instance through extended spare part. Therefore, separate value creation architectures are required in creating and capturing value from closing the loops or prolonging products and components useful life. **Figure 12** illustrates how the elements of the business models are designed to support in each cycle in maintaining value and utilization.

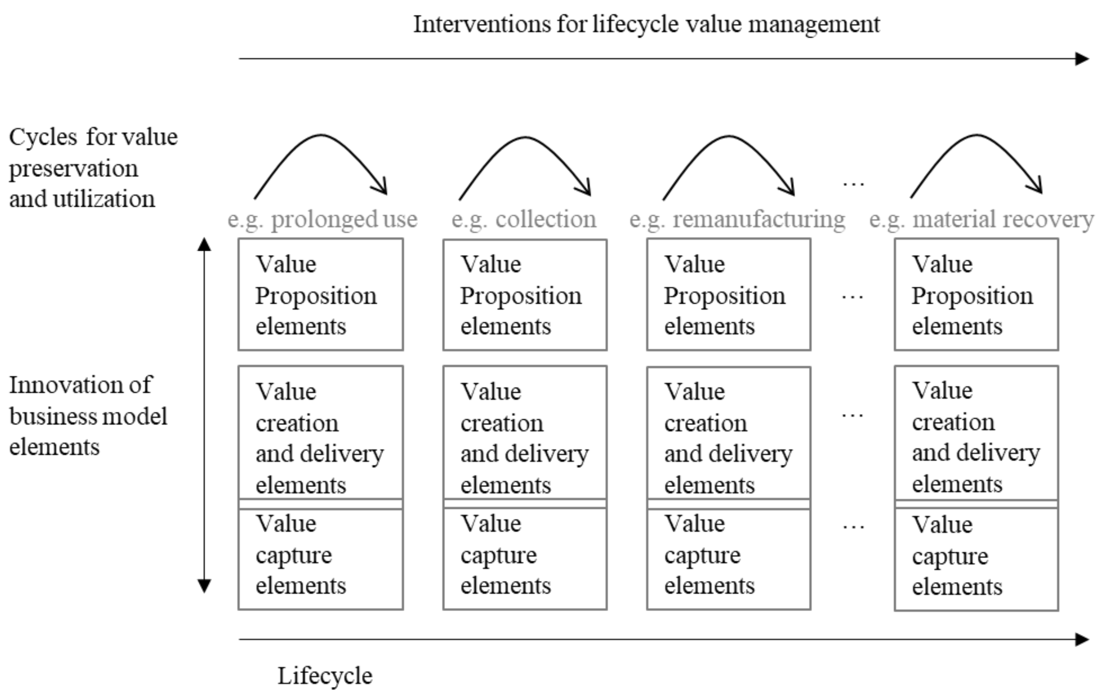

Figure 12. A conceptual framework for CBM (adapted from Nußholz, 2017)

According to Antikainen and Valkokari (2018) " Circular business model innovations are by nature networked: they require collaboration, communication, and coordination within complex networks of interdependent but independent actors/stakeholders". The key factors for CBM innovation which are on top of customer superior value are "resource efficiency, resource longevity/effectiveness and economic growth" (Geissdoerfer et al., 2017).

Moreover, CE-oriented business model innovation might create work enrichment or social relevance value (Pieroni et al., 2019). According to (Urbinati et al., 2017), circular design options can develop downstream circularity , therefore they might be part of business model innovation. Linder and Williander (2017) defines CBM as a return flow from the user to the producer, therefore the concept overlaps with the concept of closed-loop supply chains and involves refurbishment, renovation or repair. A framework for sustainable CBM innovation is shown in **Figure 13**.

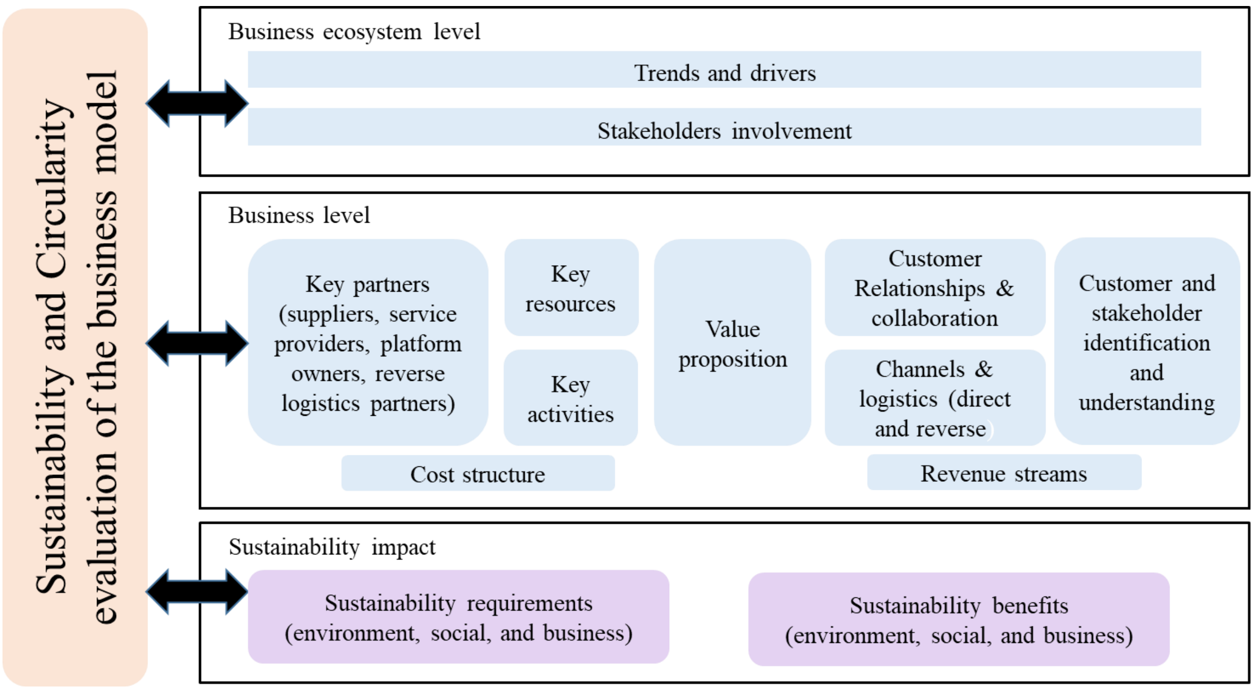

Figure 13. Sustainable CBM framework (adapted from Antikainen and Valkokari, 2018)

Since CE oriented business model adds uncertainties and complexities to conventional business model, new variables such as reverse on top of forward logistics, timing of return of resources, quantity and quality as well as customers perceptions and preferences should be considered in building a CBM (Bocken et al., 2018) . According to Urbinati et al. (2017), there are three different ways in integrating circular principles in business models: downstream circular (new schemes and customer interface make alternative value), upstream circular (change the value creation systems) and fully circular (combination of downstream and upstream principles). **Table4** presents the key business model strategies for slowing and closing the resource cycles defined by Bocken et al.

(2016). The models are illustrated through three different business model frameworks that include value proposition, value creation and delivery, value capture.

Table 4. Business model strategies of closing and slowing the resource loops (Bocken et al., 2016)

Business model strategies for slowing loops	**Business model strategies for closing loops**
Access and performance model: to provide capabilities or services to satisfy user needs without the need of owning physical products	Extending resource value: to exploit the residual value of resources by collecting and sourcing of otherwise "waste" materials and turn to new forms of value
Extending product value: to explore residual value of products	A process-oriented solution: to use residual outputs from one process as feedstock for another process
Classic long-life model: to deliver long-product life for instance by design for durability and repair	
Encourage sufficiency: Solutions to reduce end-user consumption through durability, upgradability, services, etc.	

It is argued that design and business model strategies are interrelated, therefore businesses need to implement an overall goal or vision focused on "circularity". Following are two case examples for closing and slowing the loops strategies.

Business models for slowing loops: Konecranes

The Finnish domestic company Konecranes is an example of "Classic Long Life" and "Encourage Sufficiency" business model strategies. The company is a world-leading provider of lifting equipment and services which produces high-quality Cranes. Konecranes' cranes are an example of "Classic Long Life" as a business model due to their long life of almost 35 years. Moreover, Konecranes' service and maintenance business model is the main goal of company's circular business model in which remote monitoring and extensive analytics are the key enablers. Remote monitoring provides detailed diagnostics of the usage as well as current conditions of critical parts of the system which leads to service operations optimization. Components are only changed when it is necessary and maintenance decisions are based on data, not on calendar. In this way, Konecranes owns production for spare parts for their products and other manufacturers' equipment as well. In addition, the company offers rebuilt parts by urgent repairs and refurbishing the major parts or components (Technology Industries of Finland, 2018) . In 2018, Konecranes announced their new business model in modernization of cranes to extend the life of cranes through upgrading, reliability and preventive maintenance system (KONECRANES, 2018). In overall, company has the design strategies for durability, upgradability, maintenance and repair, thus business model innovation goes along with product innovation for circularity.

Business model for closing loops: SSAB

SSAB is a global leading producer for Tempered Steels (Q&T), strip, plate, tubular products and construction solutions (Technology Industries of Finland, 2018). The production plants are in US, Sweden and Finland. SSAB's steels help in making lighter products as well as increasing strength and lifespan. Company has various circular business models in repair, re-use, return and recycling products. Closing the loop business model refers to company's business model in recycling steel, an example of "Extending resource value". The concept of circular supply-chain in steel industry in Finland is that 20-100% of the material used in production is recycled steel. Within SSAB's steelmaking process, materials are recirculated as raw material back into the production process to reduce the need for raw materials and therefore eliminates waste and CO_2 emissions. In addition, materials that are not recirculated internally is processed into by-products and will be sold externally, which creates new revenue streams (SSAB, 2019). Furthermore, industrial symbiosis is a natural way to rethink in the steel industry. SSAB together with other members in steel producing ecosystem has evaluated the types of by-products, which is generated in each other's production and whether waste of one party could be used as raw materials in some other places. Although Industrial Symbiosis is not considered as a business model innovation, in this case, by the competitive advantages that Industrial Symbiosis bring to the company, it can be used as a driver for business model innovation.

3 INDUSTRY 4.0 AS AN ENABLER OF CE

Although circular strategies aim to prolong products lifetime and to close material flow (Blomsma and Brennan, 2017), companies face serious challenges in moving towards circularity. The challenges that prevents to achieve sustainability goals in companies, pave the way towards the implication of emerging digital technologies such as industry 4.0 (Rajput and Singh, 2019). Digitalization facilitate companies in transforming towards a more circular sustainable model by providing precise information on the availability, location and condition of the products in order to close the material loops (Antikainen et al., 2018). Digitalization enables efficient processes in firms by reducing waste, enhancing longer life for products as well as minimizing the transaction costs (MacArthur, DE and Waughray, 2016). Therefore, it can help closing, slowing the material loops and narrowing the loops in the CBMs with increasing resource efficiency(Antikainen et al., 2018). Industry 4.0 technologies which are presented in Appendix 1, are identified as a technological innovation from IS/IT to smart devices which utilizes advanced automation systems, cloud computing and ubiquitous systems(Rajput and Singh, 2019). **Table 5** presents a framework of Industry 4.0 in IMS. According to (Davies, 2015; Lee et al., 2015; Rüßmann et al., 2015) , the term Industry 4.0 is a combination of Cyber-physical systems (CPS), Internet of Things (IoT), Industrial internet and AI, in other words internet services.

Table 5. A framework of Industry 4.0 IMS (adapted from Zhong et al., 2017)

Design	Machine	Monitoring	Control	Scheduling
Smart design	Real-time control and monitoring	Real-time information sharing	Data driven modelling	Marketing
Smart prototyping	Collaborative decision-making		Big data analytics	Warehouse management
Smart controller			Data-enabled prediction	Transports
Smart sensors				

By utilizing the information generated from various smart devices, it can optimize sustainable solutions in reducing the emission and resources from industrial systems (Tseng et al., 2018). Although 4IR will not overcome all requirements and challenges in moving towards circularity , they offer the tools that are more cost efficient and make the move easier (World Economic Forum and Accenture Startegy, 2019). Industry 4.0 brings advanced effects in transforming linear economy to CE based sustainable supply chain. Integration of CE and Industry 4.0 leads to sustainability, which is a motivation for business organizations to move towards the supply chain as well as a new outlook for production and consumption (Rajput and Singh, 2019). Industry 4.0, which is also known as smart manufacturing, helps managers in decision-making by providing the real time information on machines, flow of components and production, monitoring performance and tracking parts and products (Lu, 2017). Industry 4.0 technologies can certainly pave the way in integrating CE principles through tracking products post-consumption and recovering components (Jabbour et al., 2018). **Figure 14** illustrates 4IR solutions for circularity. CE business models could benefit by Industry 4.0 with applying these technologies in the form of sensors and apps; for example to plan, monitor, predict and control the lifecycle of the products (MacArthur, DE and Waughray, 2016).

Precise demand forecasts will make it easy to implement the CE principles, thus more precise plan to reuse and preparation of used materials can be made (Blunck and Werthmann, 2017). Moreover, digital technologies can help in product design and making decisions on production through sustainable operations management by providing data on the resources to reduce resource consumption, improving productivity and extending the lifecycle of products (Bressanelli et al., 2018). Utilizing products by sensors allows monitoring performance, for example to monitor the requirements for maintenance. therefore, organizations can provide high quality services to the customers. Furthermore, these technologies enable connectivity and sharing information related to supply and demand; for example by website and apps which connects people to organizations (Jabbour et al., 2018). In addition, since such technologies can collect the information on consumers' behavior, they help the organizations in improving design of products and services for a better utilization of equipment to meet the customer's needs and satisfaction (Rymaszewska, Anna and Helo, Petri and Gunasekaran, 2017). With the ability to collect data from operations, processes and objects, digital technologies can help to identify possible failures which creates waste and to prevent further failures (Jabbour et al., 2018). The concept ‘product passport’ refers to the Industry

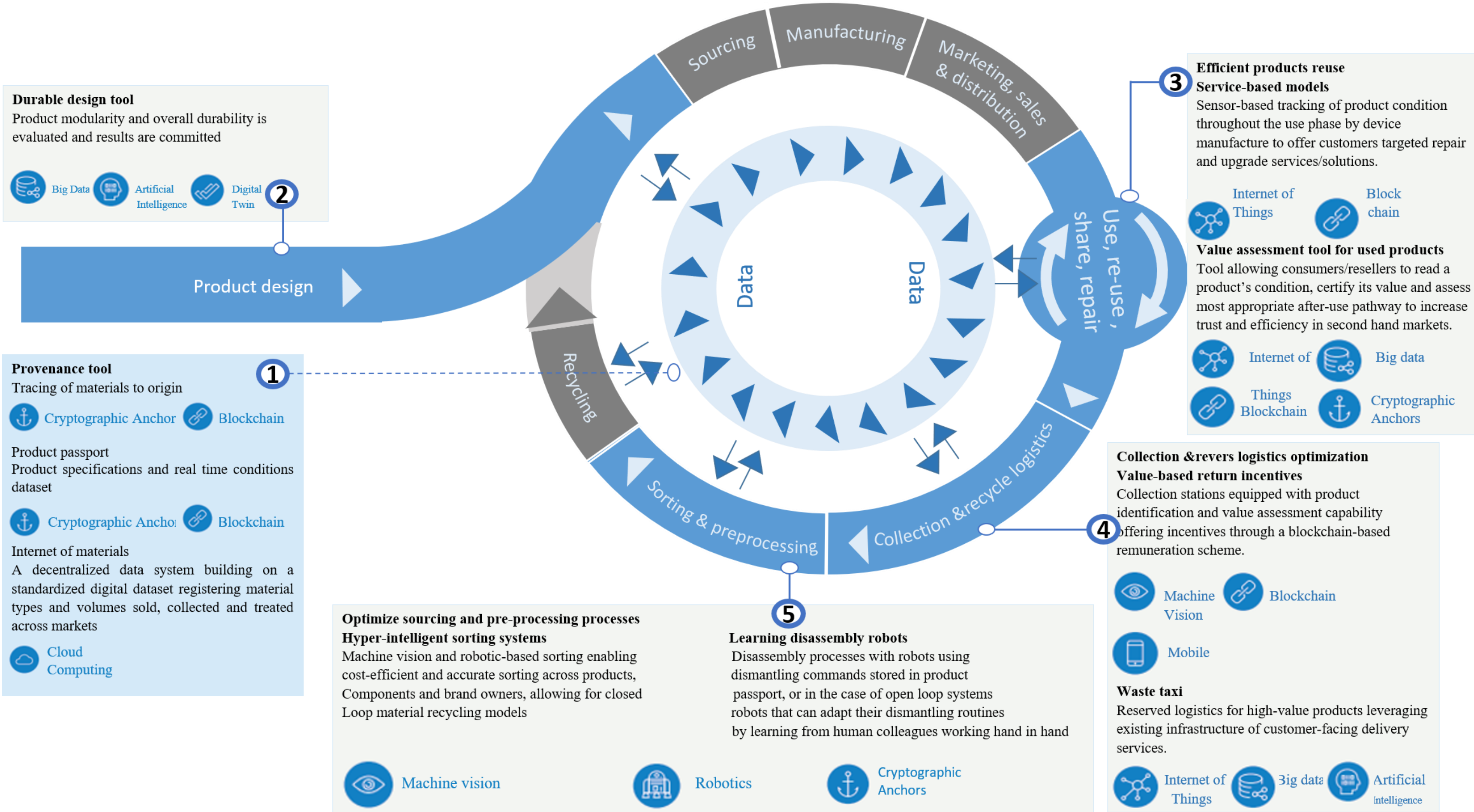

Figure 14. Industry 4.0 solutions for circularity (adapted from World Economic Forum and Accenture Startegy, 2019)

4.0 technologies that support the Loop approach by adding chips and sensors in designing products to provide the information that is needed for the users of products, components and materials as well as the possible ways of disassembling and recycling products (European Comission, 2013). This concept facilitates CE cycles through reuse, remanufacture and recycle components of products (Sung, 2017), supporting organizations to find the buyers for reused or refurbished components (MacArthur, DE and Waughray, 2016). Fewer resources will be extracted to produce entirely new goods if the companies are ensured to cover actual demand by recycling the used materials (Blunck and Werthmann, 2017). Potentials and value drivers of emerging technologies to a more sustainable manufacturing is described in **Figure 15**.

Figure 15. Potential of Industry 4.0 technologies in manufacturing more sustainable products (Blunck and Werthmann, 2017)

According to Jabbour et al. (2018) the first step in transforming to CE for organizations is to define the business models that suits their production process. Secondly, organizations have to distinguish different types of Industry 4.0 technologies and resources that are more practicable for them. Factors such as availability, technical strains and costs should be taken into account.

Third step is to make decisions on adapting sustainable operations management (SOM)in designing products as well as processes and logistics of products. Next step is to develop the integration of tires in supply chains to connect technologies and resources and to share the real time information concerning demands, deliveries, supply and customers' behavior . Fischer and Pascucci (2017) mention that collaboration facilitation and business relations development is one of the most relevant challenges organizations can face in transition towards CE.

Therefore, organizational transition plan is required both internally and externally towards CE and Industry 4.0 (Jabbour et al., 2018). The final step is to create indicators of performance for measuring the progress towards CE (Elia et al., 2017). A pioneering roadmap towards an Industry 4.0-based CE business is illustrated in **Figure 16**. In addition, referring to CE and sustainable manufacturing, improvement in using data, machinery equipment and software can reduce the need of limited resources as well as ecological footprint of the production is leading to new business models (Blunck and Werthmann, 2017). However, manufacturing industries would face challenges such as cybersecurity concerns, developing new talent, new business models and definition of the new strategy in attempting to implement Industry 4.0 (Zaouini, 2017).

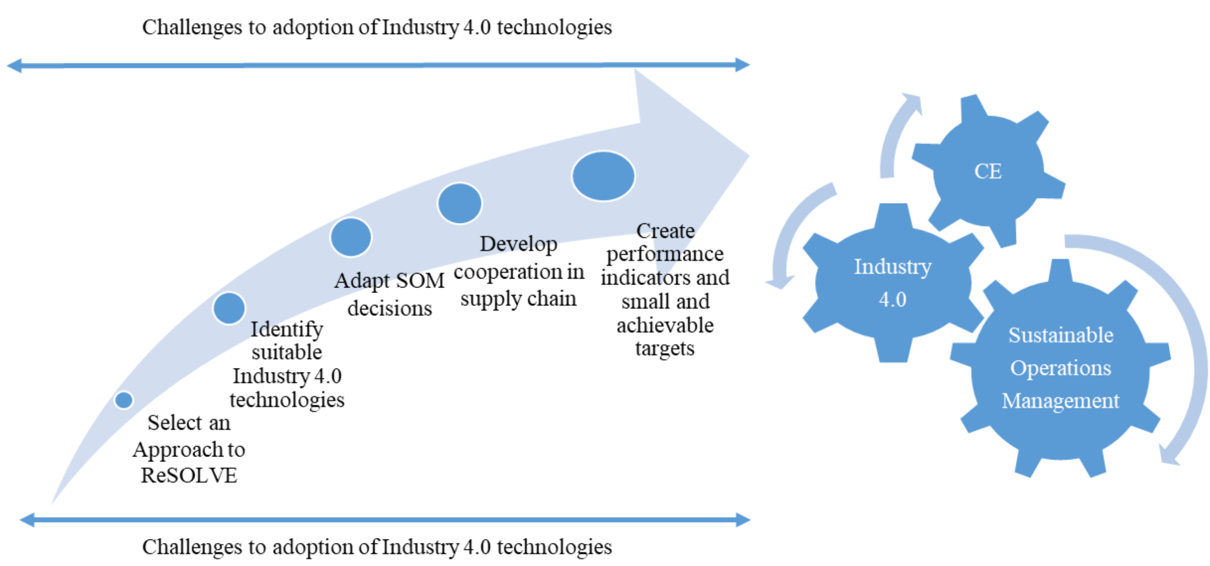

Figure 16 . Roadmap towards Industry 4.0 and CE (adapted from Jabbour et al., 2018)

3.1 Industrial AI

John McCarthy, who is known as father of AI coined the term Artificial in 1956. According to McCarthy (2007), "Artificial intelligence is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable.". Kaplan (2016) in his book, AI: What Everyone Needs to Know, defines AI as computers' programs which are able to behave in a way that would be considered as intelligent if demonstrated by human. Hence, the definition of AI concerns the comparison and alignment between human and machines. According to Ellen MacArthur Foundation (2019), AI processes data similarly to the human brain and learns to make better decisions over time. **Figure 17** illustrates the algorithm development for a deep learning application. Lee et al (2018) distinguish AI as "a cognitive science", which enhances research activities in the areas of natural language processing, machine learning, image processing, robotics etc.

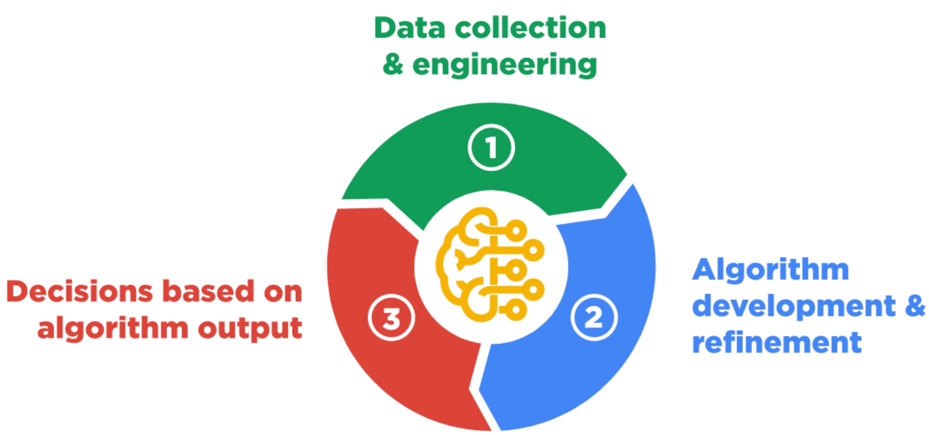

Figure 17. AI algorithm development process (Ellen MacArthur Foundation, 2019)

As it is shown in **Figure 17**, the first step is to collect data by capturing images and other metadata. The collected data is then categorized constantly and engineered into a machine-readable format where the algorithm is developed. According to the use case, different types of algorithms can be employed then (Ellen MacArthur Foundation, 2019). As presented in **Figure 18**, the algorithms can be used in various functionalities such as pattern recognition, prediction, optimization & planning, and integrated solutions with robots . Brynjolfsson and Mcafee (2017) mention that two broad areas which have the biggest advances from AI are perception and cognition. Some of the most practical advances in the former category are related to speech. Siri, Alexa and google assistant are examples of voice recognition. In addition, image recognition as well as problem solving through Machines has improved dramatically in accuracy over the past decade, from 85% to 95% (a human averages 93%) (World Economic Forum and A.T. Kearney, 2017).

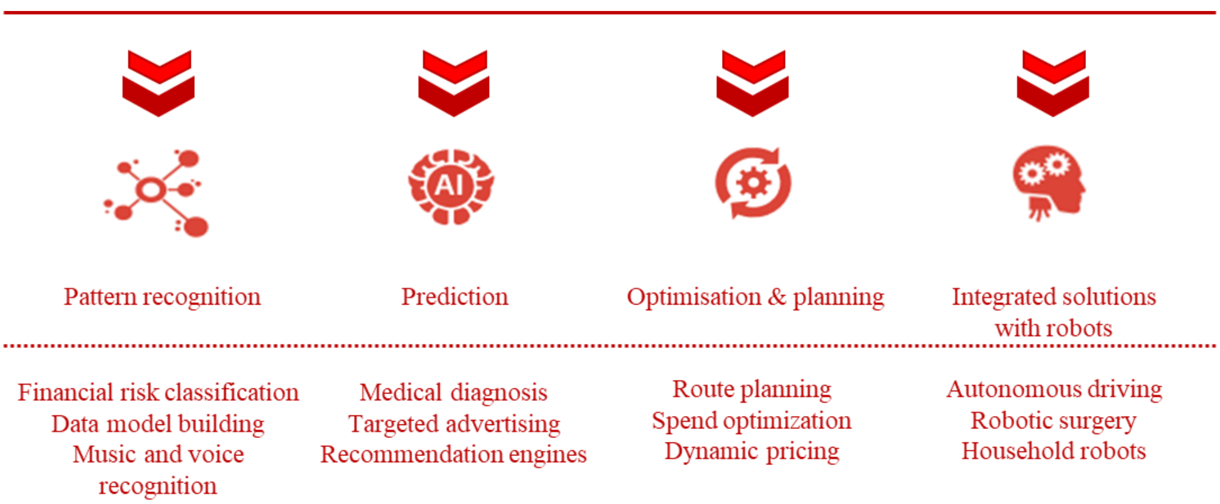

Figure 18. Decision based on algorithm output (adapted from Ellen MacArthur Foundation, 2019)

Moreover, **Figure 19** shows the development of AI and the future state of AI techniques. This progress is mainly due to the advances of three enablers of real innovations: training data, learning algorithms and computing power. Advanced robotics among many digital technologies progress in 4IR, has been identified as a significant alternative in the entire value chain. It is estimated that 1.8 million industrial robots will operate in production system globally which represents approximate market of $35billion worldwide (World Economic Forum 2017).

	100% Level of human involvement 0%				
	Rule-based computing	Machine learning			
Cognitive mode	**Rule-based inference**	**Supervised learning**	**Unsupervised narrow learning**	**Unsupervised context-aware learning**	**Self-aware unsupervised learning**
Natural language processing	• Spell and grammar check	• Voice to text dictation	• Personal assistant apps for basic voice-based Q&A	• Real-time dialogue and translation	• Idioms, sarcasm, nuance articulation, information
Computer vision	• Inspection of fruit defects with infrared images	• Facial recognition • Identifying verification by fingerprints	• Complex classification (e.g. video segment search)	• Vision systems for self-driving vehicles	• Digital security agents • Autonomous exploration agents
Pattern recognition	• Industrial inspection based on rules on faulty functioning	• Fraud detection (e.g. based on historical fraud patterns)	• Product recommendation based on customer preference	• Automated real-time clinical diagnosis	• Disease development and prediction of infections
Reasoning and optimization	• Diagnostic maintenance	• Predictive maintenance for machinery and vehicles	• Failure prediction in mission-critical systems	• Automated recommendation based on inputs in value chain	• Search engine answering questions instead of giving search results
	Over 5 years ago	**5 years ago**	**Current**	**2030 and beyond**	

Figure 19. Development of AI and the future state of AI techniques (World Economic Forum and A.T. Kearney, 2017)

However, Fleming (2018) discusses automation and robotics will not make that jobs to disappear, instead low-paid jobs are likely to increase in the near future. Moreover, Manyika et al (2018) distinguish that an extra USD 13 trillion value is predicted to add by AI to global economic activity by 2030.

According to Jacoby and Paltsev (2017), AI reduces the costs in businesses by prediction. It is capable to collect the information that human has and generate information that they did not have before. Over the recent years, industries have been facing new challenges in terms of market demand and competition, thus Industry 4.0 brings a radical change in businesses. The role of machine learning and AI techniques in industrial applications is to provide solutions in a systematic method and discipline (Lee et al., 2018). The aim of Industrial AI is to validate, develop and deploy different machine learning algorithms with a sustainable performance for industrial applications. According to Lee et al.(2018), an Industrial AI ecosystem is a progressive thinking strategies for challenges, needs, technologies and methodologies that are required to develop transformative AI systems in industry **(Figure 20)**.

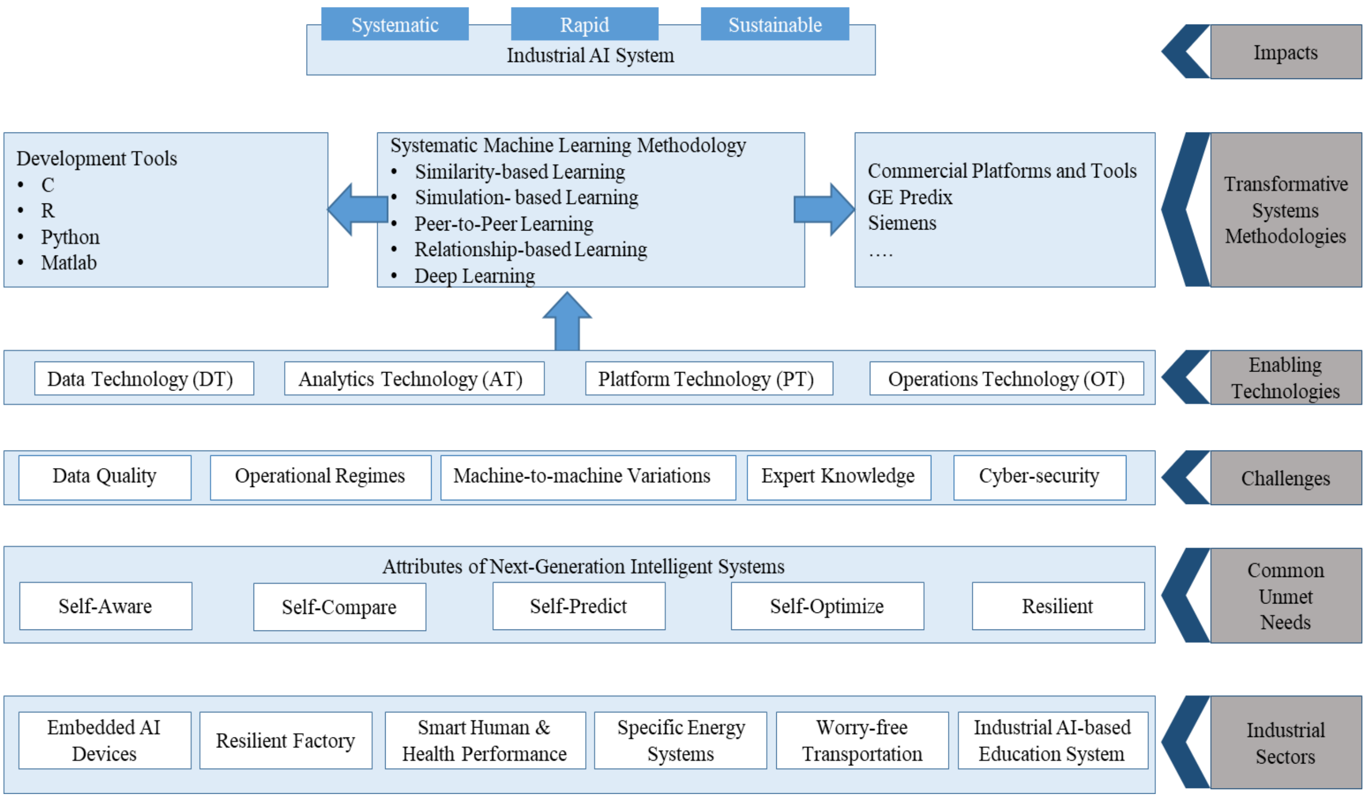

Figure 20. Industrial AI Eco-system(Lee et al., 2018)

Such ecosystem identifies the needs such as Self-aware, Self-predict, Self-compare, Self-optimize and Resilience. As depicted in **Figure 20**, the main four enabling technologies to achieve successful Connection, Conversion, Cyber, Cognition and Configuration are Data Technology, Analytics Technology, Platform Technology and Operations Technology. According to (Forbes, 2019), AI will revolutionize 13 industries in near future as follow: "cybersecurity, devOps and cloud hosting, manufacturing, healthcare, construction, senior care, retail, business intelligence, city planning, mental health diagnosis and treatment, education, fashion and supply chain". However, Applying AI to industries brings real challenges such as machine-to-machine interactions, data quality and cybersecurity (Lee et al., 2018).

3.2 Intelligent manufacturing

Intelligent manufacturing (known as smart manufacturing), refers to the manufacturing concept which uses advanced information and manufacturing technologies in optimizing production and product transactions (Kusiak, 1990). Zhong et al. (2017) define intelligent manufacturing as a modern manufacturing model based on intelligent technology and science which upgrades design, production and management significantly and integrates a typical product through product's entire lifecycle. Holubek and Kostal (2013) mention that intelligent manufacturing system consists of intelligent design, intelligent operation, intelligent control, intelligent planning and intelligent maintenance. Various smart sensors, advanced materials, intelligent devices, adaptive decision-making models and data analytics are used to facilitate the whole product lifecycle (Li et al., 2017). Accordingly, product quality, production efficiency and service level will be improved (Davis et al., 2012). Industrial manufacturing system is considered as the next manufacturing system generation which is obtained by adapting new forms, models and methodologies to transform the traditional manufacturing system into a smart system (Zhong et al., 2017). AI provides features such as reasoning, acting and learning in industrial manufacturing system and therefore plays a key role. With the use of AI technology as a complement of human's skill which deals more effectively with complexity, human involvement in IMS is minimized (Ellen MacArthur Foundation, 2019; Zhong et al., 2017). **Figure 21** presents five main types of intelligent manufacturing technology systems.

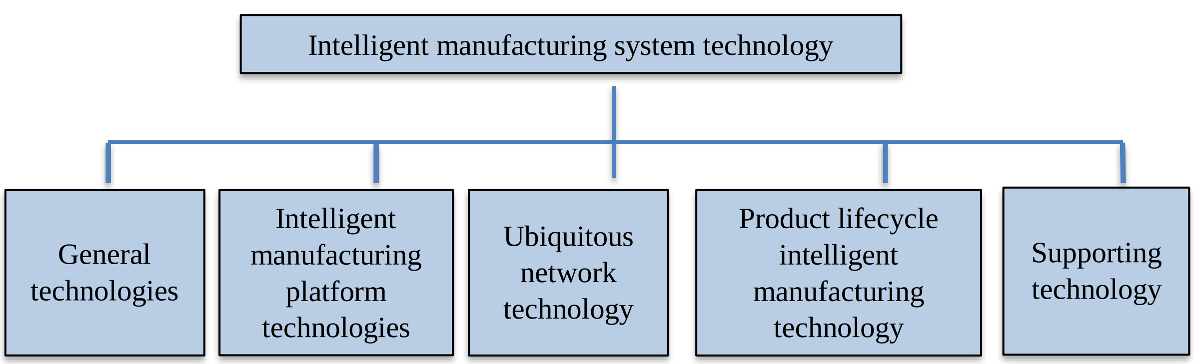

Figure 21. Intelligent manufacturing technology systems. (adapted from Zhong et al. 2017)

The application of AI in product lifecycle mainly consists "intelligent cloud product design technology, intelligent cloud innovation design technology, intelligent cloud production equipment technology, intelligent cloud operation and management technology, intelligent cloud simulation and experiment technology, and intelligent cloud service guarantee technology" (Li et al., 2017). AI can utilize production optimization in manufacturing companies. Machine learning techniques are employed to identify and rank the probable root causes of production (Seebo, 2019) AI can help product designers in IMS to create multiple prototypes versions and more efficient testing (Philips, 2018). However, implementing AI is not easy and requires experts for algorithm development, preparation of training data as well as translating the algorithm output into the meaningful results for humans (Ellen MacArthur Foundation, 2019). In addition, to train the algorithm, the availability of sufficient high-quality data is required. Poor quality outputs result from badly engineered data, in other words rubbish in, rubbish out. Next section presents the relation between AI and CE, how AI techniques have been employed in designing circular products and maintenance services.

3.3 AI and CE

According to Ellen MacArthur Foundation (2019), AI techniques are considered as an enabler of CE and enhance CE innovation in three main ways:

1. By improving the sorting and disassembling products processes, remanufacturing the components and recycling materials: AI can help in closing the loops by building and improving the reverse logistics infrastructure.
2. To expand innovative circular business models: AI can help to combine real time and historical data from users and products to increase product circulation and asset utilization through pricing and demand prediction, predictive maintenance and smart inventory management.
3. Design and develop circular products, components and materials: By rapid prototyping and testing through machine-learning-assisted design processes

AI can help in design out waste for food in CE and generate the potential value of USD 127 million by 2030 (Ellen MacArthur Foundation, 2019). Applications such as image recognition can help to determine the time to pick the ready fruit and match the supply and demand. The way AI helps food a circular food system is presented in Appendix 5. AI can facilitate farming, processing, logistics and consumption processes.

3.3.1 Infrastructure optimization business model

AI can help in circular infrastructure optimization by recycling materials and components. AI can be used in waste-sorting improvement and efficiency by increasing the value of recycled and recovered materials (Ellen MacArthur Foundation, 2019). Moreover, robots can increase precise waste-sorting and therefore enhancing the opportunities for reusing materials from wastes (Sitra, 2017a). ZenRobotics' announced its latest version of intelligent waste-sorting robots which have the most intelligent software and high speed in waste separation (ZenRobotics, 2018a). ZenRobotics Fast Picker is ideal for lightweight materials and powered by ZenbrAIn, which is a unique Artificial intelligence software. Machine learning enables the software in accurate smart sorting by real-time sensor input instead of following a pre-programmed routine. The model relies on sets of sensors; RGB camera and LED lamps for waste analysis. In addition, the strongest waste-sorting robot (ZenRobotics Heavy Picker), which can lift objects of up to 30kg, minimizes the need for pre-shredding of waste as well as pre-sorting with an excavator (ZenRobotics, 2018b). ZenRobotics share of the CE solution of the total business is 100%.

3.3.1.1 Operate innovative circular business model

In order to develop successful and profitable innovative circular business model, organizations require functions such as pricing, marketing, sales and after sales services as well as customer support (Ellen MacArthur Foundation, 2019). Digital platforms and platform business models offer new opportunities to provide services, share things and making value both for companies and users (Confederation of Finnish Industries EK, 2016). Digital platforms play a key role in businesses by extending the life-cycle of the product to attain their innovative circular business model objectives through dynamic pricing and matching algorithms (Confederation of Finnish Industries EK, 2016; Ellen MacArthur Foundation, 2019; Sitra, 2017b). AI-based analytical model which is capable to collect and analyse huge quantity of customer and product data, helps companies to make decisions on next use cycle of returned products (reuse, components recovery, recycle) faster and in a more feasible way (Ellen MacArthur Foundation, 2019). Online flea markets are the best examples of digital platforms in which sellers can sale unwanted used goods and buyers can buy cheaper products. Tori.fi is Finland’s leading online platform which offers services to consumers, small companies and communities and large companies (Sitra, 2017b).

3.3.1.2 AI design circular product business model

According to Ellen MacArthur Foundation (2019), AI technologies help to reveal high potential circular opportunities in designing circular products, components and materials. Design innovation allows cycles of reuse, repair, refurbishment and recycling of technical components as well as looping of biological nutrients. AI techniques can help scientists to evaluate a huge amount of data on the materials’ properties and structure in designing a new material b rapid analyzing. In addition, AI could help in predicting the toxicity of materials or chemicals by developing the algorithm that analyzes known chemical data in a more economic and efficient way. AI can help in closing and slowing the materials loops by reducing the faults in designing and prototyping products and materials, making less waste in manufacturing processes. According to World Economic Forum and Accenture Startegy (2019), AI-based application supports designers by connecting data on alternatives to harmful or hard-to-recycle materials within a product. The results of the product modularity and durability evaluation lead to and overall circularity index for the designed product. For more understanding of Below are two case examples of food and electronic companies taken from (Ellen MacArthur Foundation, 2019).

Design healthier food products

Over the last years, the demand for the processed and easy to prepare food has been increased significantly due to time saving and cost benefits. Each year a huge amount of world’s food crops is used in the intermediate food design stage or the process of creating final product we eat. Therefore, circular product design and strategy is a suitable model in producing processed food. Food designers and innovators can use AI tools to regenerate source ingredients by replacing animal protein with plant-based protein ingredients, reducing waste processes as well as preventing unhealthy additives. In addition, different brands and food providers can use AI in creating innovative recipes that avoids using additives which may have negative affect to return to soil as fertilizer. Food design augmented by AI requires consideration such as nutritional value, color, texture, text as well as ingredients interacting and respond to different heat and moisture conditions. NotCo uses machine learning algorithms to distinguish new plant-based foods in creating food formulas by detecting molecular structure and flavor molecules analysis. In order to compare and ensure the taste quality of the final product with the original taste, the formulas are tested and tasted by food scientists to provide a feedback to the algorithms. Moreover, the feasibility of the algorithm's output is evaluated by scientists regarding to economics and availability (Bien-Kahn, 2017).

Design circular consumer electronics

Electronic products, components and materials need to be designed in a more uniform and modular structure to allow disassembly for refurbishment, remanufacturing and recovery of materials. In addition to promote device reuse and access models, easy transferring of personal data is required. By use of AI and machine learning, companies can change the way materials are designed for electronics. For instance, to distinguish hazardous alternatives and components in lithium-ion rechargeable batteries in rechargeable electronics. Motivo uses machine learning and data analytics to accelerate design improvement in IC segment which is suitable for recycling and maintenance optimization (MOTIVO, 2019). Appendix 6 presents how AI can boost circularity in electronic sector.

4 METHODOLOGY

This section aims to provide the overall description of design and methods used in this study. Firstly, the general research strategy and case studies research strategy is described. Secondly, this chapter describes data collection and data analysis procedures. Finally, this chapter describes each stage of methodology and the overall process of theory building and discussion followed by the study.

4.1 Research Strategy

Since exploratory research mainly aims to discover the ideas and viewpoints on the topic of interest, the flexibility of the design is important to provide opportunities in different aspects (Kothari, 2004). This study relies mainly on the literature review and the case studies support the literature. Due to the inherent qualitative and exploratory nature of this study, case studies and qualitative interviews have been chosen as the main research methods (Benbasat et al., 1987; Eisenhardt, 1989). Benbasat (1987) argues when the research and theory are at their early, formative stages, the case studies research is appropriate, as in the case of the roles of AI technologies addressed in this study. According to Benbasat et al. (1987), case studies research is most appropriate at the early, formative stage of the research and theory. Darke et al. (1998) and Yin (2003) argue that case studies help in empirical investigation of a specific contemporary phenomenon which is studied insufficiently within its real-life context. In addition, the aim of case studies is to describe the current phenomenon and to make new findings within the study (Yin, 2009). Therefore, the case study approach has been selected as the methodological choice for data collection method in this study. The study creates the knowledge how the case companies are implementing CE business models and how they employ Industry 4.0 in their circular business models, especially in product design. The analysis of the results provides additional information on how much industries tend to apply technologies such as artificial intelligent in their CBM. Finally, the study introduces a framework on the role of AI in circular product design in companies and provides general recommendations.

The research methodology of this study with the use of research onion is shown in Figure 22. The research answers to the 5 W's and 1 H questions such as: What is the role of product design in CE? Why companies need to design circular products? Who are the end users of circular products? When is digitalization needed in CE? What CE processes can be utilized by digitalization? How companies implement AI in CE?

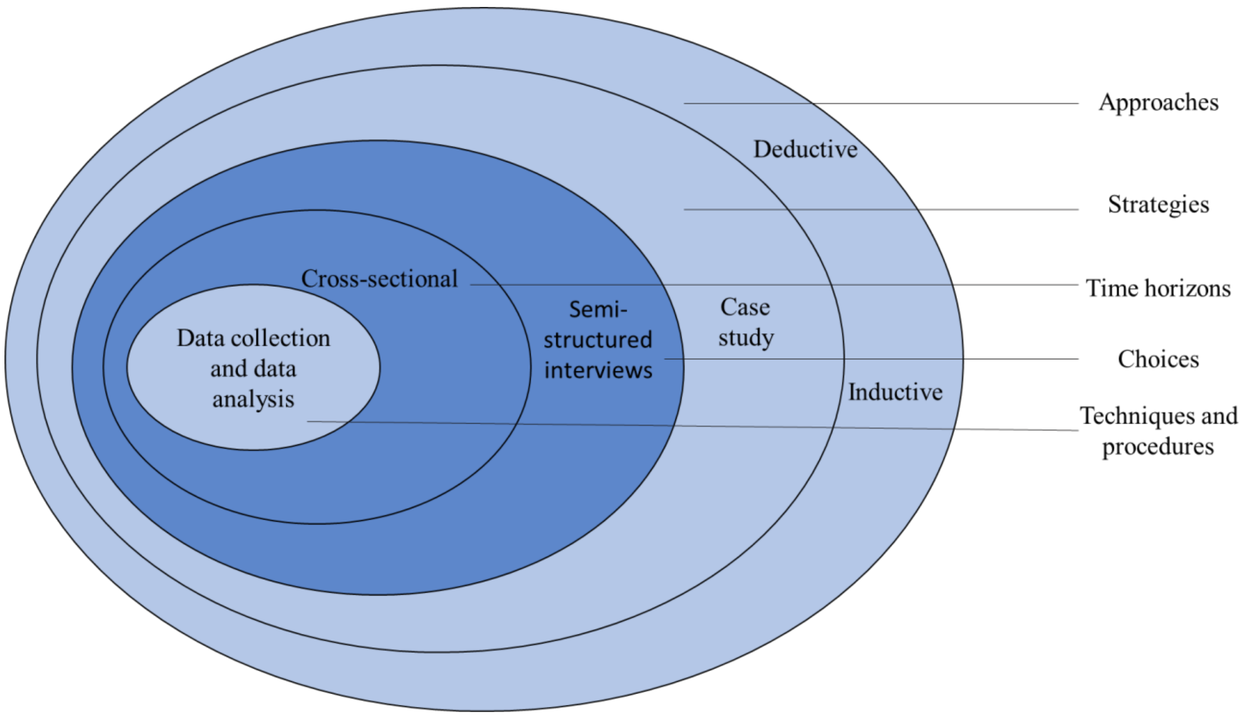

Figure 22. Research onion for the study (adaptation from Saunders et al., 2015)

4.2 Case organizations selection

Since the aim of multiple-case study is to iterate findings through different cases, it is very important to select the cases carefully (Baxter and Jack, 2008). According to Tura (2018), citing Curtis et al. (2000) in her doctoral studies, qualitative sampling provides the opportunities in selecting and analyzing the observations which helps to better understanding of the theory about the studied topic. Therefore, evaluation and choosing the case sampling can be as follow:

- Relevant to the research questions and the theoretical framework;
- Creates wide information on the studied phenomenon;
- The sample Increases the generalizability of the findings;
- The sample describes believable explanations;
- The sample is feasible;
- Sampling strategy is ethical.

Case organizations have been selected due to two general common criteria. Firstly, case organizations must have already implemented CBM in their business processes. Secondly, case organizations must be manufacturing according to the focus of the study in product design. In this study, the main research strategy is followed by three case studies and qualitative interviews and the data collection of the study is conducted by implementing qualitative interviews. The case examples of this study are three organizations working in different industries in Finland. All the three cases are large organizations and according to Sitra (2017c) are in the list of "the most interesting companies in the CE in Finland". A brief overview of the three studied organizations is provided in **Table 6**.

Table 6. Overview of the three studied organizations

Case Organization	**Description**	**Size**
Company A	One of the largest Finnish multinational telecommunications, information technology and consumer electronics company. Third largest network equipment manufacturer in 2018.	>103000 in 2018
Company B	One of the world-leading group in lifting Businesses™. The company provides services for all lifting equipment models.	>15000 employees in 50countries in 2018
Company C	One of the largest Finnish companies in food industry.	>15000 employees in 8 countries in 2018

4.3 Data collection

According to Benbasat (1987) and Yin (2003), collection of the data from different sources is one of the key characteristics in collecting data through case studies. In this study, data were collected from two main sources:

- Interviews: Since the answer to the main research question in this study can be best obtained from the experts and people involved in CE and technology practices in organizations, interviews are the most important and appropriate source of collecting data for this study.
- Open data sources: Since the topic of the study is quite novel and due to organizations privacy policies and not wishing to open all their new strategies due to competitiveness of businesses, from the technological point of view, data collection and analysis is based on open data sources on companies platform.

Semi-structured interviews with CE and Digital Transformation experts have been conducted as the first part of each case data collection. Before selecting case companies, one hour interview was conducted with one CE expert from Sitra (Sitra, 2019) and the final selection of the cases were made in cooperation with supervisors of the study. More detail knowledge and information about the companies involved in CE was gained after the interview with Sitra which helped in selection of the case organizations as well. Interviewees within each case studies have been selected by their role in organization who has the CE knowledge and have experienced of working with the topic. Interview-invitation was sent by email to the experts in each company to ask for the preferable type of interview (face-to-face, Skype). In total 3 one-hour interviews were conducted between February 2019 and June 2019. The detailed list on interviews taken in this study for the primary data collection in each of the three studied organizations is presented in **Table 7**. Some interviewees asked about the interview questions before the interview. **Appendix 7** presents the list of the interview questions. The rest of the questions were conducted by the discussions.

In the beginning of interviews, each interviewee has been asked for a permission to record the conversation before any recording started. The interviews were held in person or via Skype and were recorded via sound recorder or Skype. All interviews have been then transcribed manually for analysis. Furthermore, due to the semi-structured interview as a research method in this study and for better understanding of the discussions, the interviewer could add additional questions that were not included in the question lists during the interview. The structure of the interview questions has been developed by the help of supervisors of the study.

Table 7. List of interviewees in each organization

Organization	Date	Interview Type	Interviewee position	Tenure in organization	Duration (min)
Company A	February 26	Face to face	Head of Environment	5years	70
Company B	March 29	Skype	Environmental specialist	3 years	60
Company C	June 5	Face to Face	Head of digital transformation	1.5 years	60

Additionally, as the second part of data collection for each case studies, the open accessed data on companies' online platforms was chosen for documentation analysis of the concept, since companies didn't wish to open all the strategies in technical part due to the novelty of concept and business competition. Moreover, the interviewees were promised to receive the analysis of the results when the thesis gets ready.

3.3. Data analysis

Data analysis aims to structure the findings of the study in order to support the understanding of the results. Content analysis is the main data analysis method chosen for this study through textual coding. To analyze the textual data such as transcript interviews, content analysis can be utilized. The aim of content analysis is to form a comprehensible description of the phenomenon for further investigation. According to the content description, the frequency of certain words and phrases in documents can be analyzed through qualitative content analysis. In addition, three distinct approaches can be applied in content analysis: inductive approach, deductive approach and abductive approach. Inductive approach focuses mostly on the data and not the theoretical approach and is related to the direct delivery of coding categories from the data source, whereas deductive approach analysis focuses on theoretical findings to create codes. Abductive approach is a cross between these two approaches and consists of comparisons and counting of keywords which leads to findings definition (Yin, 2003). In addition, in an Inductive approach the reasoning logic is from specific to generalization, therefore research methods and analysis in this approach for this study are caste studies and qualitative data analysis. In abduction approach where reasoning logic is the inference to the best explanation, the research methods and data analysis is done by caste studies and qualitative data analysis.

As explained earlier in this chapter, the study focuses on exploratory and qualitative content research approach. Before data analysis, all the recorded interviews have been manually transcribed from audio to textual presentations. Then, the data analysis of the study is progressed by following the main themes and aims of the whole research, which is to explore how AI enhance and facilitates CE, and how companies are implementing AI in their CBM in designing products towards circularity. The starting point for content analysis is executed from these main themes.

Data analysis software tools such as NVivo support the case studies and qualitative data analysis. However, according to Webb (1999), in any research, the creativity and thinking part belongs to the researcher where the software tools can “alienate researchers from their data”. Webb (1999, p.329), discuss that for the beginner qualitative researcher it is preferable to use manual methods for the first project because then the process of learning the resulting will form a strong basis. Furthermore, Thompson (2002), argues that since “physically handling the data, by marking text or cutting and pasting the transcripts of interviews, seems to give the process a more human touch by connecting the researcher to the research”, manual analysis may be therefore preferable. Thus, in this study manual approach have been used as data analysis.

This study is based on qualitative content analysis approach and starts with the interest themes of the data. There are two main research themes for the study, first to explore the role of circular product design in CE, on the other hand, to find out how technologies enhance CE. Secondly, the study focuses on identifying how AI can enhance CE, in more detail, what is the role of AI in circular product lifecycle. These themes are used as the start point for the content analysis. The findings from data are then restructured and collected in iterative turns.

In addition, in this study describing research process in detail helps to ensure the reliability of the, which is presented in detail within the methodology chapter. Furthermore, the themes of the interview with precise questions is presented in the attachment. However, the study includes only the results from three companies in Finland, therefore the results cannot be generalized without further research. It should be considered that according to the interview situations, both interviewer and informant’s characteristics and skills may affect to the results. Moreover, it should be noticed that informants were allowed to give the limited information and not the whole strategies that companies did not wish to open. This may affect the reliability of the results and hence, it is the reason the study puts more emphasize on the literature review.

5 RESULTS

This section presents the results of the semi-structured interviews and are explained in subchapters based on qualitative analysis in each company. In each subchapter, firstly the case company and the current state of CE in the company is introduced. Secondly, company's strategies in circular product design is analyzed. Thirdly, how the company employs technologies in CE is defined. The final analysis, answers to the research questions. Furthermore, the framework is introduced later in Chapter 6 and will be discussed

5.1 Case Company A

First case company of this study is a Finnish company in telecommunication and customer electronics company, with various industries in over 150 years. The company is a large organization focusing in technology development, telecommunications infrastructure and licensing. The company has a major contribution in mobile phone industry and has been involved in CE for a long time and is improving all their business models according to the customer's needs and to stay in the competition worldwide. The informant summarized CE for the company as follow:

"Circular economy is about efficiencies and making the things in the most smart ways all across the organization and in the value chain. […] Operational impact, product level impact and the social impact are the idea of company's circular approach. Operational impact is about the value chain such as operational management (laboratories, offices and logistics, etc. work). Design out products and components sourced to the supply chain (how to work with suppliers and how to design products with software). […] Sustainable producer responsibility (taking back all the products) and product as a service" (Head of Environment)

The main goal of CE in the case organization is to stop the waste by avoiding waste generation, increasing reuse, improving recycling and minimizing landfill. The company is highly focused in the waste management approach of the CE for example there are not too much spaces in the rooms and offices, there are no papers in the offices and no old printers or facilities. Therefore, the company believes that they use everything in the most efficient way. In addition, the main circular strategy of the company in product design is life extension which is presented in **table 8**. As the informant described, for the company Circular product design is:

> *"We design the environmentally friendly products. The main focus in our circular product design is life extension by upgrading the products (up to thirty years), software updates, asset recovery (collecting the products and check the useful spare parts), repairing and refurbishment" (Head of Environment)*

Table 8. Circular product design strategies of case company A

Design for closing the loops	Design for slowing the loops
• Design for recycling • Design for disassembly	Design for life extension • Design for upgradability • Design for durability • Design for repair and refurbishment

The concept of product as a service helps less usage of resources and reduces the emissions. Digital technologies mainly for the company is about connectivity and sharing economy in a CE approach. Shared platform and applications which helps the society to use the resources in the more efficient way is the way company implements digitalization in CBM: Moreover, the technology solutions which are delivered by the company, help other industries to lower their carbon footprint and to use their resources more efficient. Digital technology innovations play a significant role in reducing the negative impacts on industries, society and individuals. Integrating digital technologies accelerates company's CBM through better design by best practices and tracking the key environmental issues. The company believes that they have automatic and digitalized manufacturing system. AI plays an important role to achieve the greatest impacts of circularity in the company in product design, waste management and in predictive services using intelligent analytics and algorithms. Furthermore, creating products by using less energy and material efficient is what AI can help in product design in company's circularity. **Table 9** presents the role of AI in company's CE and circular product design. The role of AI in CE and Circular product is defined as follow from the company:

> *"We deploy automated, machine-learning technology to capture and correlate previously hidden behavioral inconsistencies that can lead to more serious performance problems. Identifying these issues early helps to improve the quality, availability and connectivity of mobile networks". (Company A's website)*

Table 9. Role of AI in circular product design in case company A

Role of AI in CE	Role of AI in Circular product design
• Product design • Waste management • Predictive services • Connectivity and traceability • Service platforms	• Less energy in product design • Efficient use of raw material • Identifying flaws faster by intelligent analytics and iteration • Traceability of products

5.2 Case company B

The second organization is the leading in Lifting Businesses globally by providing lifting solutions and services for all lifting equipment. The company is considered as one of the most interesting companies in Finland. There are four key initiatives in company's circular solutions:

1. Circular product design is the core of circular business model. Developing the key components of the product from phases of design and material selection. Aims to reduce the environmental impact of product's lifecycle by seeking for new combinations of components and raw materials as well as developing smart features.
2. Lifecycle care by offering spare parts and systematic maintenance services that is supported by digital tools. Digitalization helps in real-time visibility which leads to predict failures and prolonging product's lifetime.
3. Extending product's lifecycles by remanufacturing, retrofitting and modernization.
4. Design the reusable and recyclable products by selecting repairable and recyclable materials and components. Additionally, pre-owned equipment can be re-utilized as well as rental services including preventive maintenance.

Moreover, by implementing CBM the company reduces the environmental footprints and increasing energy efficiency. **Table 10** shows Company's circular design strategies. The role of product design in company's CE is expressed by the company as follow:

> *"Circular economy has lots of advantages for the company such as energy efficiency. 98% of the products are recyclable. […] Product design is the core of circular economy in our company. By designing the product for durability and modularity we keep the product in use for longer time. […] Modernization is company's strategy to extend product's life for more than 15 years. By modernization the productivity, reliability and usability increase and reduces the need to repair" (Environmental specialist)*

Table 10. Circular product design strategies of case company B

Design for closing the loops	Design for slowing the loops
• Design for recyclability • Design for reusability • Design for disassembly	Design for life extension • Design for durability • Design for modularity • Design for upgradability • Design for modernization • Design for remanufacturing Design for ease of maintenance • Design for smart maintenance control

Digitalization plays an important role in the company which helps in real time lifecycle care, remote control of automated operations, improving the safety by analytics and customers' service. The environmental specialist described the role of digitalization in CE in the company in the following way:

> *"IoT, VR, AR, Cloud service and Intelligent assets are the technologies we use in our company. I can say digitalization is not the key but the enabler of CE: […] Selling value instead of product, quality data analysis, optimizing products, analyzing data, repair, schedule services, reducing downtime are the main functions of digital technologies in our organization which leads to decrease environmental negative impact".(Environmental specialist)*

AGILON, is company's service model solution to warehouse management. The warehouse is remotely managed by using a robot that is optimized by AI. Customers can take care of their own maintenance Logistic needs are reduced by remote control of the system. Since the required services can be identified without visiting the site, the environmental impacts of the operations will be reduced as well by efficient use of the space. In addition, due to the intelligent energy saving, the system uses less energy than “a standard hairdryer”. Real time information is shared through a web service and makes it possible to share the data with supply chain. **Table 11** presents the role of AI in CE in the company and company’s circular product design. The role of technologies in circular product design is described by the informant as follow:

> *“Digitalization accelerates remanufacturing, remodeling and repair characteristics in circular product design as well as remote maintenance” (Environmental specialist)*

Table 11. Role of AI in circular product design in case company B

Role of AI in CE	Role of AI in Circular product design
• Product design • Waste management • Predictive services • Connectivity and traceability • Shared platforms	• Less waste of prototyping • Less energy in design • Product remodeling • Remote maintenance • Real time data analyzation of product lifecycle

5.3 Case Company C

The third case company is a large Finnish manufacturing company in bakery and food services that aims to improve energy efficiency in reducing climate emission and focusing on food waste reduction. Waste prevention and Material Loss Plan are the CBMs of the company through which, company aims to reduce waste by 10 percent by 2020. Additionally, company has four core goals in sustainability towards 2030:

- 50% less emissions
- 50% less food waste
- 100% sustainability sourced

- More plant based

The informant describes what CE means for the company in the following way:

> *"Circular economy for our company is about using raw materials and sustainable source efficiently e. We have some products made up from scrap. Whenever some scrap is produced, they are mashed back and are used as the raw material for the new product and not throwing away. […] We distribute the extra batches of products such as jellies to our restaurants or our food services to prevent waste. Also, we give our extra products to the circular economy restaurant in Helsinki as well which means a transformation from industry to food services" (Head of digital transformation)*

In practice, waste management is achieved by re-use, recycling, recovery and disposal operations so that no waste goes to landfill by 2020. In addition, though company has the plan to prevent overproduction, there are always eatable food and bakery left over which is donated. The company believes product design plays a significant role in preventing waste and in CE. The circular product design strategy of the company is closing the loop due to waste reduction.

Moreover, in cooperation with a research center and information technology company, the company aims for an open innovation ecosystem where various operators can study and develop food production in a genuine consumption environment. New services and business models which are beneficial for society is the target of implementing technologies. The research center studies focused on augmented reality, robotics, new food ingredients and data management. Technologies are playing important role in the company for product development and developing food services and solutions towards enabling sustainability and CE solutions. Moreover, the technology partner is responsible to help in intelligent solutions that can be implemented by analytics, AI, blockchain technologies and IoT solutions. The head of digital transformation defines what Industry4.0 and technologies do in company as follow:

> *"Industry 4.0 helps in integrating data processes in the shop floors to collect the huge amount of data for example what kind of resources do we have there, baking temperature, etc. We have a long way to go in Industry 4.0 since our shop floors are still very manual. [...] In case of consumer experience, we use Industry 4.0 for data collection and connectivity. Right now, we have people standing in production line that we are thinking that they should be changed in future with machine vision".*

Since the company uses traditional manual ways in production line, it takes a lot of mapping for the company to be fully digitalized and the transition is more difficult for the food industry. Customer satisfaction is one of the most important goals of the company to stay in competition and add value to the business. The role of AI is summarized as follow from the company:

> *"Analytics will help us to identify our environmental impact of the products. Technologies will help us to understand what successful products is and how should we use the resources and raw materials. Industry 4.0 helps us in making best decision in optimizing ingredients of the products".*

The company has some discussion on the role of AI in their product design but not implemented in their business models and strategies yet. They believe AI can help the company analyzing the ingredients, the taste and product recipe. Furthermore, the company has recently building new manufacturing facilities to produce plant-based (oat hull-based) chewing gum which is more digitalized.

6 ANALYSIS AND DISCUSSION

This study aims to research how AI can help product design towards circularity. The following chapter answers to the research questions. **Table 12** links the set questions with the chapters including the answers. A framework on the role of AI in CE is introduced in the first subsection and the key enablers are discussed.

Table 12. Answers to the research questions

Chapter	Research question(s)
6.1 Integration of AI in designing circular product	RQ1: How AI can help product design towards circularity?
6.2 AI supports maintenance services in CE	RQ2: How AI can help in maintenance services in companies towards circular economy?

6.1 Integration of AI in designing circular products

According to the findings of this study from literature and empirical research, digital technologies are highly implemented in the manufacturing companies. Due to the literature review of this study, Industry 4.0 plays an important role in all the phases of CE in transferring data. The results of semi-structured interviews show that both electronic and lifting companies are utilizing digitalization in all the processes of the company from product design, maintenance to waste management in their CBMs. However, it is more difficult and challenging for the food industry to fully move towards digitalization in CE since in many cases the processes such as manual report or data analysis in bakery processes, are done manually. On the other hand, food industry showed the interest and plan to implement digital technologies in production line. Based on the theoretical and empirical parts of the study, AI has significant role in all phases of CE and accelerate CE in different ways. Due to the differences in the current state, implementing AI in CE solutions differs in different industries. **Table 13** shows the overall approach of the role of AI in CE.

Table 13. Framework of the role of AI in CE

AI in CE				
Eco design	**Maintenance**	**Customer Support**	**Asset recovery**	**Infrastructure optimization**
Circular product design	Smart Maintenance	Customer services	Intelligent assets	Recycling
Modular design	Remote monitoring	Digital platform	Refurbishment	Precise waste sorting
Fast, smart and precise prototyping	Product life cycle analysis by smart sensors	End-user need data analysis and prediction	Re-use	Add value to recycled and recovered materials
Failure and downtime reduction	Maintenance optimization	Product lifecycle extension by shared platform	Remanufacturing	Secondary raw materials
Material toxicity prediction	Real-time data transformation	Dynamic pricing, matching algorithms	Repair	
Cost reduction in testing		Collaborative decision-making		
Real-time data analysis		Data-enabled prediction		
Reduce energy in designing products				
Warehouse management				

AI plays an important role in all phases of CE due to the capability of machine learning in analyzing huge amount of data. According to the theoretical and empirical results, the core of CE is product design. Designing products for circularity boosts in other phases of CE such as maintenance, repair, recycle, etc. Theoretical research of the study introduced a tool in designing circular products. According to Van den Berg and Bakker (2015), a circular product should be designed for modularity that plays the key role in remake stage. AI can help to identify the modules of the products more precisely. It can speed up measuring lifecycle modularity as well as services.

Ai can help scientists to test the molecular structure of the food products and to design plant-based products based on the real tastes. Moreover, since AI can learn from previous practices and identifies the characteristics by iteration, smart prototyping through AI will make the process faster and leads to precise results. Thus, there will be less failures in prototyping and reduces the downtime. Furthermore, algorithms help in predicting the hazardous of the materials and components and helps to prevent producing toxic components and products. In addition, AI has the ability to analyze real-time data which helps in learning and preventing faults in product design. All these benefits lead to reduce energy and reducing the costs of production and therefore reducing the waste and the footprints of manufacturing.

6.2 AI supports maintenance service in CE

Based on the theoretical and empirical research, maintenance services are the important phases of CE. Optimal maintenance can be achieved when the product is designed with lifetime prognostics so that it will help in predicting the future performance of the product (Van den Berg and Bakker, 2015). Smart sensors help in predicting product maintenances by analyzing real-time data. By use of AI, companies are able to track their products and monitor the products remotely to predict maintenance and prevent unnecessary services. AI helps in prolonging the products' lifetime in modernizations so that the products are repaired just before the break time.

In addition, AI assist in establishing CE resource flows at a faster rate. In circular products it helps in faster identification and testing the new materials. In order to have a fully CE, an infrastructure system is needed to support managing and sorting waste streams for maximizing resource recovery. AI technologies such as robots can help in intelligent waste-sorting which helps in accurate and precise separation. Meanwhile, AI boosts CBMs by supporting price settings and demands forecasts on trading platforms. The study shows that AI can help in redesigning the whole systems and optimizing the network system. Since AI in CE is a radical change for the companies, it brings its risks and challenges for the businesses as well. **Table 14** presents the key enablers of AI in CE.

Table 14. Key enablers of AI in CE

Key Enablers
Regulations and policies
Sustainable productions guideline
Customer collaboration
Customer and stakeholder's understanding and identification
Sustainability benefits (Environmental, social and business)
Cost structure

Although the technologies such as AI are promising in accelerating CE, it is possible that they reshape the businesses and the world beyond human's control. AI needs human to provide the algorithms and put the data in machine learning to have receive the desired results. There could be the risk if the person is not highly skilled or wishes to put the wrong data. Therefore, smart regulations and policies to guard the benefits of technologies against the risks are needed. Furthermore, companies need a guideline in producing circular and sustainable products to support the right data to the technologies such as AI for analysis. If the input data on the components and materials are wrong or not precise the output will be not valuable. Moreover, since the main role of AI is predicting, it is highly important that customers collaborate with the businesses to give feedbacks for example in shared platform business models. Collecting the data on the feedbacks from the customers will help in analyzing the products and the services for the companies. The understanding of the customers on what the circular products are and how they can help in recycling, refurbishment and repair is important as well.

In addition, stakeholders play an important role in the businesses in achieving the goals of CE. The stakeholders should have the understanding of the advantages of CE in their businesses and how investing on technologies and digitalization will help them in the process of CE. Industries should consider the environmental and social benefits while applying CBMs and the way technologies will boost it. Finally, cost structure is an important key in the move towards a digitally circular business. The evaluation of the cost advantages over disadvantages is needed before the employing the technologies which are highly expensive. Moreover, technologies need new skills and working labor that should be considered in implementing technologies. The company has to make the decision to invest on both technologies and new skilled people with the knowledge of working with technologies such as AI. Moving towards CE needs collaboration of businesses, policies, stakeholders, and experts to make it happen and to have a safe, efficient helps of technologies.

7 CONCLUSION

This study summarizes the importance of product design and role of AI in CE from various literatures. Then, from semi-structured interviews of three case studies, the study identifies the current status of Finnish case companies in implementing AI in their circular product design solutions and processes. The study introduces the framework of the role of AI in all the phases of CE including product design and the key enablers. Theoretical and managerial implications are described in the next subsection and finally the study discusses some limitations and gives recommendations for further research areas are introduced.

7.1 Theoretical & managerial implications

As mentioned already in the literature and results of the study, CE has gained high attention in the recent years, specially the role of digital technologies in CE has been recently discussed widely. In order to redesign key aspects of economy, new technologies with the ability of faster and more agile learning processes are needed (Ellen MacArthur Foundation, 2019). The information from the companies pointed out the significant role of product design in CE and how digitalization can accelerate the transition. This study introduces a framework of the role of AI in CE on both the literature and practice. However, the current literature is lacking more detailed and focus studies related to the specific role of AI in CE, since the approach is new. In addition, the study introduces the key enablers of AI in CE for better understanding the existing and future factors that affect businesses process in digitalization of CE and the market.

Furthermore, to have a greater knowledge on how AI supports CE, it is essential for CE experts and organizations to collaborate with technical experts in AI to identify in which area the business can apply AI in their CBM. According to the study, development of AI application for CE needs the experts with the knowledge to train algorithms and to access high-quality data as well as appropriate input data. Therefore, stakeholders across the system need to collaborate to seek the opportunities to increase the investment in AI. The theoretical section of this study introduces the framework of BM canvas as well as a framework for CBM. It is beneficial for the managers to use these tools in making their CBMs and helps them with the mapping.

In addition, the literature introduces a tool for designing the circular products which helps the technical parts and designers in the businesses to design products with the right circular characteristics, therefore profitable for the company. The framework on the role of AI in CE, which is introduced in the results, allows managers to think about the benefits of AI in the whole process of business (from the usage of resources to the product's end-of-life). Finally, the lists of the key enablers suggest what managers should consider in transition towards a digital circular business and helps them in making decision in moving towards a digital CE, whether it will be beneficial for them or not.

AI application can support innovative business models in CE. The need for smart systems shows an increasing trend to boost CE in using finite resources. AI can bring huge opportunities to the CE for businesses and needs the understanding of what AI can or cannot do for the organizations. It is important to understand how businesses can integrate AI in CE and in which area of their industry.

7.2 Limitations and areas for the further research

Digital CE is a topic which is developing fast and more research needs to be done in the future. This study focuses on analyzing AI development in CE by understanding the implications in a small scale and there is a need for more concentrate studies on the approach in different phases of CE and different industries. It would be valuable to analyze how organizations achieve advantages of smart intelligent CE and to understand in what phase it is more important to utilize digitalization in CE. More technology related research on product lifecycle improvement is beneficial and recommended.

As the study was conducted on only three cases in only three industries and same country, setting other research design may show different findings. Moreover, a focus research on the collaboration of digital expertise and CE experts are needed to find out the solutions of CE for the organizations.

By researching those areas, the specific barriers and derivers in transition towards a more digitally circular development can be identified. Since customers play vital role for all businesses and are the main focuses of business improvement, it would be valuable to study customer experiences in organizations' decision making; customers as the drivers of digital CE; how to increase customers' awareness of CE by digital technologies and how digitalization can enhance collaboration with customers in CE. On the other hand, how jobs will change by utilizing such technologies would be interesting.

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APPENDICES

Appendix 1. Overview on circular business model types (Lewandowski, 2016)

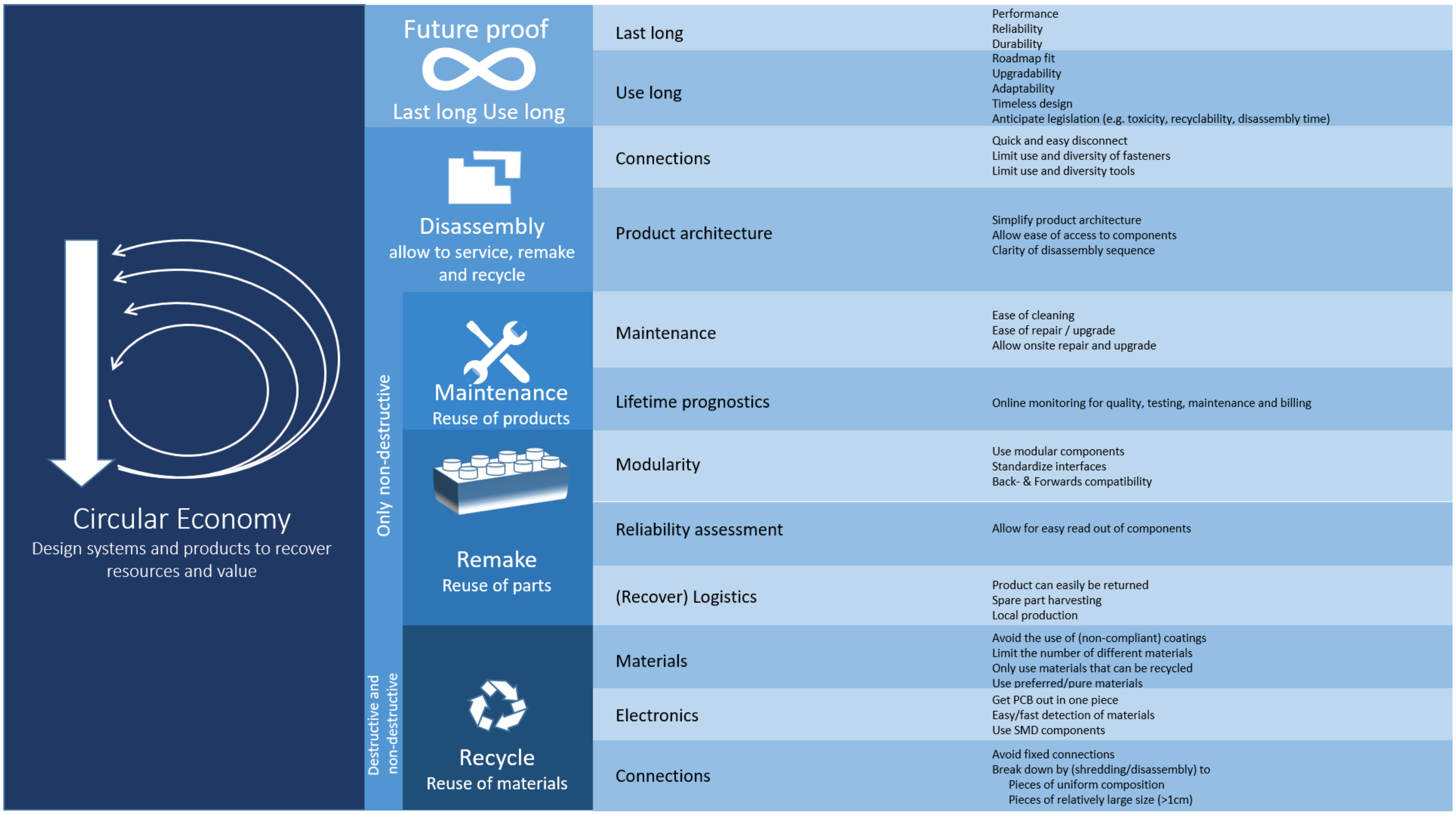
Classification	Model	Explanation
Regenerate	Energy recovery	Non-recyclable waste materials are converted into useable heat, electricity or fuel
	Circular Suppliers	Use of renewable energy
	Efficient buildings	To locate business activities in efficient buildings
	Sustainable product locations	To locate business in eco-industrial parks
	Chemical leasing	To reduce the use of hazardous chemicals and environmental impacts, the functions performed by the chemical are mainly sold by producers
	Circular Suppliers	Use of renewable energy
	Efficient buildings	To locate business activities in efficient buildings
	Sustainable product locations	To locate business in eco-industrial parks
	Maintenance and Repair	By maintenance and repair, the product lifecycle is extended
	Collaborative Consumption, Sharing Platform, PSS: Product renting, sharing or pooling	To enable use, access or ownership sharing of product among people or businesses
	PSS: Product lease	Non-ownership exclusive use of products
	PSS: Availability based	Availability of products or services for the customers for a specific time period

Share	PSS: Performance based	The revenue is generated according to delivered solution, effect or demand-fulfilment
	Incentivized return and reuse or Next Life Sales	Returned products after collecting from customers with an agreed value, are resold or refurbished and sold
	Upgrading	To replace the components and materials with the better-quality ones
	Product Attachment and Trust	To create the products that will be liked or trusted longer
	Bring your own device	Bringing devices by owners to get the access to the services
	Hybrid model	Durable products contain short-lived consumables
	Gap-exploiter model	Exploiting “lifetime value gaps” or leftover value in products systems
	Remanufacture, Product Transformation	To restore a product or its components as a new quality
Loop	Recycling, Resource recovery	To recover resources out of disposed products or by-products
	Upcycling	Reusing materials and upgrading their values
	Circular Supplies	To use supplies from material loops, bio based or fully recyclable
Virtualize	Dematerialized	To shift physical products, services or processes to virtual
Exchange	New technology	New technology of production

Appendix 2. Fourth industrial revolution technology description (World Economy Forum, 2018)

Type	Technology	Description
Digital	Artificial Intelligence	Applies a set of technologies like machine learning and vision that enable machines to simulate human intelligence and act without explicit instructions Example: Artificial intelligence can be used, to enhance sorting of waste streams through AI-based robots
Digital	Big data analytics	Computationally analyses extremely large data sets to reveal patterns, trends, and dependencies Example: Big data analytics can be applied to improve forecast of waste streams or provide suitable material recommendations for certain markets
Digital	Blockchain	Draws on distributed ledgers storing an immutable record of transactions shared with multiple participants in a business network Example: Blockchain can be applied to trace the origin of components back through every step in the supply chain
Digital	Cloud computing	Retrieves information through web-based tools and application instead of a direct connection to a server Example: Cloud computing enables establishing a platform to connect customers and drivers for e.g. a waste transportation platform
Digital, physical, biological	Cryptographic anchor	Is attached to or embedded in a physical product as means of authentication to link a physical product to the related data stream e.g. in a blockchain. Anchors can have different security levels and be physical (e.g. Fluorescence markers), digital (e.g. RFID tags) or biological (e.g. DNA marker) Example: Cryptographic anchors can be chemical marker applied to consumer electronics with a unique composition ensuring authentication and preventing counterfeits
Digital	Digital Twin	A virtual model of a process, product or service, pairing virtual and physical worlds. This allows the analysis of data and monitoring of systems to develop new solutions or conduct predictive maintenance Example: Digital twins can be used to simulate the performance of electronic devices in different usage scenarios under varying conditions to develop maintenance solutions
Digital	Internet of things	Deploys wireless devices with embedded sensors that interact and trigger actions Example: Internet of things can connect smart bins with a platform to communicate information on their fill level
Digital	Machine vision	Provides a computing device with the ability to acquire, process, analyse and understand digital images, and extract data from the real world Example: Machine vision can be used in waste sorting enabling waste sorting robots to identify certain waste types for separation
Digital	Machine learning	Enables machines to perform new tasks after being trained using historic data sets Example: Machine learning can be used to improve algorisms optimizing routing in reversed logistics e.g. based on historic patterns
Digital	Mobile device	Accesses a cellular radio system to exchange voice and data without a physical connection to a network Example: Mobile devices can be used to participate in a reward scheme
Physical	Robotics	Applies machines that are programmed to automatically carry out a complex series of actions. Especially suitable for repetitive and rule based processes using structured data Example: Robots can be used to sort and pick objects with various weight and shape
Physical	UV/ IR/ NIR/ NMR Spectroscopy	Uses different spectrums of electromagnetic radiation to analyse material based on the molecular composition of the matter Example: Near infrared sensors can be used in waste sorting machines

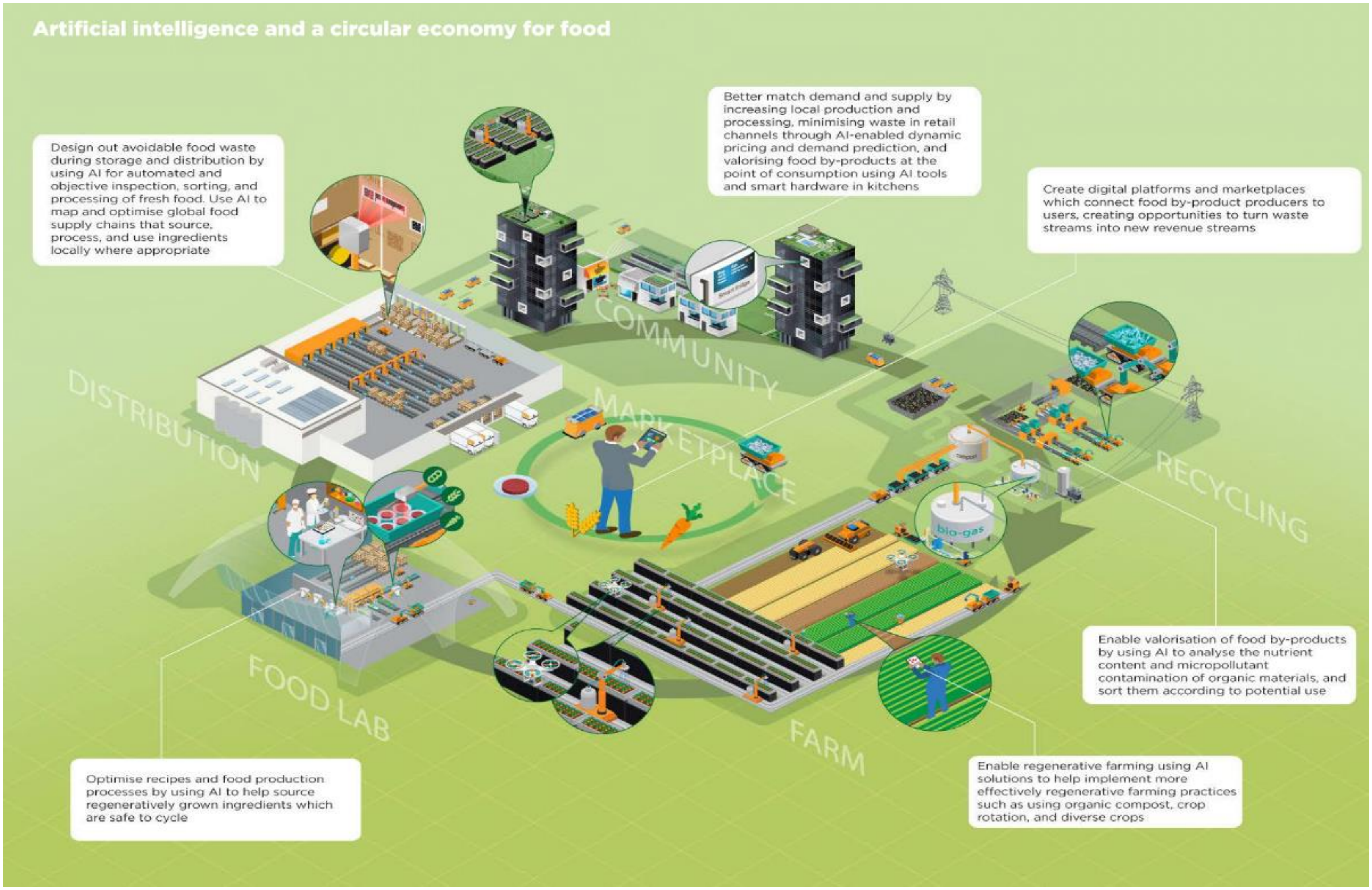
Appendix 3. Guideline list overview of circular design (Van den Berg and Bakker, 2015)



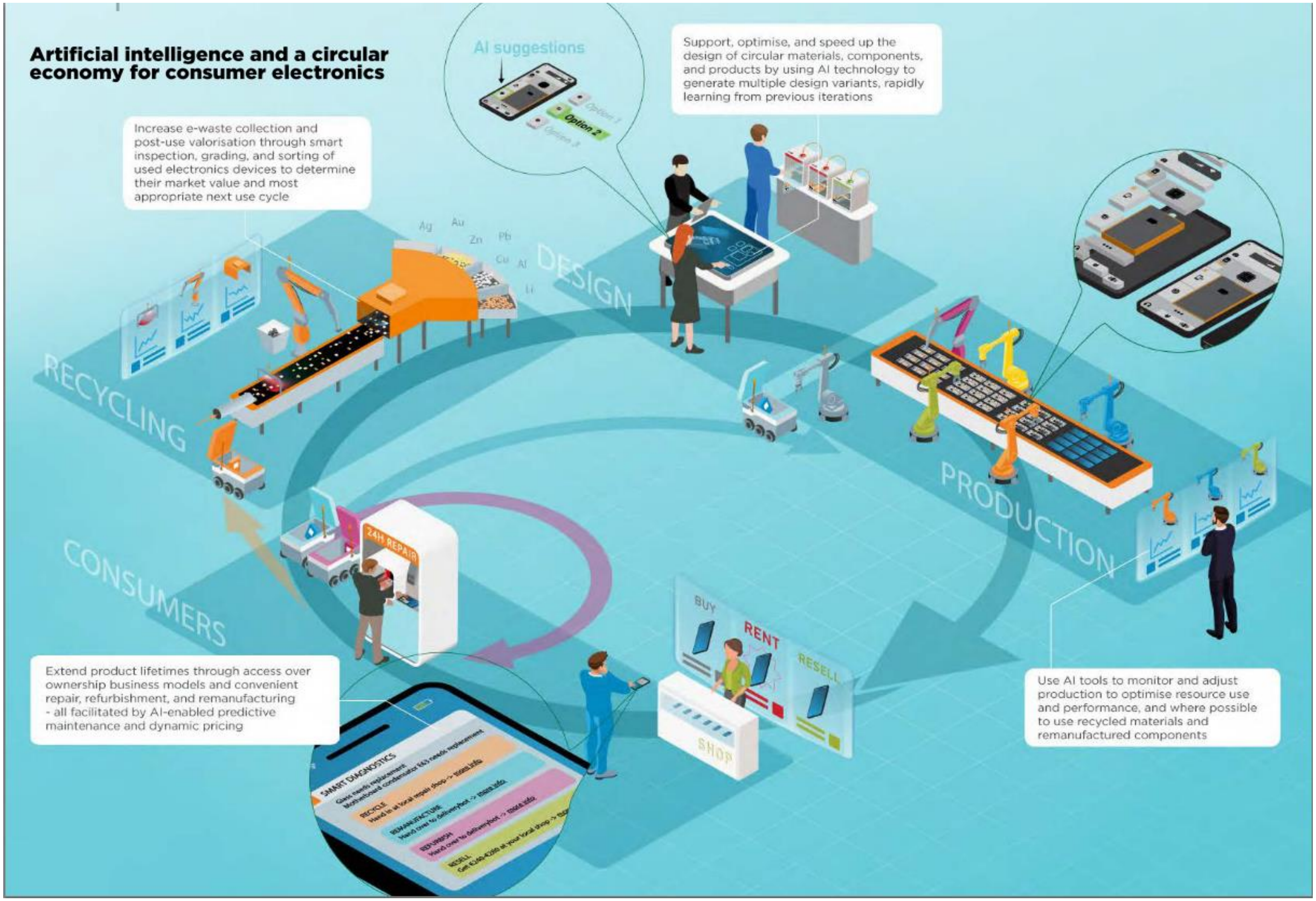
Appendix 4. CE, Industry 4.0 relationships matrix (Jabbour et al., 2018)

ReSOLVE	**Design of products**	**Production of products**	**Logistics/reverse logistics**
Regenerate	Internet of things	Internet of things	_
Share	Cloud manufacturing Internet of things	Cloud manufacturing Internet of things	Internet of things
Optimize	_	Cyber-physical systems Internet of things	Internet of things
Loop	Internet of things	Internet of things Cyber-physical systems	Internet of things Cloud manufacturing
Virtualize	Cloud manufacturing Internet of things	Cloud manufacturing Internet of things Additive manufacturing	Internet of things
Exchange	Additive manufacturing	Additive manufacturing	

Appendix 5. AI and circular food system (Ellen MacArthur Foundation, 2019)



Appendix 6. AI and circular consumer electronic system (Ellen MacArthur Foundation, 2019)



Appendix 7. Basic themes of interview questionnaire

About CE
1. What is your opinion about Circular Economy?
2. To what extent do you think your company is Circular?
3. Have you seen any benefits in applying Circular Economy?
4. What are the strategies and Circular business models your company has implemented?
5. What do you think can be the internal and external challenges your company may face towards circularity?
About product design in CE
1. In your opinion what is the role of product design in Circular Economy?
2. How do you think maintenance can help in Circular Economy?
About Technologies in CE
1. What is your opinion on the ways technologies help companies to overcome the challenges towards Circular economy?
2. How do you think industry 4.0 can help your company in transition towards CE?
3. Is there any gap between your current Circular business model and actual Circular business model?
4. How do you think technologies can help you close the gaps.
About AI in Circular product design
1. How do you think AI and machine learning can help in Circular product design and lifecycle?
2. How much do you think companies tend to invest for experts in digitalization and artificial intelligent to enhance their Circular economy?