Digital Data Technologies

to help

Technology Manufacturing Companies

towards

Circular Business Models

Master Thesis

Written by Henk Yip

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Digital Data Technologies to help Technology Manufacturing Companies towards Circular Business Models

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"Success is no accident. It is hard work, perseverance, learning, studying, sacrifice and most of all, love of what you are doing or learning to do."

~ Pelé

Preface and Acknowledgements

This thesis document concludes the end of a challenging and amazing journey of my master's degree program in MSc Management of Technology at the Delft University of Technology. This thesis also stands as the last step of my entire educational journey and the end of a wonderful phase of life in which it was mainly about building knowledge, growth, finding where my interest lies and personal development.

Therefore I would like to share my acknowledgement and my sincere thanks to the people who supported and helped me along the way and throughout the writing of this master thesis.

First, I would like to thank my graduation committee. My first supervisor Hanieh Khodaei, she has accepted the request to be my first supervisor without any hesitation, after I had just proposed a rough and broad idea of my research topic back in September. She has helped me a lot in refining the research topic, giving me directions to form a good research methodology and always giving me helpful feedback along the way and proposing new ideas to improve my research.
My second supervisor Robert Verburg provided me valuable feedback and helped me further specifying and narrowing down the scope of the research and forming of a good research methodology. Both supervisors have extensive knowledge in their field of expertise and helped me to acquire the necessary knowledge and information.

Secondly, I would like to thank the companies and interviewees for taking part of the case studies by sharing their perspective, insights and way of thinking on certain topics has helped me to further refine my thesis. It is interesting to see how each company has its own view on circular business models and strive to achieve their ultimate goals.

Finally, I would like to thank my family and friends for the support they have given me while writing this thesis, as well as the motivation and inspiration they have given me to keep me going and complete this difficult and wonderful educational journey.

Henk Yip

Den Haag, July 2020

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Executive Summary

Background

Currently, manufacturing companies are driven by revenue, based on volume sales, cost reduction of supply chains, factories and operations. This is all based on the current linear economy business model; it is dependent on short product life cycles and maximization of sales. However, this approach is increasingly coming under pressure. In order to go against those negative environmental impacts, sustainability plays a major role by the aim to achieve sustainable growth and enhanced resource efficiency. The optimal solution for the companies is the circular economy. Because of this, more and more companies are making the switch to a circular economy, whereby other companies are also being forced to make this switch, because they are part of a value chain.

In reality, the technology manufacturing companies are still far from operating closed-loop systems. Companies' business models and strategies are still based on the linear business models. However, it has not yet been completely successful to overcome the challenge and barriers, making the transition towards a circular business model more of as wishful thinking, than an objective that can really be achieved.

Therefore, as a key driver, digital data technologies can play a critical role in order to overcome such challenges and barriers, as well as being a key driver in gaining competitive advantages. However, there is limited knowledge of what the new emerging digital data technologies are, how it can help companies to gain competitive advantages and how it can support the transition and overcome the challenges and barriers of the companies towards a circular business model.

Research Scope

The scope of the research topic is limited to the consumer and business innovative technology manufacturing sector, with the perspective of improving the technology manufacturing companies' business models to become more circular.

The research is a descriptive qualitative research and it is based on a structured literature analysis to identify and expand the necessary knowledge about the business model challenges and barriers for the technology manufacturing companies to become more circular and to find out the link between the digital data technologies and circular business models.

Literature review

The emphasis of the reviewed papers during the structured literature analysis on the most important challenges and barriers towards circular business models, points out that there is not one particular solution to support this process. Based on the three main elements of the business model; value proposition, value creation delivery, and value capture, the reviewed papers all have a similar view of how the technology manufacturing companies can improve and on what challenges and barriers they have to focus on in order to succeed. It is realistically possible and feasible to apply digital data technologies in the challenges and barriers perspectives of internal

organizational structure of companies, the entire supply chain, and to improve the companies' product and service designs to help the technology manufacturing companies towards circular business models.

Digital data technologies can play a factor to overcome the challenges and barriers towards circular business model. According to the obtained literature, the adoption of data collection, data integration and data analysis technologies such as Internet of Things, blockchain technology, artificial intelligence and big data and analytics are the main technologies with the most potential in improving the business model elements and supporting the companies towards circular business models.

Besides being a factor to overcome the challenges and barriers, digital data technologies lead to new competitive advantages in the comprehensive and optimal use of operations, virtualization and network cooperation. The key advantages are the differentiations of resource-based, management, information, relational, time and location advantages. Furthermore, it leads to additional characteristics advantages in company flexibility, availability, digital serialization, digital integration and customization.

Case studies

The purpose of the case study is to get an in-depth understanding and to analyze the reality in terms of examining the issues, challenges and barriers during the real life applications, and to gain addition insights on the other key drivers besides digital data, and to generate knowledge and understanding, to refine the flow diagram.

Business model

The case studies have shown that when technology manufacturing companies want to apply circularity, a B2B Product-as-a-service business model has the most potential to realize this. The other companies pay a mixed monthly fee for maintenance services, product or system updates and take-back of the products when the products reach their end-of-life phase.

Challenges

The challenges are providing the product or service at an appropriate technological level, ownership of the product, legal ownership issues, the organizational, adaptive logistics and financial complexities of this business model, and cooperation and coordination between all the parties. This leads to high administrative costs, need of trust, transparency and long-term agreements between the chain partners.

Strategies

The strategies for those technology manufacturing companies are to provide products that are on 'the generally accepted technological level' to its customers. Retain the right and responsibility of the product, which enables the opportunity to take the functionality and circularity together into account. Development of a financeable business model, make extensive calculations of the estimations of fees, scenarios, cash flows and profit/loss statements and corresponding contracts between the company and its customers.

Other key drivers

The findings of the case studies shows that besides the digital data technologies, the other key drivers towards circularity for those companies are the openness and flexibility of the company to be able to experiment with new business models, collaboration and transparency between the parties within the supply chain, online platforms that allow companies to improve their relationship with their customers, -government regulations and legislation to positively influence and accelerate the business models transition towards circular business models. The second main driver are the digital data technologies, for instance big data that shifts the approach in which the problems can be solved, it provides deeper market knowledge and increase the opportunities of customer- focused solutions.

Conclusion

In order to achieve a circular economy and competitive advantages, technology manufacturing companies have to implement digital data technologies. Digital data technologies have high potential to help the technology manufacturing companies to adapt their business model to a circular business model, by changing the three business model elements to the three circular business model elements; circular value proposition, circular value creation and delivery, and circular value capture.

The approaches of implementation of digital data technologies in circular business models are described here below:

- The data-driven approach to improve the circular value proposition element:
    - Digital data technologies in big data, data analytics, Internet of Things and artificial intelligence can improve the circular value proposition of companies through circular strategies in designing products and services based on circularity, it can help improve the value proposition by process and system optimization and help the company to further understand the customer needs.
- The data-driven approach to improve the circular value creation and delivery element:
    - Digital data technologies in big data, data analytics, Internet of Things and blockchain technologies can improve the circular value creation and delivery of companies through circular strategies in creating value through supply chain orchestration and collaboration, managing and circulate the inventory to reduce and eliminate resource requirements, and extend the life of inventory, maintain multiple product generations through collaboration of modular product designs, improving the security of the collaboration and data sharing within the supply chain, creating new extended offering of product and services and revising the operational processes and activities of the companies.
- The data-driven approach to improve the circular value capture element:
    - Digital data technologies in big data, data analytics and Internet of Things can improve the circular value capture of companies through circular strategies in improving the internal processes that enables cost efficiency, new or increased

revenue streams, and new approaches to risk management.

Research and flow diagram contributions

To contribute to the existing literature and knowledge, this research has analyzed the challenges and barriers and based on the results, the challenges and barriers are categorized into three main perspectives. Those perspectives are the internal organizational structure and business model of the companies, the supply chain, and the product and service design that affects the customers. The study contributed to the research by generating data-driven approach and strategies based on digital data technologies allowing technology manufacturing companies to overcome those three perspectives with challenges.
More specifically, the research has generated a flow diagram to give an overview of order of the big amount of literature. It shows the challenges, strategies, characteristics and competitive advantages of the implementation of digital data technologies towards circular business models.

The flow diagram provides the following contributions:
First, the flow diagram enables technology manufacturing companies to have a structured overview, and to look at the list of challenges and barriers categorized in different perspectives. These challenges are divided into perspectives in such a way that it facilitates the technology manufacturing companies to overcome these challenges simultaneously with a certain solution.
Second, the flow diagram shows that in order for the technology manufacturing companies to gain circularity and competitive advantages, the main goal for those companies is to adapt the business model elements to circular business model elements, this is realized by enabling the digital data technologies that have the highest potential. Those digital data technologies are; big data, analytics, internet of things, blockchain technology and artificial intelligence. As one of the key drivers, those digital data technologies have a positive influence on the development of circular business model strategies and enable the companies to become more circular in their business model. Ultimately, each specific digital data technology has its own properties and capabilities to help companies realize some specific circular strategies to overcome the challenges and barriers.
Third, the flow diagram shows that the digital data technologies could lead technology manufacturing companies to new competitive advantages in the comprehensive and optimal use of operations, virtualization and network cooperation. The key advantages are the differentiations of resource-based, management, information, relational, time and location advantages. Furthermore, it leads to additional characteristics advantages in company flexibility, availability, digital serialization, digital integration and customization.
Finally, this flow diagram adds to the current studies, since based on the performance attributes and capabilities of those digital data technologies, the flow diagram shows how it could help the technology manufacturing companies and the people that are on the strategic level within those companies that are considering becoming more circular in their business model. This is a first step for them, the flow diagram maps out where they are and what they should pay

attention to, in order to overcome the challenges and barriers within the three main perspectives. It furthermore provides data-driven approaches and strategies for each circular business model element and their characteristics that ultimately allow those companies to become more circular and gain competitive advantages. Furthermore, this research also gives researchers and educational institutions a comprehensive and structured insight into the studies that have been carried out to date. In which the researchers can set up a follow-up study based on the results of this study. To further improve the phenomenon of digital data technology and circular economy.

Limitations

Although, this research has established a flow diagram to help technology manufacturing companies towards circular business models, but at the end, it is unfeasible to have a certain fixed sets of challenges and barriers or strategies for every technology manufacturing companies. Because in practice, every company is unique, therefore every company has their own specific challenges and barriers.

Nevertheless, the flow diagram that is generated from this research is remarkably extensive; therefore many potential challenges and barriers already have been included in the analysis. Comprehensive digital data technologies approaches and solutions with unique characteristics have been generated to help those technology manufacturing companies to overcome all those challenges and barriers. This ensures that the flow diagram can still be of unique value for each individual company. Ultimately allowing those technology manufacturing companies to successfully make the transition towards circular business models and gain competitive advantages. This research also gives researchers and educational institutions a comprehensive and structured insight into the studies that have been carried out to date. In which the researchers can set up a follow-up study based on the results of this study. To further improve the phenomenon of digital data technology and circular economy.

Recommendations for future research

For future research, it is necessary to apply the flow diagram in practice. Many literature studies, on which the flow diagram has been created, are based on theories of those literature and case studies that have been done during this research. Further research in practice and more case studies should be conducted to further develop the flow diagram to refine and make more reliable.

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List of Abbreviations

AI	*Artificial Intelligence*
B2B	*Business to Business*
B2C	*Business to Consumer*
BCT	*Blockchain Technology*
BM	*Business Model*
BMI	*Business Model Innovation*
CBM	*Circular Business Model*
CE	*Circular Economy*
EoL	*End-of-Life*
IoT	*Internet of Things*
KET	*Key Enabling Technologies*
LBM	*Linear Business Model*

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1. | Introduction

This chapter of the research thesis provides a background study that includes a review of the area being researched, and the current information surrounding the current issue. Furthermore, this chapter also includes the problem statement, research scope, research objectives and research questions on the topic around the digital technologies in the business model transition towards the circular economy.

1.1 Background

Currently, innovation technology and manufacturing companies are driven by revenue, based on volume sales, cost reduction of supply chains, factories and operations. This is all based on the current linear business model; this model follows the "take-make-dispose" philosophy, it is dependent on short product life cycles and maximization of sales. This means that materials are collected, thereafter transformed into products that are used until they become obsolete and are discarded as waste. However, this approach is increasingly coming under pressure. Non-renewable resources are approaching the deletion of resource stocks. Problems such as climate change and biodiversity loss are becoming noticeable and receiving attention at local, national, and international levels by the introduction of new regulations (Pagoropoulos, Pigosso, & McAloone, 2017).

In order to go against those negative environmental impacts, sustainability plays a major role by the aim to achieve sustainable growth and enhanced resource efficiency. The optimal solution for the companies is the concept of circular economy. The circular business model is a new model which based on this concept. Being the opposite of the linear business model, circular business model focuses on the principle of "closing the life cycle" of goods, services, waste, materials, water and energy. It provides strategies to continuously keep the products and materials at their highest utility and value as long as possible, based on the principles of designing out waste and pollution (Ramkumar, et al., 2018). Also, for the technology manufacturing companies, their goal is to ultimately gain market share, make their business process more effective and optimize, or to maximize their profit. Because of this, more and more companies are making the switch to a circular economy, whereby other companies are also being forced to make this switch, because they are part of a value chain.

Nowadays, the digital data technology is changing rapidly. The shift from mechanical and analogue electronic technology to digital data technology has resulted in widespread impacts on the social environment and advancing the globalization. In addition, the new opportunities for technology manufacturing companies to gain competitive advantages are also involved, because of the increased and improved ability to communicate and to share important information. Furthermore, because of the existing barriers and challenges and the increasing demand to improve the transition towards a circular business model, the intersection between

digital data technologies and circular economy is a fast- growing area (Pagoropoulos, Pigosso, & McAloone, 2017).

1.2 Problem Statement

Besides the choice that a company has, whether they want to apply circularity in their business model and company structure, companies are also forced to switch to circular economy. This is because every company is a part of a value chain, in which different companies are connected and dependent on each other. So this allows the value chain to indirectly force companies, for instance technology manufacturing companies to also apply the concept of circular economy.
In reality, the technology manufacturing companies are still far from operating closed-loop systems. Companies' business models and strategies are still based on the linear business models. Many recent studies have been focused on the implementation of the circular business models while trying to overcome the many challenges and barriers. However, it has not yet been completely successful to overcome the challenge and barriers, making the transition towards a circular business model more of as wishful thinking, than an objective that can really be achieved.

Therefore, digital data technologies can play a critical role in order to overcome such challenges and barriers. Little attention has been paid and there is limited knowledge of what the new emerging digital data technologies are, and how it can support the transition and overcome the challenges and barriers of the companies towards a circular business model (Pagoropoulos, Pigosso, & McAloone, 2017). Furthermore, digital data technologies could also enable different type of new capabilities for the companies, which can lead to competitive advantages. To complete this knowledge gap, the purpose of the thesis is to explore how the application of digital data technologies can help technology manufacturing companies towards a more circular business model.

1.3 Research scope

There are many different sectors that all work on circularity in their own ways, such as: the infrastructure & construction building sector, energy, resources & industry sector, automotive sector, consumer and business innovative technology electronics sector, health & social care sector, and the financial sector. All the companies in the above mentioned sectors apply circularity through, for example, reuse of resources, energy and products, or providing the necessary financial support to companies in the enabling of the profitable circular solutions.

The company's business development towards circular economy involves four segments: materials and product design, new business models, global reverse networks, and enabling conditions. However, the transition itself also depends on the policymakers and their decisions, as well as on the business entities that are open-minded about introducing circularity into their business models. For the sake of having a clear, detailed, structured, and successful research, the scope of the research topic is limited to the consumer and business innovative technology

manufacturing sector, with the perspective of improving the technology manufacturing companies' business models to become more circular. The research identifies the challenges and barriers towards a circular business model, as well as to explore how the emerging digital data technologies can help the technology manufacturing companies that are based on B2C and B2B businesses to become more circular and to gain competitive advantages. The aim of the research is to come up with a flow diagram that helps those technology manufacturing companies to become more circular in their business model.

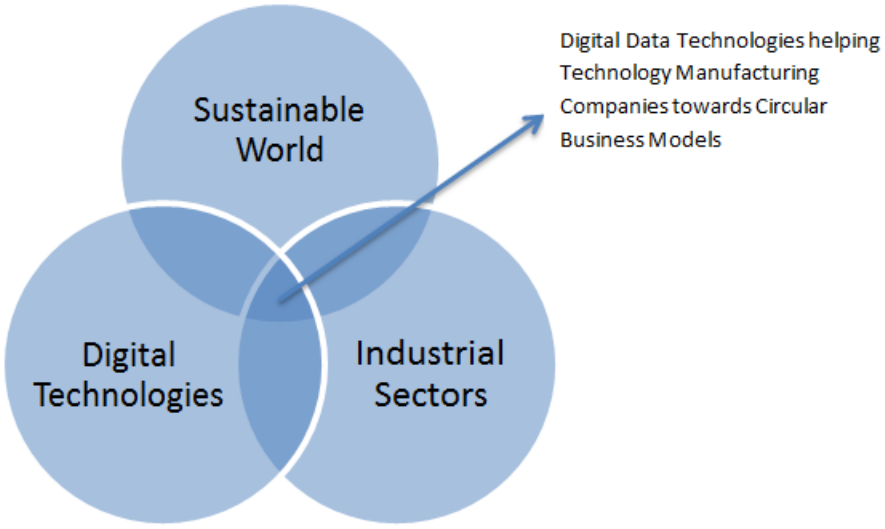


Figure 1.1 - Research Scope

1.4 Research approach

In order to reach this goal, sub-objectives are set:

- Investigate the research landscape, and the barriers and challenges of the technology manufacturing companies towards circular business models, to understand what has been researched so far;
- Identify the emerging digital data technologies that can accelerate the technology manufacturing companies towards circular business models;
- Justify that there are ways for the emerging digital technologies to support the circular business models;
- Propose a flow diagram that is based on digital data technology solutions and provide recommendations to solve the challenges and barriers of the business model to become more circular.

1.5 Research question

In order to achieve the research objectives, research questions are formulated. The main research question of the thesis is:

How can the digital data technologies help technology manufacturing companies towards circular business models?

Thereafter, to obtain the input and knowledge that are necessary to answer the main research question, some sub-research questions are formulated:

1. What is a circular business model?
2. What are the challenges and barriers towards circular business models?
3. What kind of digital data technologies solutions are available to enable circular business models?
4. How can the digital data technologies solutions help the technology manufacturing companies to overcome the challenges and barriers towards circular business models?

1.6 Research methodology

This section will discuss the research methods and methodology that are used to collect and analyze the data, in order to meet the research objectives and to answer the research questions.

The research is a descriptive qualitative research and it is mostly based on a structured literature analysis. The aim of the structured literature analysis is focused on data collection and analysis of secondary sources to obtain and expand the necessary knowledge about the business model challenges and barriers for the technology manufacturing companies to become more circular and to find out the link between the digital data technologies and circular business models. Furthermore, to find out the bridge between what specific digital data technologies works in different circumstances. The structured literature analysis leads to answering the first, second and third sub-questions. Thereafter, because of the results of the structured literature analysis, the fourth sub-question is answered by generating a flow diagram that helps the technology manufacturing companies to become more circular in their business model. The flow diagram is focused on the business model and circular business model, with the emerging digital data technologies in between as the necessary variable that makes this transition possible. Also, by taking into account the main elements of the business model; value proposition, value creation and deliver and value capture, as well as the business model challenges and barriers.

Thereafter, follows the case study, the purpose of the case study is to get an in-depth understanding and to analyze the reality in terms of examining the issues, challenges and barriers during the real life applications, and to gain addition insights on the other key drivers besides digital data technologies that have significant influences on those manufacturing companies and companies that are helping technology manufacturing companies towards circular business models. The generated knowledge and understanding are used to refine the flow diagram. The data collection method is an interview that is semi-structured and guided by a list of topics and questions. The data analysis approach are done by company document analysis, recording the interview and thereafter based on the recording, the interview is transcribed. For the case study, innovation and technology manufacturing companies will be targeted like Circularise, Fairphone and Signify. After the case study, the fifth sub-question is answered with a refined flow diagram. This is followed by the answer to the main research question and a conclusion to the research.

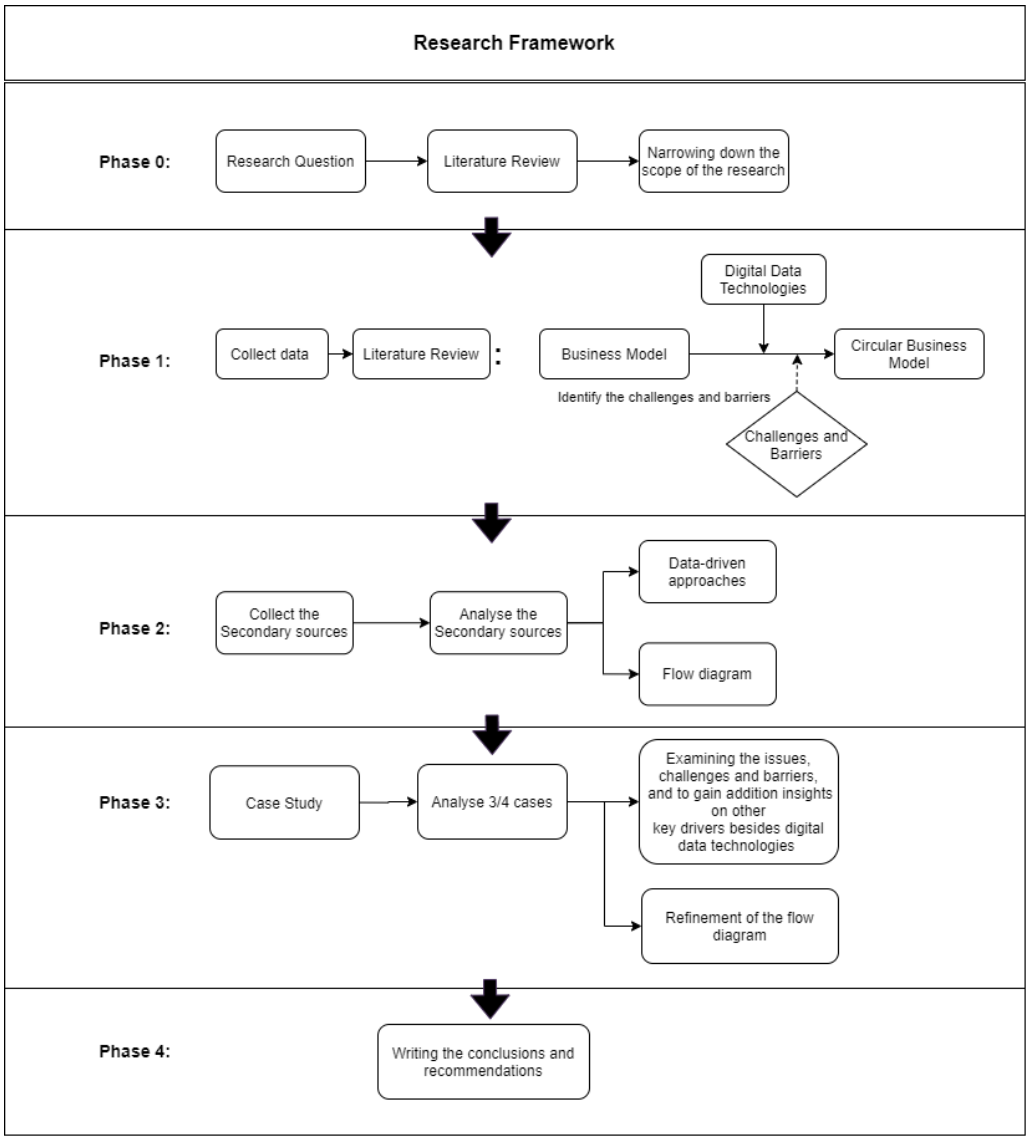


Figure 1.2 - Overview of the research phases

2. | Literature Review

This chapter proposes a literature review that attempts to provide a complete, exhaustive summary of the current literature relevant to the sub research questions. The main topic of this research focuses on circular economy business models, the role of the implementation of digital technology in business model design, key enabling factors of digital technologies in a circular economy and the main challenges of technological advancement in the context of a circular economy. In order to find the answer to the sub- questions, different keywords should be looked into separately.

A systematic 'step-by-step' approach is conducted in order to go through the literature. Scientific academic articles are done by a computerized search by the following keywords:

- Circular economy
- Opportunities and benefits of the circular economy
- Transition towards circular economy
- Challenges and barriers of the transition towards circular economy
- Business model, business model innovation, sustainable business model and circular business model
- Features and characteristics of business models towards circular Economy
- Key enabling digital technologies towards circular economy
- Digital data technologies for circular Economy

The above mentioned keywords will be inserted in online academic databases such as Google Scholar, Science Direct, Research Gate, Elsevier, Scopus and Wiley Online Library. The criteria to select articles for the literature review are based on the research question. The purpose of the review is to gain understanding of the circular economy, the emerging digital technologies and the existing business models, to be able to find out the causes, why the business model transition towards a circular economy is not yet fully realized. In this case, in order to obtain as much useful literature as possible, the search has no filter set on the article type, the search included journal papers, reports, conference articles, books, and theses. However, the subject is focused on the future, therefore, the obtained literature about the digital data technologies, business models and circular economy have a decisive influence on the outcome of this review. Therefore, the literature cannot be too outdated, due to the reliability and rapid developments of technology and business models that follow each other quickly whereby the information is becoming obsolete very fast. Hence, the aim of this literature review is to obtain works of literature with a date of publication of 2010 or newer. Furthermore, the scientific articles that are obtained may not be about the business models or digital technologies in general or on the surface level. But they must be specific about the digital technologies and business models that influence the circular economy and innovative companies.

Thereafter, the acquired scientific articles that match the selection criteria are scanned and read, will be subsequently included if the articles contain relevant information. Afterward, they will be analyzed and reviewed in order to gain an understanding and an extensive in-depth overview of the current state of the digital technologies in the business model transition towards a circular economy. At last, the major observed points and relevancies of this literature review for the research will be covered comprehensively in the conclusion.

The topic of this literature review is quite broad because of the three domains in circular economy, business model and digital technologies. Therefore, to maintain a structured overview, the three domains are separated in three sub-chapters, where the findings for each domain are described in each sub-chapter extensively. A summary and analysis of the findings are described in the fourth sub-chapter.

2.1 Circular Economy

Circular Economy was first developed in the report of Ellen MacArthur Foundations as an industrial system that is designed based on the main elements of restoring and regenerating (Lewandowski, 2016). In other words, it is a concept that aims at reducing the societal production- consumption systems' linear material and energy throughput flows by minimizing the resource input and waste, emission and energy leakage along the production chains. Therefore, applying materials cycles and renewable energy flows to the linear system will close, slow, and narrow down the material and energy loops. This in turn ensures benefits such as reducing pressure on the environment, improvements of the security of the supply of raw materials, stimulation of innovation, advancing economic growth, job creation and could also safe companies billions of money. For more detailed information about definition, importance and benefits of circular economy, please refer to the article on the webpage of the European Parliament.

Through the years, the circular economy has become a new aimed standard of the treatment of materials, resources, energy value creation and entrepreneurship (Lewandowski, 2016).

The concept of circular economy is further refined by a large amount of perspectives, such as Regenerative Design, Performance Economy and Industrial Symbiosis. Those perspectives are harmonizing one another and provide the support for the main principles of this circular economy approach (Lewandowski, 2016):

1. Design out waste/ Design for reuse
2. Circulate materials and resource
3. Build resilience through diversity
4. Rely on energy from renewable sources
5. Think in systems
6. Waste is food/ Think in cascades/ Share values (symbiosis)

Ultimately the circular economy is about the inventory, extending the life, reusing it, repurposing it or the eliminating the need of it altogether. For more detailed information about how to harness the power of supply chain in your circularity makeover, please refer to the article of Deborah Dull on the webpage of Greenbiz.

2.2 Business model

The business model involves a concept that describes how an organization creates, delivers and captures values (Manninen, Koskela, Antikainen, Bocken, Dahlbo, & Aminoff, 2017). It can be characterized as the conceptual and constructive implementation of a business strategy and as the basis for the implementation of business processes. For carrying out the strategies, the business model is focused on the value concept.

According to Boons & Lüdeke-Freund (2013) and Oghazi & Mostaghel (2018), a business model concept can be identified into three elements:

1. **Value proposition**: It refers to the value that is embedded in the product or service offered by a company. For example: the design of the sustainable products and services in order to survive the technology and fashion trends. Also, maintain the durability and customer attraction, the question of why it is more valuable than the similar offerings of the competitors is an important task;
2. **Value creation and deliver**: Every business starts with value creation, the main purpose is to create and deliver value in the most efficient way that will generate profit after the costs.
   - **Supply chain**: How upstream relationships with suppliers are structured and managed. The collaboration with partners has an influence on the success of the Circular business models;
   - **Customer interface**: How downstream relationships with customers are structured and managed;
3. **Value capture**: This is the company's ability to create profits from it's transactions;
   - **Financial model**: The costs structure, revenue model and benefits from and their distribution across business model stakeholders. Circular Business models require unexpected costs and higher risks.

2.2.1 Business model innovation

Business Model Innovation is the responsive change of the existing business models or the creation of new business models that better satisfies the needs of the customers than the existing business models. Those innovative business models are essential to the success of business as it creates competitive advantages by enabling a more complete differentiation and a greater influence on a company's sales and costs than a particular product or process innovation. Furthermore, the current linear business models are creating resource waste that creates external pressures for the companies. This is the reason why new Business Model Innovations are

being created, such as, sustainable business models and circular business models (Oghazi & Mostaghel, 2018).

2.2.2 Sustainable business model

Sustainable business models aim to create, deliver and capture value, as well as bringing businesses, stakeholders and environmental entities to the table by not depleting the natural, economic, and social capital it relies on (Breuer & Lüdeke-Freund, 2014). It is an approach that provides financial benefits to the business over the long term, while not causing environmental damage, but instead actually helping the environment to improve. It provides competitive advantage by adjusting profit and environmental objectives. For more detailed definition of sustainable business model, you can find it on the webpage of Scottish Enterprise.

2.2.3 Circular business model

The relevancy of the circular business model nowadays is very high as the role of companies is changing dramatically as a response to the social, environmental and economic pressures. Besides creating sustainable value, employing pro-active multi-stakeholder management, and creating long-term perspectives, identically to the sustainable and closed- loop business models, the purpose of the circular business model are environmental sustainability and cutback in the use of limited resources. Furthermore, circular business model is also centralized on resource efficiency by focusing on closing, slow intensifying, de-materializing, and narrowing down the resource loops by reusing, repairing and remarketing (Ünal, Urbinati, Chiaroni, & Manzini, Value Creation in Circular Business Models: The case of a US small medium enterprise in the building sector. Resources, Conservation & Recycling 146 (2019) 291–307, 2019). According to Nußholz (2017), a circular business model is how a company creates, captures, and delivers value with the value creation logic designed to improve the resource efficiency. As a result, Circular business models provide new perspectives in terms of value proposition, creation and delivery and capture.

According to Lewandowski (2016), the circular business models can be classified into different types, based on which sector it is applied in:

Classification	Model	Explanation
Regenerate	Energy recovery	Circular business models based on conversion of non-recyclable waste materials into usable heat, fuel, or electricity. Efficient use of renewable energy, buildings, eco-industrial park and chemicals
	Circular Supplies	
	Efficient buildings	
	Sustainable product locations	
	Chemical leasing	
Share	Maintenance and Repairs	Circular business models based on extending the Product life cycle by extending it through maintenance and repair, enabling sharing use, access of product between members of the public or between businesses, refurbishing, upgrading and reselling used products. Or
	Collaborative Consumption, Sharing Platforms	
	PSS: Product lease, Availability based, Performance based	
	Incentivized return and reuse or Next Life Sales	
	Upgrading	

	Product Attachment and Trust Bring your device Hybrid model Gap-exploiter model	creating products that are loved, liked and trusted longer. Use of own devices to get access to services
Optimize	Asset management Produce on demand Waste reduction PSS: Activity management/ outsourcing	Circular business models based on more efficient use of materials and goods, internal collection, reuse and resale of used products. Producing when products are ordered, reduce the waste during the production process and before.
Loop	Remanufacture, transformation Recycling, Resource Recovery Upcycling Circular Supplies	Circular business models based on restoring, upgrading the value of the products or its components to a 'new' quality, recovering materials out of disposed products, or using supplies from material loops, bio based- or fully recyclable.
Virtualize	Dematerialized services	Circular business models based on shifting physical products, services or processes to virtual.
Exchange	New technology	Circular business models based on new technology of production.

Table 2.1 - An overview of the circular business models categorized in classifications. Retrieved from (Lewandowski, 2016)

According to Moreno, De Los Rios, Rowe, & Charnley (2016), the circular business models can be divided into different archetypes, based on the purpose of the circular business model:

Circular business models Archetypes	**Description**
Circular supplies	Business models based on industrial symbiosis, which means that the output from one process can be a useful resource for another process.
Resource value	Business models based on the recovering of the resource value of materials to be used in alternative forms of value.
Product life extension	Business models based on the extension of the life of a product.
Extending product value	Business models based on the extension of a product value.
Sharing platforms	Business models based on the enabling of utilization rates of products, by making is possible to share the use, access and ownership of products.

Table 2.2 - An overview of the circular business models archetypes. Retrieved from (Moreno, De Los Rios, Rowe, & Charnley, 2016)

2.2.4 Challenges and barriers towards circular business models

Besides the benefit of Circular Business models, there are also challenges and barriers towards circular business model. Based on various papers, the challenges and barriers according to each paper are listed below.

Authors	Challenges and barriers towards circular business models
Rizos, et al. (2016)	1. Company environmental culture 2. Lack of capital 3. Lack of government support/ effective legislation 4. Lack of information 5. Administrative burden 6. Lack of technical and technological knowledge 7. Lack of support from the supply and demand network
Bressenali, et al. (2018)	1. Operational risks 2. Loss of ownership 3. Willingness to pay 4. Technology improvement 5. Return flow uncertainties
Debacker, et al. (2017)	1. Fragmented policy framework 2. Conflicting energy and environment policy measures 3. Lack of standardization of qualitative data over the entire value chain 4. Intellectual property of material and product related data 5. General perception that revisible design solutions entail high financial costs 6. Lack of certification and quality assurance for reclaimed products and recycled materials 7. Lack of a business model framework related to circular economy
Adams, et al. (2017)	1. Lack of interest 2. Limited awareness across supply chain 3. Lack of circular economy knowledge 4. Lack of incentive to design for end of life (products) 5. Lack of consideration for end-of-life issues 6. Lack of market mechanisms for recovery 7. Unclear financial case 8. Low value of material/products at end of life 9. Fragmented supply chain
(Oghazi & Mostaghel, 2018)	1. Product design 2. Supply chain design 3. Infrastructure 4. Internal activities (Logistics, the offerings provided, services, and manufacturing processes)

Table 2.3 - The challenges and barriers towards circular business models

Rizos, et al. (2016) refer to the lack of support from the supply and demand network as the main challenge and barrier of the companies. Also, the other reviewed papers have a similar view of how the companies can improve and on what elements they have to focus on in order to succeed.

According to Oghazi & Mostaghel, (2018), the transition towards circular business model requires multiple strategies, approaches, methods and tools that go well together. The most crucial challenges in the transition that can lead to the acceptance of circular business models are product and service design, the supply chain design, the key enabling technologies that could support the circular business models, and infrastructure. Changes also have to be done within the internal activities, for example, logistics, the offerings provided, services, and manufacturing processes. Furthermore, the transition is also affected by many constraints, including technological, economic, political and cultural limitations. Risk management is an important part of each step in this complex organization restructuring (Oghazi & Mostaghel, 2018).

Within the circular business model transition, the product design is a major challenge as well; products need to be adapted for multiple lifecycles and upgradability. The main fundamental strategies for product design have to be based on the resource loops by extending the life of products through reuse, repair and remanufacture; by closing the loop by recycling and narrowing the resource flows by reducing the amounts of materials and components in the production system (Oghazi & Mostaghel, 2018). Oghazi & Mostaghel (2018) conclude that although the transition towards circular business models is a challenging case. However, it is possible to contribute and having positive effects on the environmental perspective and economic perspective of the firms. As well as providing positive social and ecological contributions.

Planing (2015) has argued that circular business models can actually provide big opportunities for companies, customers and the environment. However, the benefits will not translate into a widespread acceptance of the circular business models. The emphasis of Planing (2015) corresponds with the point of view of Oghazi & Mostaghel (2018) by arguing that the reasons for the not full acceptance of circular business models are because of the conceptual flaws of the economic perspective and consumer perspective. From the economic perspective, the unbalanced profit-share along the supply chain is one of the main reasons for the imperfect product design. In other words, the current product design is actually based on cost and production efficiency. For example, when a product is returned for remanufacturing or recycling, this leads to a situation where the optimization of the product design is actually based on cost and production efficiency and not based on repair and re-manufacturing. Although when repair and re-manufacturing are more economical than product replacement from a lifecycle point of view. Meanwhile, consumers' behavior tends to boost this development by only taking into account the purchase price, even if the net present value of upgrading to a more expansive but durable product would be more economical. The motives of consumer behavior will be important to optimize the value proposition of circular business models. More research about consumer behavior in the recognition progress will be necessary to develop the knowledge about the value proposition in order to design and implement new circular business models.

Analysis of the challenges and barriers

From the papers and as shown in table 2.3, it can be extracted that there are different challenges and barriers. To get a clear overview, the challenges and barriers are divided into different perspectives, see table 2.4; the challenges and barriers of the external effects that affects the companies, the challenges and barriers within the internal organizational structure of the companies, the challenges and barriers of all the parties within the supply chain, the challenges and barriers of the product design that affects the customers.

Challenges and barriers of the different perspectives	
The external effects that affects the companies	1. Lack of government support/ effective legislation 2. Fragmented policy framework 3. Conflicting energy and environment policy measures 4. Lack of information
The internal organizational structure of the companies	1. Company environmental culture 2. Lack of interest and circular economy knowledge 3. Lack of consideraetion of circular product design 4. Lack of consideration for end-of-life issues and the incentive to design for end of life 5. Low value of material/products at end of life 6. Lack of technical and technological knowledge 7. Lack of a business model framework related to circular economy 8. High financial costs and lack of capital 9. Administrative burden 10. Unclear financial case 11. Operational risks 12. General perception that revisible design solutions entail high financial costs
All the parties within the supply chain	1. Fragmented supply chain and lack of support and collaboration from the supply and demand network 2. Limited awareness across supply chain 3. Complexity throughout the supply chain in regard to logistical, financial, and legal aspects 4. Intellectual property of material and product related data 5. Lack of standardization of qualitative data over the entire value chain 6. Return flow uncertainties (in regard to the quantity, the mix, the quality, the time and the place of returns of products offered through a system that decrease the probability of achieving an economic scale in reverse logistics and renovation activities) 7. Lack of certification and quality assurance for reclaimed products and recycled materials 8. Lack of market mechanisms for recovery
Product design that affects customers	1. The shift of customer value proposition, awareness, lifestyle and cultural behavior 2. Loss of ownership (This can bring a loss of the sense of control, availability, self-esteem or status symbol connected with the product ownership.) 3. Willingness to pay (becomes critical: customers usually look for substantial savings when accessing renovated or 'second-hand' products, even though they are 'as good as new.) 4. Technology improvenent: Since products in a circular economy are designed to last for a longer amount of time, rather than for usage and being thrown away afterwards, this can results into unattractiveness for a part of the customer base

Table 2.4 - The challenges and barriers categorized in perspectives

From the data analysis, it can be concluded that there are many challenges and barriers from different perspectives across the entire process towards a circular business model. However, the scope of the research is limited to the perspective of improving the technology manufacturing companies' business models to become more circular through support of the emerging digital data technologies. Therefore, the challenges and barriers in the table that are underlined are the expected challenges that can be overcome by using digital data technologies. The research will mainly focus on these challenges and barriers and on how they will be overcome.

To explain it more extensively, digital data technologies will have little impact on the external effects that affects the companies, so the government itself must also introduce policy measures, effective regulations and legislation to promote the circular economy. Furthermore,

digital data technologies also have no effective way of influencing awareness, lifestyle and behavior of the customers.

However, it is realistically possible and feasible to implement digital data technologies in the internal organizational structure of companies, the entire supply chain, and to improve the companies' product designs to help the technology manufacturing companies towards circular business models. So therefore, the underlined challenges are the expected challenges that can be overcome by using digital data technologies. The research will mainly focus on these challenges and barriers and on how they will be overcome.

2.2.5 Transition towards circular business model

According to Frankenberger, et al (2013), the business model innovation can be divided into four different phases.

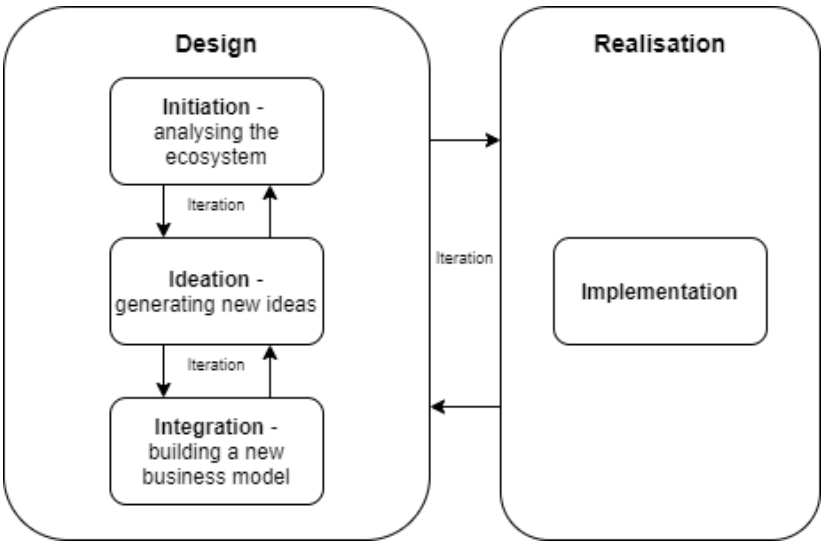


Figure 2.1 - The 4I- framework of business model innovation process and their key challenges. Adapted from (Frankenberger, Weiblen, Csik, & Gassmann, 2013).

The first phase is Analysis (Initiation), where the players and drivers of the current business model are analyzed. The second phase is Innovation (Ideation), during this phase, the company will come up with idea's to overcome the current linear business logic, thinking in multiple value creation, business systems and trying to come up with new circular business model ideas. The third phase is Design (Integration), this phase tries to design and integrate all the new pieces of the system by designing the business architecture, for example, by coordinating the collaboration of the partners throughout the whole system, dealing with trust issues and managing the dependencies. The fourth phase is the Realization (Implementation) phase, in this phase the new business models will be realized. The external and internal resistances and

conflicts within the companies will be tried to overcome, as well as the resistance of the old applied linear business model.

The 4I- framework of business model innovation helps companies to organize the existing contributions and to identify the current 'blind spots'. Also, it helps companies to develop a process model of business model innovation in a structured approach and offers a comprehensive list of challenges which arise during the business model innovations (Frankenberger, Weiblen, Csik, & Gassmann, 2013).

According to Bocken, De Pauw, Bakker, & Van der Grinten (2015), strategies of slowing and closing the resource flows are the most important factor for the transition towards a circular economy. The aim of slowing the resource loops is to extend the utilization period of products, whereas the purpose of closing resource loops is to close the loop between post-use and production. Also, the business model and design strategies have to go hand in hand in order to be able to transform the economy from linear to circular. Multiple business models and design strategies, approaches, methods and tools are eventually needed to support the transition. Bocken, De Pauw, Bakker, & Van der Grinten (2015) have developed a circular economy strategy framework that provides an overview of the possible design and business model strategies for a circular economy.

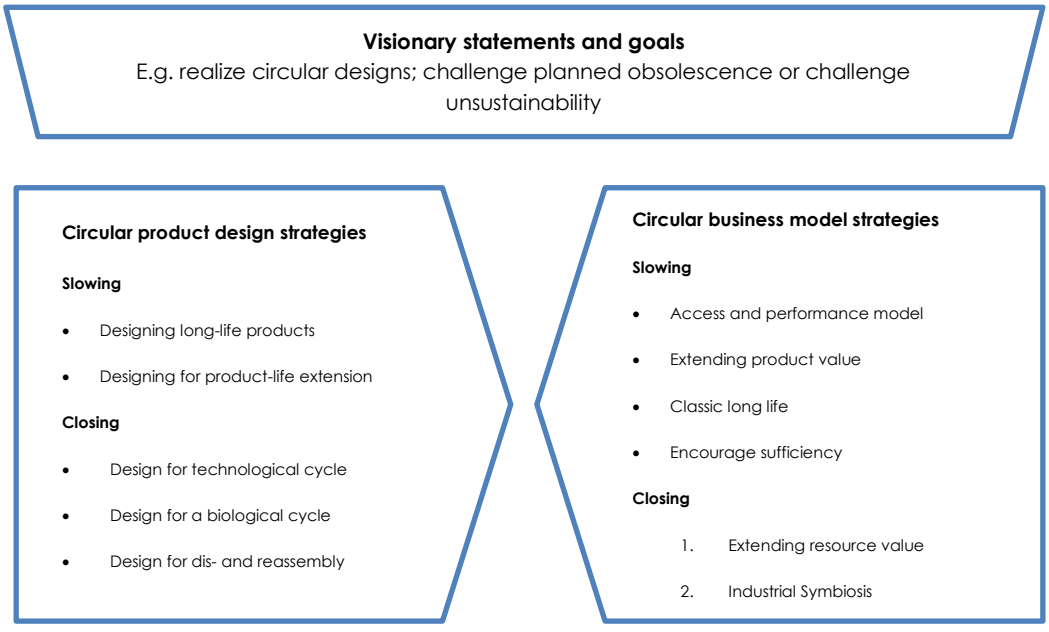


Figure 2.2 – Circular economy product and business model strategy framework. Adapted from (Bocken, De Pauw, Bakker, & Van der Grinten, 2015)

2.2 Digital Technology

In context of the digital innovation in the business, according to Del Vecchio, Di Minin, Petruzzelli, Panniello, & Pirri (2017), it makes the companies possible to manage the increasing amount of captured and transferred knowledge and information flows within and outside the company's boundaries, as well as enhancing the process performances and giving the company the possibility to redesign their organizational structure and to innovate their business model. Furthermore, these technologies are defined by cross-industries profiles of application, causing rapid innovation cycles, new business models, creation of new industrial domains and continuously improvement of competencies at individual and industrial level.

Digital technologies can be divided into two groups, the so-called "key enabling technologies" and the massive digital data technologies.

2.2.1 Key Enabling Technologies

The Key Enabling Technologies (KETs) are a group of technologies with a wide range of product application, such as developing low carbon energy technologies, improving energy and resource efficiency, and creating new medical products. The technologies that are causing radical innovation in industry and society are the micro- and nano-electronics, nanotechnology, advanced materials, industrial biotechnology and advanced manufacturing technologies.

Those technologies make material stronger and more durable, whereas the end products can be lighter and safer as well as making other products like biofuels and mobile devices more effective and sustainable. The KETs have the potential to help the industry to grow; therefore, they are a priority for European industrial policy to accelerate the transition towards circular economy. For more detailed information about KETs, please refer to the webpage of the European Commission.

2.2.2 Digital Data technologies

The emerging digital data information technologies play a big role in the proliferation of circular economy. According to Pagoropoulos, Pigosso, & McAloone (2017), the digital data technologies can be grouped into three architectural layers.

Data collection

Radio Frequency Identification (RFID): RFID is a data collection technology that uses electromagnetic fields to automatically identify and track the tags of objects. This technology has attracted significant attention within the context of circular economy because it helps track material flows to enable value recovery through implementation of the Re-strategies. In other words, it facilitates the transition to closed-loop systems. Moreover, networked RFID systems enable object and products tagged with an RFID chip to connect to an information network, providing complete information about the product's life cycle to all networked partners (Pagoropoulos, Pigosso, & McAloone, 2017).

Internet of Things (IoT): Internet of things is the inter-networking of computing devices, machines and objects through electronics and sensors in order to collect and exchange data. The sensors and actuators are connected by networks computer systems that can monitor and manage the health and actions of the object. In the case of circular economy, IoT enhances the circular economy. Internet of things technology enables the observation of users' activities. This will discourage careless behavior and reducing operational risks. By automatically and remotely monitoring the efficiency of a resource during the harvesting, production and at the end of its use cycle will also enhance the organization of collection activities. Moreover, by making the products connected through Internet of things, results in easier product upgrade, because of avoiding the technology improvement challenge (Bressanelli, Adrodegari, Perona, & Saccani, 2018). Furthermore, it provides the fundamental basis for the evaluation of the consequences of the actions of various stakeholders during the life of the products and objects. In the end, it can make the value chain more efficient and improve the profitability and conservation of the stakeholders. For more detailed information about internet of things, please refer to the article of Mark Esposito on the webpage of Greenbiz.

Blockchain Technology (BCT): Blockchain Technology is a decentralized technology; it is based on consensus protocols across a network of nodes in order to confirm a transaction performed on the network. Therefore the way of storing data is distributed and transparent instead of being stored at a central point of control. This technology is known as a technology with a high potential because of the distributed nature, the immutability that provides security and trust, as well as the transparency. The data in BCT is public, therefore in the case of circular economy, companies are hesitant to implement this technology into their business model and share information through BCT because of the fear of losing the competitive advantage. However, BCT can still be utilized to accelerate the transition towards a circular economy by solving some of the existing challenges and barriers. For example, a Dutch company called Circularise has developed a blockchain system called CIRbase. This system is based on the validation of manifests that can be stored by different parties into the blockchain. Thereafter, it is possible for all the parties to use the smart questioning system, and anonymously ask and answer a smart question to any parties involved the system. For this system to work it is necessary that the value of using this type of information sharing is accepted and adopted by the users and becomes the norm (Bolier, 2019).

Data integration

Relational Database Management Systems (RDBMS): Due to the emerging of digital technologies and the increase in the volume of data, the integration, recognition of data sources and valuable information are a big business challenge. RDBMS is a collection of software programs that enable firms to create, update, administer and interact with a relational database. It integrates the wealth of information produced by heterogeneous data collection systems such as IoT systems. In the end, RDBMS has a huge influence on the successful implementation of circular economy (Pagoropoulos, Pigosso, & McAloone, 2017).

Product Lifecycle Management (PLM) systems: PLM are information management systems that integrate data and processes of multiple life cycles. It allows manufacturers and supply chains to enable digital manufacturing planning techniques, clear visibility and the chance to provide feedback on the product development phases (Pagoropoulos, Pigosso, & McAloone, 2017). The PLM opportunity in the circular economy is to fix the end-of-useful-life retrieval, refurbishment and upgrading the tasks of creating innovative new products together with the supporting lifecycle processes. For more detailed information about PLM opportunity in the circular economy, please refer to the article of Peter A. Bilello on the webpage of Raconteur.

Data Analysis

Machine Learning and Artificial Intelligence: Machine learning is an application of Artificial Intelligence that provides the ability to systems to automatically learn and improve from experience without being explicitly programmed. For a more detailed definition of Machine Learning you can find it on the webpage of Expert System.
Due to the speed with which an artificial intelligence algorithm, it can analyze the large amounts of data and suggest design adjustments, machine learning can be applied to accelerate the transition to a circular economy by supporting the process and system optimization that leads to the most effective designs (Ellen Macarthur Foundation, 2019).

Big data Analytics: Big data are extremely large data sets that are computationally analyzed to reveal patterns, trends and associations. Within the context of a circular economy, big data Analytics are a viable approach to make use of information from various systems such as sensors and IoT, in order to improve the decision making. However, big data is not always discussed as a concept directly, but it is more of an approach to analyzing the high volume of data, that comes from different data sources. For example, big data can integrate lifelong information and enable the implementation of new strategies, real time data analytics can also enable decision making and provide insights from raw data as well as embedded data on multiple machine/equipment/product objects. Also, big data is able to monitor processes of production and consumption; this will allow the system of material flow to be closed earlier which leads to minimization of waste by keeping materials in the economy (Pagoropoulos, Pigosso, & McAloone, 2017).

Blockchain Technology: Implementing the blockchain technology into the big data analytics adds an additional data layer to the big data analytics process. The big data generated with blockchain Technology is more secure, the network architecture ensures that the data can not be forged. Also, the combination between blockchain technology and big data is more valuable, because of the more structured, sufficient and complete. In other words, it increases the quality of the data, and therefore this combination makes the data an even more advanced source for further analysis (Vedak, 2018).

From this it can be confirmed that digital data technologies have a high potential to overcome some of the barriers, including the data-issues.

2.2.3 Role of digital technologies to overcome circular economy challenges

The results of Pagoropoulos, Pigosso, & McAloone (2017) argue that digital data technologies can play a factor towards a circular economy. However, it is still in an early stage and the maturity level of digital data technologies is still disputed. Other studies like Lewandowski (2016) argue that there is still a lack of business perspective in the literature, therefore, it is important to consider and do further research on how technology manufacturing companies and the whole supply chain can use digital data technologies, such as IoT and data management technologies to support material tracking and recycling. Also according to Pagoropoulos, Pigosso, & McAloone (2017), Lieder & Rashid (2016) argues that the current studies are focusing on the digital data technologies within the circular economy. In regard to the life cycle stages, digital data technologies can help close the material loop, so the main focus has to be on the End of Life (EoL) and the link to production. According to Pagoropoulos, Pigosso, & McAloone (2017), the main identified gap within the application of digital data technologies is the limited technological perspective. In the future, researches should focus on the application of digital data technologies in actual case studies in order to create more observational results.

As a result of the case study of Bressanelli, Adrodegari, Perona, & Saccani (2018), they argue that digital data technologies can support companies to overcome the circular economy challenges. According to them, the adoption of the Internet of Things (IoT), big data and analytics offer the companies a set of functionalities that can help overcome those challenges. Combining those digital data technologies, the challenges related to the loss of ownership, the willingness to pay and the return flow uncertainties are able to overcome. The results as shown in Table 2, shows that five out of the seven challenges can be prevented by enabling the IoT, big data and analytics technologies. The challenges can be overcome by monitoring users' activities, the advanced services such as preventive and predictive maintenance or optimization of the usage phase that lead the customer to leave the ownership of products to companies, digital upgrade and reducing the return flow uncertainties by the estimation of products and components residual life. However, the financial risks and cannibalization can not be prevented through the adaption of digital technologies; an investment analysis should be done before investing in these technologies. Also, new challenges related to privacy and data security will arise when products become smart.

2.2.4 Overview of the role of digital data technologies towards circular business models

This section of the literature review looks at the role of the digital data technologies to overcome the challenges and barriers towards circular business model. First, a thorough data collection has been done of all the studies that have been done to date. Subsequently, a thorough data analysis was done to identify the core concepts of each study. Below is an extensive overview of all studies that have been done up till now.

Circular Economy challenges	How the challenge is overcome (i.e. through which functionality)	Digital Technologies	
		Internet of Things	Big Data & Analytics
Financial risks	N.a.	N.a.	N.a.
Operational risks	Monitoring users' activities	✓	
Loss of ownership	Advanced services such as the optimization of the usage phase or the provision of preventive and predictive maintenance	✓	✓
Willingness to pay	Advanced services such as the optimization of the usage phase or the provision of preventive and predictive maintenance	✓	✓
Cannibalization	N.a.	N.a.	N.a.
Technology improvement	Digital upgrade	✓	
Return flow uncertainties	Product tracking and estimation of products and components residual life	✓	✓

Table 2.5 - Internet of Things, big data and data analytics to support the companies to overcome circular economy challenges. *Adapted from (Bressanelli, Adrodegari, Perona, & Saccani, 2018)*

2.2.5 Digital data technologies and competitive advantages

Digital data technologies are also used to gain a competitive advantage. This ultimately leads to an increase in market share and profits.

Technology manufacturing companies understand that digital data technologies are a key factor to stay ahead of the competition. Digital data technologies such as big data, data analytics, artificial intelligence, blockchain technology and internet of things are creating new technological capability opportunities in data storage, sharing, security and intelligence.

These technological capabilities ensure extended efficiency, improved workflows, improved business practices and strategies, better innovation, better access to new statistics, knowledge and insights,
In other words, as shown in table 2.6, it leads to new competitive advantages in the comprehensive and optimal use of operations, virtualization and network cooperation. The key advantages are the differentiations of resource-based, management, information, relational, time and location advantages. Furthermore, it leads to additional characteristics advantages in company flexibility, availability, digital serialization, digital integration and customization.

Ways of creating competitive advantage	Key advantages
Comprehensive and optimal use of operations ICT, interoperability; dynamic capabilities, system partnering, knowledge partnering **Virtualization** Robotization, modularity; decentralization, real-time assessment of capabilities, service orientation **Network cooperation** Smart networks, machines processes, systems products, supply chains, factories and a sharing economy of new business models in B2C and B2B	**Differentiations:** - resource-based advantages - management advantages - information advantages - relational advantages - time advantages - location advantages **Offer advantage:** - advantage of flexibility - advantage of availability - advantage of digital serialization - advantage of digital integration - advantage of customization

Table 2.6 – Competitive advantages of implementing digital data technologies. *Adapted from (Adamik & Nowicki, 2017)*

2.2.6 Data results

As a result of the data analysis and the identification of the core concepts of each paper, it can be confirmed that digital data technologies can help technology manufacturing companies to overcome the challenges and barriers towards circular business model.

An extensive overview of all the studies that have been done about the digital data technologies helping technology manufacturing companies towards a circular business model is made and can be found in Appendix I.

According to the obtained literature, the adoption of data collection, data integration and data analysis technologies such as internet of things, blockchain, artificial intelligence, big data and analytics are the main technologies with the most potential in improving the business model elements and supporting the companies towards circular business models. The reviewed papers all have a similar view of the performance attributes of those particular digital data technologies and how they can help the companies to improve and overcome the challenges and barriers, in order to succeed.

However, the emphasis of the reviewed papers on the most important elements towards circular business models, points out that there is not necessarily one particular solution to support the transition. It appears that the papers; Pagoropoulos, Pigosso, & McAloone (2017), Bianchini, et al (2018), Okorie, et al (2018), Jabbour, et al (2017), Bolier, (2019), Ramadoss, et al (2018) and Bressanelli, et al (2018) argue that the adoption of data collection, integration and analysis

technologies such as internet of things, blockchain, big data and analytics are the main technologies in order to support the companies to overcome the challenges the supply chain as a whole, for example; a collaboration of producers and suppliers leads to a shared network and trustable data exchange of material and resource flows, which will automatically lead to better productivity and efficiency.

While the papers of Lieder & Rashid, (2016), Ramadoss, et al (2018), and Bressanelli, et al (2018) argue that the digital technologies can help the technology manufacturing companies by changing the internal structure of the company. It help companies to monitor activities in a more productive and efficient way that leads to a reduction of raw material and energy consumption, this in turn leads to cost savings. In regard to the product life cycle stages, it can help close the material loop, improve the product design, and focus on the End of Life of a product. However, those performances particular attributes are more focused on the usage and the End of Life phase of a product.

2.3 Conclusion

In the literature review, we reviewed the academic works published on the current trend of circular economy, business models, business models elements, existing circular business models and the challenges and barriers toward a circular business models according several papers. Furthermore, the current emerging digital data technologies and the adoption and its performance attribute to overcome the challenges and barriers are also reviewed.

With this literature review, the sub research questions formulated in the introduction can be answered.

1. What is a circular business model?

The business model can be characterized as the conceptual and constructive implementation of a business strategy and as the basis for the implementation of business processes. For carrying out the strategies, the business model is centered on the concept of value. The values can be identified into three the elements: value proposition, value creation and delivery, and value capture.

The relevancy of the circular business model nowadays is very high as the role of companies is changing dramatically as a response to the social, environmental and economic pressures. The goals of the circular business models are environmental sustainability and reductions in the use of finite resources. It also focuses on closing, slow intensifying, de-materializing, and narrowing down the resource loops by reusing, repairing and remarketing. As a result, Circular business models provide new perspectives in terms of the three elements of the normal business models and making it circular value proposition, circular value creation and delivery and circular value capture.

In addition, the circular business models can be classified into different types, based on which sector it is applied in: regenerate, share, optimize, loop, virtualize and exchange. Also the circular business models can be divided into different archetypes as well, based on the purpose of the circular business model: circular supplies, resource value, product life extension, extending product value and sharing platforms.

Ultimately the circular economy is about the inventory, extending the life, reusing it, repurposing it or the eliminating the need of it altogether.

2. What are the challenges and barriers towards circular business models?

From the data analysis, it can be concluded that there are many challenges and barriers from different perspectives across the entire business process towards a circular business model. However, the scope of the research is limited to the perspective of improving the technology manufacturing companies' business models to become more circular through support of the emerging digital data technologies.

The emphasis of the reviewed papers on the most important challenges and barriers towards circular business models, points out that there is not one particular solution to support this process. Based on the three main elements of the business model; value proposition, value creation delivery, and value capture, the reviewed papers all have a similar view of how the technology manufacturing companies can improve and on what challenges and barriers they have to focus on in order to succeed. It is realistically possible and feasible to apply digital data technologies in the internal organizational structure of companies, the entire supply chain, and to improve the companies' product designs to help the technology manufacturing companies towards circular business models. As a result of the data analysis, the challenges below are the challenges divided into three perspectives with the greatest potential to be overcome by the implementation of digital data technologies:

Perspective 1: The internal organizational structure and business model of the companies:

1. Lack of consideration of circular product design or circular business model design
2. Lack of consideration for end-of-life issues and the incentive to design for end-of-life
3. Low value of material/products at end-of-life
4. High financial costs and lack of capital

Perspective 2: The supply chain:

5. Fragmented supply chain and lack of support and collaboration from the supply and demand network
6. Complexity throughout the supply chain in regard to logistical, financial, and legal aspects
7. The intellectual property of the material and product-related data
8. Lack of standardization of qualitative data over the entire value chain
9. Return flow uncertainties
10. Lack of certification and quality assurance for reclaimed products and recycled materials
11. Lack of market mechanisms for recovery

Perspective 3: Product and service design that affects the customers

12. The shift of customer value proposition, awareness, lifestyle and cultural behavior
13. Willingness to pay

3. What kind of digital data technologies solutions are available to enable circular business models?

Digital data technologies can play a factor to overcome the challenges and barriers towards circular business model. According to the obtained literature, the adoption of data collection, data integration and data analysis technologies such as Internet of Things, blockchain

technology, artificial intelligence and big data and analytics are the main technologies with the most potential in improving the business model elements and supporting the companies towards circular business models.

Digital data technologies lead to new competitive advantages in the comprehensive and optimal use of operations, virtualization and network cooperation. The key advantages are the differentiations of resource-based, management, information, relational, time and location advantages. Furthermore, it leads to additional characteristics advantages in company flexibility, availability, digital serialization, digital integration and customization.

From the literature review it can be concluded that most of the papers agree on the perspectives: internal structure of the company and the entire supply chain in which the company is located, have the most potential for improvements and to stimulate the companies towards circular business models.

The findings show that there is a gap in the literature; the potential perspectives that have influences on the companies towards circular business models are not precisely mentioned or related to the specific challenges and barriers. In addition, nor has it been elaborated in detail in relation to the main elements of the business model in value proposition, value creation and delivery and value capture. An extensive overview of all the studies that have been done about the digital data technologies helping technology manufacturing companies towards a circular business model is made and can be found in Appendix I. In the next chapter all the relevant literature is brought together. Based on those results and observations, a flow diagram is created that helps the companies with the implementation of digital technologies in circular business models.

3. | Flow diagram

In this chapter all the relevant concepts obtained during the structured literature review is brought together.

Based on those results and observations, an overview diagram of the challenges and enablers of circular business model is made to get a structured overview, see appendix II. In section 3.1, an overview of the capabilities of the digital data technologies is made, in order to have a structured overview of the capabilities of digital data technologies. Based on that, data-driven approaches are generated to improve each individual circular business model elements. Thereafter, a flow diagram is created that helps the technology manufacturing companies with the successful implementation of digital data technologies towards circular business models.

3.1 Digital Data Technologies capabilities

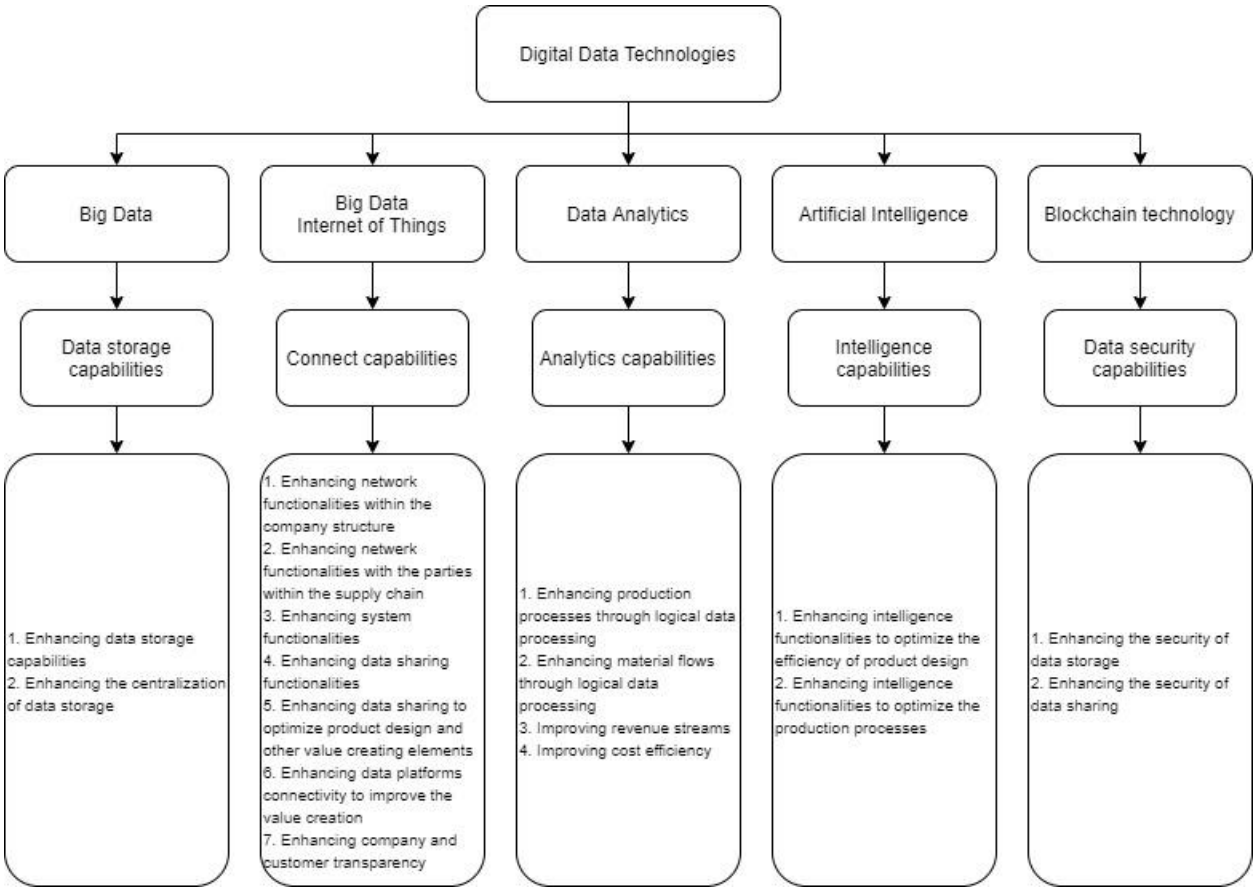


Figure 3.1 - Digital Data technologies capabilities

From the analysis it can be observed that the digital data technologies enable different capabilities; data storage capabilities, connect capabilities, intelligence capabilities, analytics capabilities and data security capabilities.

These digital capabilities provide new additional business opportunities. For example, companies have various challenges in implementing circularity. Accepting digital data technology into the business will depend entirely on the capabilities and implementation strategies to overcome those challenges. Ultimately, the implementation of those digital capabilities encourages the company to become more circular in their business model, supporting the innovation, making the business process and the network functionalities more effective, better data security, accelerating their business growth, and to increase their market share and profits.

Data storage capabilities represent the ability to improve the company's data storage capabilities and enhancing the centralization. This ensures that companies can store their information on a large-capacity central database, which provides structured overview and optimization.
Data connect capabilities represent the ability to share data and automatic acquisition of data, this enhances the functionalities within the company, as well as the collaboration with the parties within the supply chain. This allows the company to optimize its process and product design through M2M communication and networking, or even enhancing the company and customer relationship through more transparency.
Data analytics capabilities represent the ability to allow the big data to analyze its data automatically through logical data processing. These enhance the company to optimize its material flows, processes and even revenue streams.
Data intelligence capability represents the ability to even further improve the efficiency of the product design and production processes through artificial intelligence and machine learning. Those technologies provide the ability to systems to automatically analyze, learn and improve from experience through algorithms without being explicitly programmed.
Data security capability through blockchain technology represents the ability to enhance the security and reliability of the usage of big data and Internet of Things, because of the immutability of the data. This immediately improves the performances of the company's data storage, the company internal data sharing and the external data sharing with the parties within the supply chain.

3.2 Data-driven approaches to improve the circular business model elements

In the next sections the data-driven approach to improve each circular business model element is described individually with the digital data technologies and its capabilities, corresponding circular strategies, overcoming the specific challenges, and the characteristics and attributes.

3.2.1 Circular value proposition

The circular value proposition refers to the product design or service offer of the company that addresses the preservation of the economic and environmental value embedded into the

products and materials.
This value allows companies to survive the technology and fashion trends, as well as to maintain the durability and customer attraction. Circular value proposition can be created through digital data technologies.

	Digital Data Technologies	**Digital Data Technologies Capabilities**	**Circular strategies**	**Overcoming the challenges**	**Characteristics / Attributes**
1.	Big data, data analytics and artificial intelligence	- *Data storage* - *Analytics* - *Intelligence*	- *Designing products and services based on circularity*	- Lack of consideration of circular product design - Incentive to design for end-of-life - Lack of consideration for end-of-life issues - Low value of material/products at end-of-life	- Positive environmental impact - Increase in profits Extended product life span - Product and service design based on circularity
2.	Artificial intelligence into the big data and data analytics	- *Data storage* - *Analytics* - *Intelligence*	- *Improve the value proposition by process and system optimization*	- Difficulties of circular product design and design for end-of-life	- Effective product design - Improved process and system optimization
3.	Internet of Things	- *Connection*	- *Understand the customer needs*	- Return flow uncertainties - Quality assurance of the products and materials - Encouraging companies to recover more products and materials	- Receive necessary information of customer needs

Table 3.1 – The data-driven approach to improve the circular value proposition element

First, one of the strategies is to improve the value proposition is by ***designing products and services based on circularity*** through big data, data analytics and artificial intelligence. Designing products based on circularity means that products are designed to enable product life extension, extending their value through design for long product life, remanufacturing and repairing. Designing services based on circularity means that a company is designing a service for other companies that enables the circularity. A service based on big data allows a company to monitor their processes of production and consumption. Therefore, big data and data analytics can be effective systems to facilitate the production process and choice of materials. As well as enabling the companies to improve its product design and its focus on the design for end-of-life of the product, and minimization of waste. This solves the challenges and barriers in

both the lack of consideration of circular product design and incentive to design for end-of-life, the lack of consideration for end-of-life issues, as well as the low value of material/products at end-of-life

Second, another strategy is to ***improve the value proposition by process and system optimization***. This means that the processes of designing products are further optimized through implementing artificial intelligence into the big data and data analytics. In order to optimize the effectiveness of the product design, artificial intelligence can be implemented. It provides the ability to systems to automatically analyze, learn and improve from experience through algorithms without being explicitly programmed. This enables improvement of device-to-device interactions, and the operational efficiencies through automation, connectivity and analytics. Therefore, machine learning can be applied to accelerate the process and system optimization that leads to the most effective designs and manufacturing productivity and efficiency.

This strategy supports the companies and eases the challenges and barriers in both the difficulties of circular product design and design for end-of-life.

A third strategy is to ***understand the customer needs***, this is necessary for every company to gain an effective value proposition. Although, digital data technologies are not necessary needed in order to understand the customer needs. However, adding Internet of Things, leads to the inter-networking between the company and product after it is sold to a customer. The sensors and actuators implemented to the products are connected to the computer systems of the company that can monitor the usage of the product. This ensures the company to receive the necessary information about the customer usages and needs, this knowledge enables the company to improve their circular value proposition. However, this strategy is only applicable to certain products. Also, Internet of Things could overcome the challenges and barriers in return flow uncertainties and the quality assurance of the products and materials and encouraging companies to recover more products and materials, by taking it back for remanufacturing, recycling and re-use. Furthermore, this could attract the customers with high environmental awareness, due to the underlying awareness of the products.

Another approach of this strategy is based on companies that base their business on circularity by providing circularly related products and services to other companies. By understanding their customers' needs, allows those companies the opportunity in providing them with a circular product or service based on circularity that will positively impact their customers' profits.

3.2.2 Circular value creation and delivery

The circular value creation indicates the types of products and services offered by the specific company; it is often more advanced and therefore more valuable to the customers that leads to competitive advantages. Digital data technologies can help companies to create circular values.

	Digital Data Technologies	Digital Data Technologies Capabilities	Circular strategy	Overcoming the challenges	Characteristics/ Attributes
1.	Big data, data analytics and Internet of Things	- *Data storage* - *Analytics* - *Connection*	- *Create value through supply chain orchestration and collaboration*	- The complexity throughout the supply chain in regard to logistical, financial, and legal aspects - The issues of a fragmented supply chain, lack of support and collaboration between the parties - The standardization of data over the entire value chain - Lack of market mechanisms for recovery - Lack of certification and quality assurance for reclaimed products and recycled materials	- Managing and circulate inventory - Efficient networking and collaboration - Optimization of waste collection, energy, material and logistics efficiency - Extend the life of inventory
2.	Blockchain technology	- *Data security*	- *Security of the collaboration and data sharing within the whole supply chain*	- Reliability and trust of data sharing	- Reliable, safe and trustable data sharing platform
3.	Internet of Things	- *Connection*	- *New extended offering of products and services*	- Low number and complexity of circular value creation	- Effiicient and optimization of data sharing and transparency - Ease the contributions of supports from different roles in the ecosystem
4.	Big data, data analytics and remote monitoring	- *Data storage* - *Analytics*	- *Revising companies' operational processes and activities*	- The feasibility of the company's transition process towards circular business models	- Redesign of workflows - Improve operational efficiency, effectiveness, productivity

Table 3.2 – The data-driven approach to improve the circular value creation and delivery element

First, one of the strategies is to ***create value through supply chain orchestration and collaboration*** through digital collaboration platforms in big data, data analytics and Internet of Things. This means that all parties within the supply chain are interconnected to each other through a network. The data of all the parties are placed in a shared database, where all companies have the access to it. This allows companies to cooperate together and share data

within the supply chain and managing (circulate) their inventory around the world, this leads to efficient networking, collaboration and co-creation, distribution of accurate and trustable data, sharing of knowledge and skills, and the opportunity to enable a network between machines, products, and logistics through the supply chain, that creates the opportunity for continuous monitoring of the movements, and therefore extend the life of inventory and optimizing the waste collection, energy, material, and logistics efficiency, by reducing and eliminating resource requirements.
This solution can therefore, fix the challenges and barriers in the complexity throughout the supply chain in regard to logistical, financial, and legal aspects. As well as the issues of a fragmented supply chain, lack of support and collaboration between the parties and this could also positively influence the standardization of data over the entire value chain, the lack of market mechanisms for recovery and the transparency fix the issues of lack of certification and quality assurance for reclaimed products and recycled materials.

Second, the ***security of the collaboration and data sharing within the whole supply chain*** can be restrained through the blockchain technology. The blockchain technology is known as a technology with a high potential because of the distributed nature, the immutability that provides security and trust, as well as the transparency. This leads to high security and immutability of the data. The integration of this technology into the supply chain ensures an improved security of the exchange of material and product information that can be trusted between the parties. Therefore, this strategy helps the companies to overcome the challenges of reliability and trust of data sharing.

Third, another important strategy is ***the creation of new extended offering of products and services*** by Internet of Things. Internet of Things gives companies the necessary insight and opportunity to revise and extend their portfolio of products and services. Internet of Things on digital platforms enables new business model value creation through contributions of supports from different roles in the whole ecosystem. Furthermore, this has the potential to reduce transaction costs and the adaption of products and services. This strategy helps the companies to overcome the challenges of complexities and low number of circular product offering.

Fourth, for the creation of value it also requires a strategy in ***revising companies' operational processes and activities*** through big data, data analytics and remote monitoring. For this strategy it is necessary for companies to develop a platform that utilize modularity within the organization, through the connectivity and analytics, this enables a better information flow, and a centralized monitoring of processes and integration of activities. This will enable the company to redesign its workflows and improve the company's operational efficiency, effectiveness, productivity and helps the company's transition process towards circular business models. Furthermore, in an advanced level, it could also enable automation, monitoring and control of processes and objects in real time. This strategy supports the companies and eases the challenges in the feasibility of the company's transition process towards circular business models.

3.2.3 Circular value capture

The circular value capture refers to the financial viability, cost structure and revenue model. The revenue model is a determining part of a business model. After all, it provides insight into the way in which a company generates (financial) value by mapping the revenues and costs. Although, the revenue model cannot in itself be circular, but it does determine who is responsible for the product or service throughout the life cycle. The preservation of a product or service depends on who is responsible for it. Digital data technologies can help companies to capture the value in different ways.

	Digital Data Technologies	**Digital Data Technologies Capabilities**	**Circular strategies**	**Overcoming the challenges**	**Characteristics/ Attributes**
1.	Big data, data analytics and Internet of Things	*- Data storage* *- Analytics* *- Connection*	*- Improve the internal processes that enables circularity and cost efficiency*	- High financial costs and lack of capital	- Reduce costs - Saving resources
2.	Big data and data analytics	*- Data storage* *- Analytics*	*- New or increased revenue streams*	- The customers' willingness to pay - The shift of customer value proposition, awareness, lifestyle and cultural behavior	- Creation of new revenues models that leads to flexible and customized pricing - Profitable pricing
3.	Big data and Internet of Things	*- Data storage* *- Connection*	*- New approach of risk management*	- Customers perspective of loss of ownership of certain products	- Increase of transparency - Increase of trust

Table 3.3 – The data-driven approach to improve the circular value capture element

First, one of the strategies is to ***improve the internal processes*** that enable an increase of cost efficiency through collecting product data flow, collaboration with the supply chain and an improved customer interaction. This can be done by big data, data analytics and Internet of Things. It allows companies to improve their internal processes and their cooperation with the parties within the supply chain, this leads to business models that are more based on circularity, cost reduction, and saving resources. Although, the investment costs of implementing digital data technologies are high, but the long term revenue projection is more promising, it reduces operating costs and resource costs and therefore recouping the investment of the company. This strategy solves the challenge of high financial costs and lack of capital of circular business model transition.

Second, big data and analytics also enable ***new or increased revenue streams***. Big data enables companies to introduce new revenue models based on operational data. For example, other way of pricing, for instance subscriptions and pay per use. This leads to a more profitable pricing model and a more flexible and customized pricing. This could overcome the challenges and barriers of the customers' willingness to pay and the shift of customer value proposition, awareness, lifestyle and cultural behavior.

Third, another strategy is to introduce a ***new approach of risk management***; this approach is based on transparency between the company and customer by sharing data insights. Big data and Internet of Things are the main enablers of this strategy. The transparency ensures that companies can take a different approach to their risk management, giving the companies the opportunity to take more risks in certain choices.

From the opposite perspective, the transparency between company and customer can create trust and positively influence the customer awareness, lifestyle and cultural behavior and to balance out the challenge of customers perspective of loss of ownership of certain products.

3.3 Flow diagram

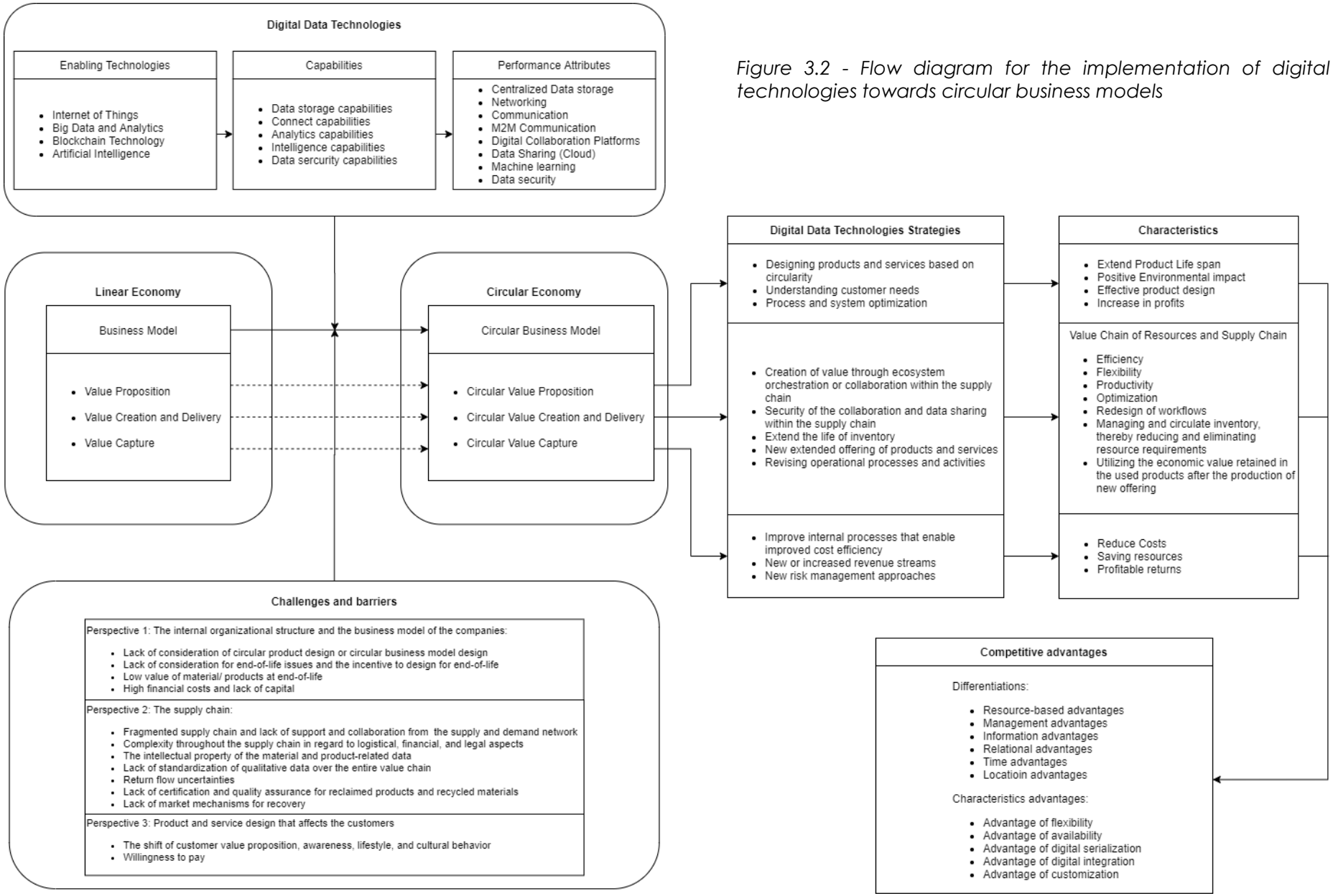


Figure 3.2 - Flow diagram for the implementation of digital data technologies towards circular business models

The flow diagram shows the list of challenges and barriers categorized in different perspectives, the main goal and the solution process of how the digital data technologies can help technology manufacturing companies towards circular business models. The main focuses of the flow diagram are the three elements of the business model innovation and as mentioned in the previous sections, rethinking it into circular value proposition, circular value creation and delivery and circular value capture. Aligning these three elements together will ultimately lead the company to become a fully adapted circular company. Companies can also make a part of their business model more circular, for example, by applying the circular value creation and delivery element. This allows the companies to change their internal organizational structure, redesign workflows and therefore excel in circular way to gain more profit. Optimistically, on a larger scale, a company can try to influence the other parties in their supply chain to excel in a circular way as well, bringing together the fragmented supply chain and data sharing of the materials and products. Making the entire process and workflows in the supply chain more effective and to allow each party can get an additional value out of it.
Another way for companies is to apply the circular value proposition element. This can be done by stimulating circular product designs, fixing the end-of-life and low value of the material issues, or to introduce a product or service that brings the fragmented supply chain together through data sharing of the materials and products.
This can be all achieved through digital data technologies. The research has shown that Internet of Things, blockchain technology, artificial intelligence and big data and analytics are the main technologies with the most potential in improving those business model elements.

These digital data technologies have the performance attributes in networking, communication, M2M communication, digital collaboration platforms, data sharing and machine learning. Adding these attributes to the business model contributes to the improvement of the efficiency, productivity and optimization of the business process, as well as closing, slowing, de-materializing, and narrowing down the resource and product loops by reusing, repairing and remarketing.

3.4 Conclusion

In this chapter, an overview diagram of the challenges and enablers of circular business model is made to get a structured overview. Thereafter, a flow diagram is created that helps the technology manufacturing companies with the successful implementation of digital data technologies towards circular business models.

With this chapter, the sub research question formulated in the introduction can be answered.

4. How can the digital data technologies solutions help the technology manufacturing companies to overcome the challenges and barriers towards circular business models?

Based on the literature, in order to achieve a circular economy, technology manufacturing companies therefore have to adapt their business model to a circular business model, by changing the three business model elements to the three circular business model elements; circular value proposition, circular value creation and delivery, and circular value capture.
In the previous chapter, the challenges and barriers have been analyzed and divided into 3 main perspectives. Those three perspectives with challenges have the greatest potential to be overcome by the implementation of digital data technologies; those perspectives are the internal organizational structure and business model of the companies, the supply chain, and the product and service design that affects the customers. In this chapter, the potentially most influential digital data technologies have been analyzed, and their individual capabilities have subsequently been exposed in a structural overview.

After the extensive analysis, we succeeded to connect all these variables together. The flow diagram shows the list of challenges and barriers categorized in different perspectives. It also shows the main goal of the technology manufacturing companies, this is to adapt the business model elements to circular business model elements, and this could be realized by enabling the digital data technologies that have the highest potentials. Thereafter, based on the performance attributes and capabilities of those digital data technologies, strategies and their characteristics have been generated to help the companies to overcome the challenges and barriers within the three main perspectives.

The flow diagram shows that the digital data technologies; Internet of Things, blockchain technology, artificial intelligence and big data and analytics, have the potential and can have a positive influence on the development of business model strategies and enables the companies to become more circular in their business model. Ultimately, each specific digital data technology has its own properties and capabilities to help companies realize some specific strategies and approaches to overcome the challenges and barriers.

The approaches of implementation of digital data technologies in circular business models are described here below:

- The data-driven approach to improve the circular value proposition element:
    - Digital data technologies in big data, data analytics, Internet of Things and artificial intelligence can improve the circular value proposition of companies in designing products and services based on circularity, it can help improve the value proposition by process and system optimization and help the company to further understand the customer needs.
- The data-driven approach to improve the circular value creation and delivery element:
    - Digital data technologies in big data, data analytics, Internet of Things and blockchain technologies can improve the circular value creation and delivery of companies through creating value through supply chain orchestration and collaboration, improving the security of the collaboration and data sharing within the supply chain, creating new extended offering of product and services and revising the operational processes and activities of the companies.
- The data-driven approach to improve the circular value capture element:
    - Digital data technologies in big data, data analytics and Internet of Things can improve the circular value capture of companies through improving the internal processes that enables cost efficiency, new or increased revenue streams, and new approaches to risk management.

3.5 Limitations of the flow diagram

The findings of the papers have been analyzed in order to realize a flow diagram. However, the flow diagram is therefore mostly based on theory, so it is necessary to apply and test it in real practices. Further research has to be done by focusing on obtaining observational results by appraising the application of digital data technologies in actual case studies, this not only improves the flow diagram, but it also confirms the strategies and that it is actually applicable.

Throughout the analysis and for the creation of the flow diagram, only the factors related to the company, in other words, the factors that the company can have an influence on have been taken into account. For example, the internal organizational structure, structure of the parties within the supply chain, and the assumption that the customers are open to it.
However other external factors have not been taken into account during this research and analysis, for example the managerial commitment, the management of the company has to be fully open-minded, trust and commit to the implementation of digital data technology to introduce circularity in their business model.
The government legislation factors, the government has a very big influence to stimulate companies towards circularity, through their commitment, decision making, regulations and legislation.
Last but not least, the customers' behavior. Even though companies can influence customers in

some way to buy their products, the most obvious main drivers are price, ease and efficiency. In this case, the underlying idea about circularity is an additional positive driver. However, a barrier is that customer's still lacks the awareness of circularity. For example, people do not understand it, are not aware that this is happening, and lack of trust. Furthermore, much also depends on other drivers, such as: the identity, value, experience, connectivity, quality and need. At the end, the customer behavior and awareness plays a major role in the acceptance of circularity, because the profits of companies depend entirely on the demand of their customers.

4. | Case study

In order to complement the findings of the research, case studies are done to see if the theoretical findings intersect with the issues in practice. The second objectives of the case studies are to gain insight into certain issues and factors that were not thought of in advance, to reinforce the understanding of the transition issues and the potential of applying digital data technologies; it also adds strength to what is known by the previous research and the practical relevance of the theories.
At the end, the purpose of the case study is to obtain a broader theoretical relevance, to find out how the obtained data of the case studies matches with the generated flow diagram and the proposed strategies, to further refine it, to produce a quality, valuable, and matured flow diagram with strategies that is probable and can be used as a guideline for companies towards circular business models.

4.1 Unit of Analysis

For the case studies of this research, technology manufacturing companies have been targeted. However, the technology manufacturing companies that apply circularity are in limited numbers, therefore it is decided for the case studies to go a bit broader, this gives the opportunity to include other companies into the case studies. For those case studies, circular companies that supply digital data technologies and therefore try to cooperate with the technology manufacturing companies and also consultancy companies are suited for analysis. Since those companies are related to the technology manufacturing companies, they can provide us with necessary information, knowledge and insights, for further analysis and lastly to refine the flow diagram.

The case study uses a multiple case design, this means that several companies have been contacted for interviews and/or sharing of documents as data collection and thereafter the data is analyzed. The companies in these case studies are: Circularise, Deloitte, Fairphone, and Signify (Philips Lighting).
In the next sections, the background information, mission, goals and audience of the companies are described.

Interviewee	Function	Company	Company Type	Business Model
1.	Co-Founder of a startup company	Circularise	Circular Product/Service Company	B2B
2.	Director Technology Strategy	Deloitte	Services Network Company that consults companies about business model transformations	B2B
3.	Co-founder, Circular Innovation Lead	Fairphone	Circular Product/Service Company	B2C and B2B
4.	Senior Director Sustainability	Signify (Philips Lighting)	Circular Product/Service Company	B2B

Table 4.1 - Interviewee details and main characteristics

4.1.1 Company description: Circularise

The first company that has been included to the case study is the startup company Circularise, this company is a part of the TU Delft's university business incubator Yes!Delft. Although, Circularise is not a technology manufacturing company, but Circularise is a business to business company that bases their business model value proposition on circularity. This means that the company offers a product or service that is based on circularity to its customers, by its focus on the enabling of established suppliers and technology manufacturing companies to become more circular, by developing an open-source protocol and a decentralized network that is based on Blockchain technology. For more detailed information about Circularise, please refer to the webpage of Circularise.

Circularise is a company that supply digital data technologies and therefore try to cooperate with the technology manufacturing companies. It is an excellent suitable company for the case study, because of its knowledge in this field of practice and the development of the open-source protocol and a blockchain based decentralized network, to enable technology manufacturing suppliers and companies to become more circular. This case study is focused on obtaining a more extensive understanding of the transition issue and the potential of applying digital data technologies; it also adds strength to what is known by the previous research, the practical relevance of the theories, to find out how it matches with the generated flow diagram and the proposed strategies and to further refine the flow diagram and proposed strategies.

4.1.2 Company description: Deloitte

The second company that has been included to this case study is the company Deloitte. Deloitte is an international business to business consultancy company that provides organization analysis, consulting, risk advisory, financial advisory, and tax and legal services. Deloitte focuses on different sectors, for instance, the energy, resources & industrials, life sciences and health care, and public sectors. For more detailed information about Deloitte, please refer to the webpage of Deloitte.

A specific work that Deloitte does and may be valuable for this research is that Deloitte also consults companies within different industries with their business model transformation as well. So in other words, Deloitte advises technology manufacturing companies on how to improve their business model in order to be more successful in the future and to overcome the challenges and barriers towards circular economy.

Therefore, Deloitte is an excellent company to gain knowledge from, because of its experiences with those particular clients that were or are currently transforming their business model towards a more circular business model.

4.1.3 Company description: Fairphone

The third company that has been included to this case study is the company Fairphone. Fairphone is a company that develops smartphones with sustainability and circularity in mind. Therefore, the smartphones are designed and produced with minimal environmental impact.

Fairphone is a technology manufacturing company that currently is applying the B2C for-sales business model in which the company loses ownership and control of the device after it is sold. However, to reach a more circular mobile solution, Fairphone is working on the business model transformation between linear and circular by moving from B2C product sales business model to offer a B2B business model based on Fairphone-as-a-Service to business. This business model requires businesses to pay a mixed monthly fee, maintenance services, device updates and take-back of devices when the devices reach their end-of-life phase. For more detailed information about Fairphone, please refer to the webpage of Fairphone.

Therefore, Fairphone is an excellent company for the case study, because of its company properties as a technology manufacturing company, its knowledge in the field of the development of a sustainable smartphone, and its plans of moving from a linear product sale business model toward a product-as-a-service business model that is based on circularity that allows the product to last longer and to reduce waste. Thereby digital data technologies could be a key enabler of this business model transition.
The case study is focused on bringing me a more extensive understanding of the business model of the company, and the challenges, barriers and key drivers of bringing a sustainable/circular product into the market.

4.1.4 Company description: Signify

The fourth company that has been included to this case study is the company Signify. Signify is a technology manufacturing company that focuses on producing light sources. Signify was traditionally a division of Koninklijke Philips Electronics N.V. This division focuses on the philosophy of circular economy by bringing as many materials as possible back into the production loop and to keep products and materials on its highest utility and value for as long as possible.

Signify adopts the strategy of B2B product-as-a-service business model that includes the manufacturing, installation, maintenance, reuse and recycling of the lighting products and equipment. This strategy comes together with the possibilities for data-driven solutions, this means that the lighting systems can be linked to its data network to manage and optimize the lighting infrastructure on a system-wide level. For more detailed information about Signify, please refer to the webpage of Signify.

Signify is an excellent company for the case study, because of its company properties being a technology manufacturing company, its knowledge in the field of the product-as-a-service business model that is based on circularity that allows the product to last longer and to reduce waste. Thereby digital data technologies could be a key enabler of this business model.
The case study is focused on bringing me a more extensive understanding of the business model of the company, and the challenges, barriers and key drivers of bringing a circular product into the market.

4.2 Data collection

The data collection is done with a qualitative data collection method, by conducting interviews and document analysis. Conducting interviews is an insightful and effective way to collect data, because of its specific and targeted approach. This approach enables the opportunity to ask the interviewee more detailed questions, this allows me to investigate the issues in an in depth way by obtaining detailed information and deeper understanding about the knowledge, experiences and perceptions of the interviewee. During the document analysis, the obtained documents provided by the company are interpreted to gain additional insights and knowledge and to give a voice and meaning around the research topic.

4.2.1 Circularise

The interview with the co-founder of Circularise, is conducted in a semi-structured way. Circularise a startup company that base their business model value proposition on circularity, this means that the company offers a product and service that is based on circularity to their customers. Therefore, the interview questions were mainly focused on Circularise as a startup, their business model, the challenges that they are experiencing, and the drivers to overcome the transition.

During the interview, the questions have been divided into five main topics, those topics are:

- General overview of the company related to circularity
- The company business model
- The stakeholders, partnerships, and customers of Circularise
- The challenges towards circularity
- Driver and enabling factors of specific technologies to overcome the transition

In the appendix, you can find the full transcript of the video interview with the questions and answers.

4.2.2 Deloitte

The interview with the director of technology strategy at Deloitte, is conducted in a semi-structured way. Deloitte is an international consultancy company that helps companies from different industries with their business model transformation. So in other words, Deloitte advises companies on how to improve their business model in order to be more successful in the future and to overcome the challenges and barriers towards circular economy. Therefore, this interview allowed me to see this problem from another perspective. The interview questions were mainly focused on the knowledge and experience of the interviewee. For example, about the business model transformation challenges and barriers that he experiences from his clients, and the strategies that he would advise to his clients.

During the interview, the questions were based on the topics:

- The digital data technologies that helps technology manufacturing companies in their business model transformation
- The business model transformation towards circularity
- The challenges, barriers, drivers and enabling factors towards circularity

In the appendix, you can find the full transcript of the telephone interview with the questions and answers.

4.2.3 Fairphone

For the case study of Fairphone, contact was made with the Co-Founder and Circular Innovation Lead of Fairphone. Due to lack of capacity of Fairphone, contact person was not able to conduct an interview with me. However, based on our conversation and the insight about the research topic, the contact person shared two business documents on Fairphone's circular business model and tracking value across the lifecycle.

The appendix contains the full documents summary, which summarizes the most important and relevant points of the documents.

The documents are based on the topics:

- Fairphone's business model and structure
- Key enabling factors for the business model Fairphone-as-a-service model
- Challenges of the transition to a Fairphone-as-a-service model:
- Strategies to overcome the challenges
- Key drivers of overcoming the challenges and barriers to circular business models

4.2.4 Signify

For the case study of Signify, contact was made with the Senior Director Sustainability at Signify. Due to his busy schedule it was not possible to conduct an extensive interview. However, based on our conversation and the insight about the research topic, the contact person shared some business documents on Signify's circular business model.

The appendix contains the full documents summary, which summarizes the most important and relevant points of the documents.

The documents are based on the topics:

- Signify's business model and structure
- Key enabling factors for the business model light-as-a-service model
- Challenges of the transition to a light-as-a-service model:
- Key drivers of overcoming the challenges and barriers to circular business models

4.3 Data analysis

In order to exclude any bias the data collection is done through triangulation; mixed methods are used with interviews and documents analyses, to see if the findings and observations of interviews and documents are confirming each other.

The data are analyzed after the interviews were conducted or when the documents of the companies are obtained. The method of analysis is a qualitative approach of thematic analysis. This analysis is based on the identifying, analyzing and reporting patterns within the data (Boyatzis, 1998).

First, in order to familiarize with the data, everything that was said during the interviews is encoded through transcribing the recorded interviews by means of a transcript. The questions and answers are written out in details and chronological order.
Second, the interviewee's most important answers were extracted, by labeling the pieces which I believe may have an influence in helping to advance the research.
Third, this stage is about the family code development, the different family codes are made to categorize the codes. Thereafter, an analysis is made about the connections and relations between the codes and if there is a hierarchy among the codes, looking if some particular codes are more important than the other themes.
At the end, the results of this approach are the findings from the analysis, these findings serve as a source to further strengthen my propositions or provide new knowledge and thinking that has not been thought of until now (Bowen, 2009).

For analyzing the documents, includes coding the content into family codes similar to how interview transcripts are analysed (Bowen, 2009).

4.4 Findings

In this section, the important findings of the analysis of each case study are described here below. For a more extensive overview of the coding tables, see appendix VII, VIII, IX and X, the findings for each case study are integrated into a table that is categorized into the family code, codes, description and specific quote taken from the interview transcript or document analyses. For an extensive summary overview of the case studies including all the important findings combined can be found in appendix XI.

4.4.1 Circularise

The interview with Circularise shows that the findings could be categorized into codes. The most important categories are: the challenges of implementing digital data technologies, circular strategies and the drivers towards circularity. For a more extensive overview of the coding table, see appendix VII.

Theme: Challenges of implementing digital data technologies

- The digital data technologies are quite new and therefore it is quite unknown. Companies have no understanding or knowledge of those technologies. So for a startup, the first few years a basically educating those companies to get familiar to it
- Companies have no trust, because it is a new technology
- Implementation of digital data technologies takes a lot of time, especially in big companies
- The link between physically and digitally within a company structure to make it work effectively and the performances optimal

Theme: Strategies

- Target small companies to implement digital data technologies, because it will take less time to implement the systems.
- For big companies, implement the system in a tiny part of their whole structure.
- Aim for companies at the beginning of the value chain, for example material industries.
- Every supply chain is operating very differently from each other, so it takes a lot of time to adapt
- Since the digital data technologies are quite new, knowledge institutes are doing research about it. So target knowledge institutes to get access to their network and target new potential customers.
- In order to create value, focus on agile development, an iterative approach to project management and software *development* that helps teams deliver value to their customers faster and with fewer headaches.
- Also focus on pilot projects, this is a small scale preliminary study conducted in order to evaluate feasibility, duration, cost, adverse events, and improve upon the study design prior to performance of a full-scale research project.

- Co-creating with the customers is a great strategy, through this partnership and sharing knowledge, the customers can be convinced and to gain the trust.

Theme: Drivers towards circularity

- The digital data technology needs to have a new attractive value to the companies. Every single party in the supply chain has to get their value before they decide to implement it.
- Mindset, customers are lacking trust, because their lack of knowledge.
- Regulations can accelerate the transition to circularity. However, it must be divided into parts to make it more understandable, because circularity is a big general word.

4.4.2 Deloitte

The interview with Deloitte shows that the findings could be categorized into codes. The most important categories are: the limitation of implementing digital data technologies and the potential of implementing digital data technologies into business models, challenges and barriers. For a more extensive overview of the coding table, see appendix VIII.

Theme: Limitation of implementing circularity into the business models

- From the technology manufacturing companies' perspectives and actually from every company, their ultimate goals are always to ultimately gain market share, to make their business process more effective and optimized, or to maximize their profit. It is actually too optimistic to expect the companies to think, care, or even worrying about the environmental well being, and therefore spend money to circularity as a result.
- Circularity can actually be an intermediate step for those companies to achieve their main goal, and that is to gain market share, to make their business process more effective and optimized, or to maximize their profit.

Theme: The potential of implementing digital data technologies into business models, challenges and barriers.

- Digital data technologies, for instance: Big data, data analytics, blockchain, artificial intelligence and robotics have great potential to help the innovative technology manufacturing companies in their business model transformation.
- But not every digital data technology can be applied in every company. In practice, it therefore depends very much on each specific company and what they need. Each individual company has its own specific solution that is totally designed based on their structure and problems.

4.4.3 Fairphone

The documents of Fairphone show that the findings could be categorized into codes. The most important categories are: the challenges of implementing digital data technologies, circular strategies and the drivers towards circularity. For a more extensive overview of the coding table, see appendix IX.

Theme: Product-as-a-service - business model for a circular economy

- The product-as-a-service proposition is that the company will retain the ownership of its products. This gives the opportunities to increase the value created as the company can deploy circular strategies for instance maintenance, repairs, refurbishment and recycling to extend the lifetime of its products and therefore optimizing the value creation.
- Products that consist of various modules have the advantage of becoming circular. The modules can be taken out and repaired or replaced without the need to return the whole product. The strength of the modular nature ensures for the financial viability of the proposition as circular value creation can be structured around the individual characteristics of the modules, instead of having to focus on the aggregate performance of the whole product.

Theme: Challenges

- Product challenges
    - Due to the continuing reuse nature of the product-as-a-Service proposition and the fast-moving nature of the products nowadays, a key challenge is to provide and service products at an appropriate technology level, and that also remains at the desired technological level when time passes.
- Organizational and financial challenges
    - The product-as-a-Service business model gives organizational and financial complexities. While products are normally sold and the company immediately earns its turnover to earn back its investments, in this case there is an additional backdrop of longer payback periods; this puts pressure on the cash- flows of the company.
    - Additional contracts are required to stipulate the terms and conditions between customers, end-users and the product supplier.
- Supply Chain challenges
    - Circular supply chains require cooperation and coordination between all the parties. This leads to high administrative costs, need of trust, transparency and long-term agreements between the chain partners.
- Privacy challenges
    - Retaining ownership of the devices gives interesting opportunities to access user data; however the use of those data is subject to strict privacy considerations.

Theme: Strategies

- Product challenges solutions
  - The company has to provide products that are on 'the generally accepted technological level' to its customers, which does not require the company to provide state-of-the-art or latest generation products.
  - Also, the product-as-a-service business model allows the company to retain the right and responsibility of the product to take both functionality and circularity into account. Therefore, allowing the company for the use of refurbished modules, means the product does not become outdated when new products becomes available.

- Operational and financial challenges solutions
  - Hardware management. In particular, the development of preventative maintenance solutions and off cost-effective module management solutions.
  - Before the company realizes the business model, make an extensive calculation of the estimations of service fees, realistic scenarios, modeling the cash flows, financial solutions, profit and loss statements and balance sheets to be fully prepared with all scenarios and not to face unexpected situations.
  - Development of a financeable business model and corresponding contracts.

- Supply Chain challenges solutions
  - For the supply chain, the solution is to structurally generating, gathering and storing of the existence of data regarding material composition, condition, location, maintenance, supply chain actors, asset use and corresponding revenues and costs.

Theme: Key drivers toward circular business models

- The openness and flexibility of the company to be able to experiment with new business models. The concept of 'learning by doing' trajectories can help to advance the development of its new business models and even unlock additional potential values of the circular economy.
- Collaboration and transparency to create synergies between different fields of expertise, for instance, business, legal, operational and financial.
- In practice, every company and sector all have their own unique challenges and barriers and key drivers. Therefore, each single individual company has its own specific organization, structure, vision, process, problems and challenges.

4.4.4 Signify

The documents of Signify show that the findings could be categorized into codes. The most important categories are: the challenges of implementing digital data technologies, circular

strategies and the drivers towards circularity. For a more extensive overview of the coding table, see appendix X.

Theme: Product-as-a-service - business model for a circular economy

- The company adapts to a product-as-a-service business model that includes the manufacturing, installation, maintenance, upgrades, reuse and recycling of the lighting products and equipment. This allows the company to create value by retaining the ownership of its products and selling product-as-a-service to optimize its use of resources.
- The company also looks at the possibilities for data-driven solutions, this means that the lighting systems can be linked to its data network to manage and optimize the lighting infrastructure on a system-wide level.

Theme: Challenges

- Ownership of the product, the product remains the property of the company, the user may be less careful with the product compared to when the user really owns the product.
- Legal ownership issues, data flow between the customer and company are a crucial factor. The free flow of data are caused by the legal uncertainty surrounding the emerging issues on 'data ownership' or control, reusability and access to or transfer of data and liability arising from the use of data.
- Adaptive logistics, the company's flexibility and quickness to fully adapt to the operations related to the recovery and reuse of materials and products. Furthermore, the processes, strategies and infrastructure are from necessity to enable a cost-effective collection, treatment and redeployment of the materials and products.
- Financial strategies, the company has to adapt to longer payback periods because of the product-as-a-service model; the cash flows of the company are therefore different from the normal product-sale business models.

Theme: Key drivers towards circular business models

- Big data shifts the manner and scale in which the problems can be solved, it provides deeper market knowledge and increase the opportunities of customer- focused solutions. Enabling the intelligence and knowledge where the resources are within the economy, the product properties and status. This makes the manufacturing process more optimized and additive.
- Government regulations and legislations are crucial factors to positively influence and accelerate the business model transition towards a more circular business model.
- New business models of consumer consumptions. Customers' product interests are starting to shift toward the concept based on access and performances rather than ownership. In contrast to goods, services also help the companies to redefine their relationship with the consumers.

- Online platforms allow companies to improve their relationship with their customers through new levels of engagement and connectivity's.

4.5 Discussion

In the case studies, various companies are studied in practice about the influences of the digital data technologies, how the companies try to apply circular economy into their business models to achieve circularity, their existing challenges and barriers along the way and their strategies and the key drivers according to them towards circularity.

4.5.1 Business model

The case studies have shown that when technology manufacturing companies want to apply circularity, a B2B Product-as-a-service business model has the most potential to realize this. The other companies pay a mixed monthly fee for maintenance services, product or system updates and take-back of the products when the products reach their end-of-life phase.

4.5.2 Challenges

The challenges are providing the product or service at an appropriate technological level, ownership of the product, legal ownership issues, the organizational, adaptive logistics and financial complexities of this business model, and cooperation and coordination between all the parties. This leads to high administrative costs, need of trust, transparency and long-term agreements between the chain partners.

4.5.3 Strategies

The strategies for those technology manufacturing companies are to provide products that are on 'the generally accepted technological level' to its customers. Retain the right and responsibility of the product, which enables the opportunity to take the functionality and circularity together into account. Development of a financeable business model, make extensive calculations of the estimations of fees, scenarios, cash flows and profit/loss statements and corresponding contracts between the company and its customers.

4.5.4 Other key drivers

The findings of the case studies shows that besides the digital data technologies, the other key drivers towards circularity for those companies are the openness and flexibility of the company to be able to experiment with new business models, collaboration and transparency between the parties within the supply chain, online platforms that allow companies to improve their relationship with their customers, -government regulations and legislation to positively influence and accelerate the business models transition towards circular business models. The second main driver are the digital data technologies, for instance big data that shifts the approach in which the problems can be solved, it provides deeper market knowledge and increase the opportunities of customer- focused solutions.

4.5.5 Limitations

However, the case studies have shown that the digital data technologies are not necessary to be able to apply all the strategies to overcome the challenges and barriers to achieve circular business model.

Ultimately, the application of digital data technologies depends specifically on the internal

structure of a company, time availability to fully make the transition, as well as the specific business model of the company, for instance, is it a B2B or B2C company and is their business model based on product-sale or product-as-a -service. Also, the business purpose of the company in how circular they want to become is a factor, because it depends on the company's vision and mission. Whether they see circularity as an intermediate step to gain market share, to optimize their process and to maximize profit or whether the companies see circularity as their main business purpose, vision and mission to achieve competitive advantages.

5. | Refined flow diagram

In this chapter all the relevant findings obtained during case studies in chapter 4 is brought together to refine the flow diagram that is generated in chapter 3. Ultimately, a refined flow diagram was realized based on the findings from the case studies, based on the knowledge and experiences of companies in practice. At the end, the refined flow diagram helps the technology manufacturing companies with the successful implementation of digital data technologies towards circular business models.

The refined flow diagram is shown below; the flow diagram shows the list of challenges and barriers categorized in different perspectives and the solution process of how the digital data technologies as one of the key drivers can help the technology manufacturing companies towards circular business models.

5.1 Challenges and barriers

The components of challenges and barriers have been improved with the additional relevant challenges and barriers analyzed from the case studies.

Based on the case studies, these challenges and barriers have been added to the flow diagram:

- Perspective 1: The internal organizational structure and the business model of the companies
  - Providing services and products at an appropriate technological level while being circular
  - The link between physically and digitally within the organizational structure to make it work effectively
  - Takes a lot of time to implement digital data technologies into the company structure and business model successfully
  - Organizational, adaptive logistics and financial complexities

- Perspective 2: The supply chain
  - Data is subject to strict privacy considerations

- Perspective 3: Product and service design that affects the customers
  - Digital data technologies are a quite new phenomenon, therefore customers have no trust or knowledge

5.2 Strategies

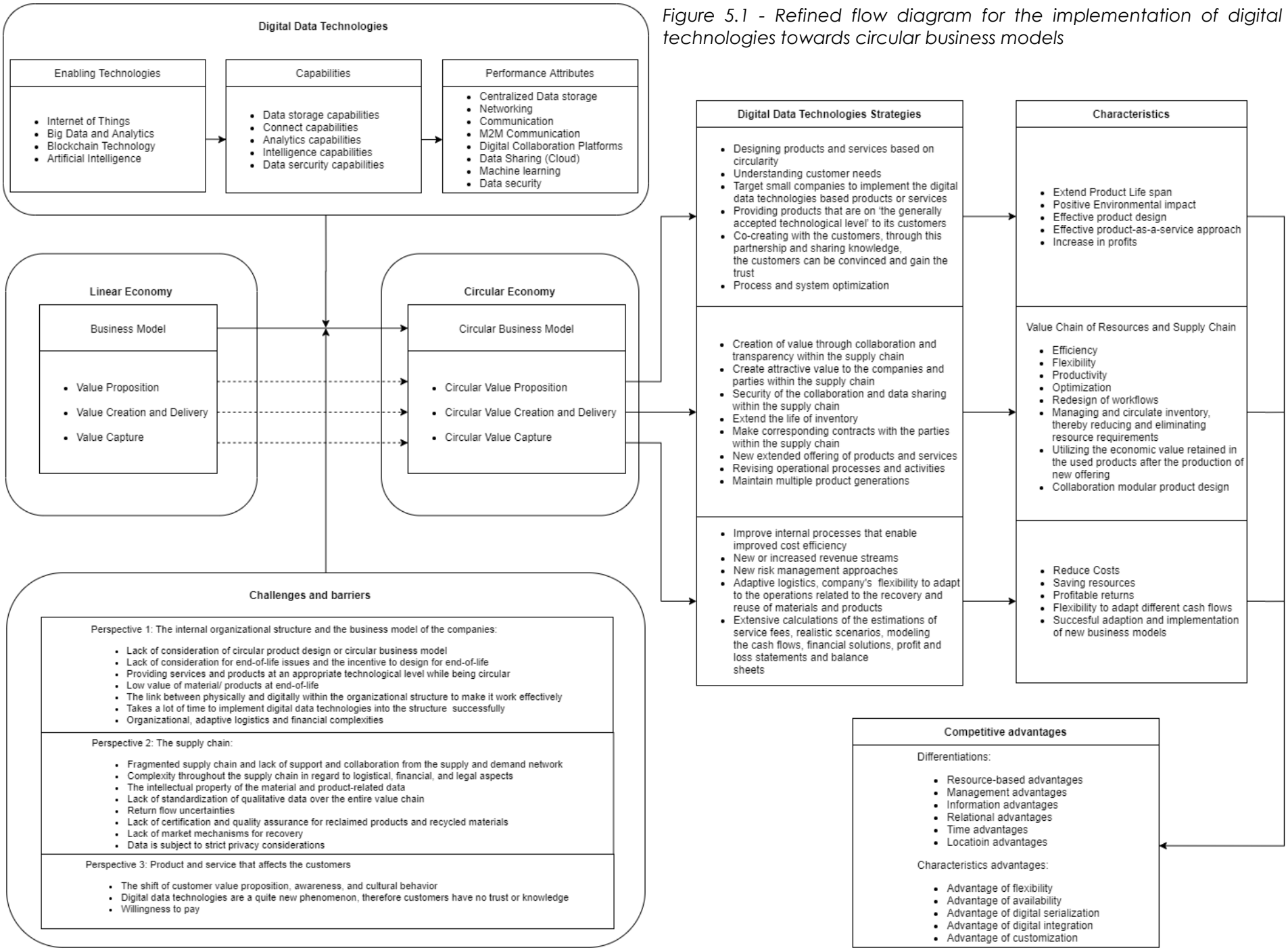
The strategies have been improved with the additional relevant practical strategies based on the other key drivers analyzed from the case studies. Although the newly added strategies could be applied without the help of digital data technologies, but it has been proven in practice by companies that it is successfully applicable to achieve the ultimate goal of a circular business model.

Based on the case studies, these strategies have been added to the flow diagram:

- Circular value proposition strategies:
  - Target small companies to implement the digital data technologies based products or services
  - Providing products that are on 'the generally accepted technological level' to its customers
  - Co-creating with the customers, through this partnership and sharing knowledge, the customers can be convinced and gain the trust
- Circular value creation and delivery strategies:
  - Create attractive value to the companies and parties within the supply chain
  - Make corresponding contracts with the parties within the supply chain
  - Maintain multiple product generations

- Circular value capture strategies:
  - Adaptive logistics, company's flexibility to adapt to the operations related to the recovery and reuse of materials and products
  - Extensive calculations of the estimations of service fees, realistic scenarios, modeling the cash flows, financial solutions, profit and loss statements and balance sheets

Figure 5.1 - Refined flow diagram for the implementation of digital data technologies towards circular business models



5.3 Discussion and reflection

The research has generated a flow diagram for the implementation of digital data technologies towards circular business models to give an overview of order of the big amount of literature. It shows the challenges, strategies, characteristics and competitive advantages of the implementation of digital data technologies towards circular business models.

The flow diagram provides the following contributions:
First, the flow diagram enables technology manufacturing companies to have a structured overview, and to look at the list of challenges and barriers categorized in different perspectives. These challenges are divided into perspectives in such a way that it facilitates the technology manufacturing companies to overcome these challenges simultaneously with a certain solution.
Second, the flow diagram shows that in order for the technology manufacturing companies to gain circularity and competitive advantages, the main goal for those companies is to adapt the business model elements to circular business model elements, this is realized by enabling the digital data technologies that have the highest potential. Those digital data technologies are; big data, analytics, internet of things, blockchain technology and artificial intelligence. As one of the key drivers, those digital data technologies have a positive influence on the development of circular business model strategies and enable the companies to become more circular in their business model. Ultimately, each specific digital data technology has its own properties and capabilities to help companies realize some specific circular strategies to overcome the challenges and barriers.
Third, the flow diagram shows that the digital data technologies could lead technology manufacturing companies to new competitive advantages in the comprehensive and optimal use of operations, virtualization and network cooperation. The key advantages are the differentiations of resource-based, management, information, relational, time and location advantages. Furthermore, it leads to additional characteristics advantages in company flexibility, availability, digital serialization, digital integration and customization.
Finally, this flow diagram adds to the current studies, since based on the performance attributes and capabilities of those digital data technologies, the flow diagram shows how it could help the technology manufacturing companies and the people that are on the strategic level within those companies that are considering becoming more circular in their business model. This is a first step for them, the flow diagram maps out where they are and what they should pay attention to, in order to overcome the challenges and barriers within the three main perspectives. It furthermore provides data-driven approaches and strategies for each circular business model element and their characteristics that ultimately allow those companies to become more circular and gain competitive advantages. Furthermore, this research also gives researchers and educational institutions a comprehensive and structured insight into the studies that have been carried out to date. In which the researchers can set up a follow-up study based on the results of this study. To further improve the phenomenon of digital data technology and circular economy.

6. | Conclusion

During this research, an extensive structured literature review is done, reviewing the academic works published on the current trend of circular economy, business models, business models elements, existing circular business models and the challenges and barriers toward a circular business models according several papers, and the current emerging digital data technologies and the adoption and its performance attribute to overcome the challenges and barriers. Thereafter, a flow diagram is created that helps the technology manufacturing companies with the successful implementation of digital data technologies towards circular business models. In the case studies, various companies are studied in practice about the influences of the digital data technologies, how the companies try to apply circular economy into their business models to achieve circularity and competitive advantages, their existing challenges and barriers along the way and their strategies and the key drivers according to them towards circularity.

After going through all these steps during this research, it is finally possible to answer the main research question formulated in the introduction, in an accepted manner with a lot of prior research and good substantiation.

How can the digital data technologies help technology manufacturing companies towards circular business models?

Ultimately the circular economy is about the design for reuse, circulating materials and resources, managing the inventory, extending the life, reusing it, repurposing it or the eliminating the need of it altogether.
In order to achieve a circular economy and competitive advantages, technology manufacturing companies have to implement digital data technologies. Digital data technologies have high potential to help the technology manufacturing companies to adapt their business model to a circular business model, by changing the three business model elements to the three circular business model elements; circular value proposition, circular value creation and delivery, and circular value capture.

The approaches of implementation of digital data technologies in circular business models are described here below:

- The data-driven approach to improve the circular value proposition element:
    - Digital data technologies in big data, data analytics, Internet of Things and artificial intelligence can improve the circular value proposition of companies through circular strategies in designing products and services based on circularity, it can help improve the value proposition by process and system optimization and help the company to further understand the customer needs.
- The data-driven approach to improve the circular value creation and delivery element:

- Digital data technologies in big data, data analytics, Internet of Things and blockchain technologies can improve the circular value creation and delivery of companies through circular strategies in creating value through supply chain orchestration and collaboration, managing and circulate the inventory to reduce and eliminate resource requirements, and extend the life of inventory, maintain multiple product generations through collaboration of modular product designs, improving the security of the collaboration and data sharing within the supply chain, creating new extended offering of product and services and revising the operational processes and activities of the companies.

- The data-driven approach to improve the circular value capture element:
  - Digital data technologies in big data, data analytics and Internet of Things can improve the circular value capture of companies through circular strategies in improving the internal processes that enables cost efficiency, new or increased revenue streams, and new approaches to risk management.

6.1 The contribution of this study to research

To contribute to the existing literature and knowledge, this research has analyzed the challenges and barriers and based on the results, the challenges and barriers are categorized into three main perspectives. Those perspectives are the internal organizational structure and business model of the companies, the supply chain, and the product and service design that affects the customers. The study contributed to the research by generating data-driven approach and strategies based on digital data technologies allowing technology manufacturing companies to overcome those three perspectives with challenges.
More specifically, the research has generated a flow diagram to give an overview of order of the big amount of literature. It shows the challenges, strategies, characteristics and competitive advantages of the implementation of digital data technologies towards circular business models.

The flow diagram provides the following contributions:
First, the flow diagram enables technology manufacturing companies to have a structured overview, and to look at the list of challenges and barriers categorized in different perspectives. These challenges are divided into perspectives in such a way that it facilitates the technology manufacturing companies to overcome these challenges simultaneously with a certain solution.
Second, the flow diagram shows that in order for the technology manufacturing companies to gain circularity and competitive advantages, the main goal for those companies is to adapt the business model elements to circular business model elements, this is realized by enabling the digital data technologies that have the highest potential. Those digital data technologies are; big data, analytics, internet of things, blockchain technology and artificial intelligence. As one of the key drivers, those digital data technologies have a positive influence on the development of circular business model strategies and enable the companies to become more circular in their business model. Ultimately, each specific digital data technology has its own properties

and capabilities to help companies realize some specific circular strategies to overcome the challenges and barriers.

Third, the flow diagram shows that the digital data technologies could lead technology manufacturing companies to new competitive advantages in the comprehensive and optimal use of operations, virtualization and network cooperation. The key advantages are the differentiations of resource-based, management, information, relational, time and location advantages. Furthermore, it leads to additional characteristics advantages in company flexibility, availability, digital serialization, digital integration and customization.

Finally, this flow diagram adds to the current studies, since based on the performance attributes and capabilities of those digital data technologies, the flow diagram shows how it could help the technology manufacturing companies and the people that are on the strategic level within those companies that are considering becoming more circular in their business model. This is a first step for them, the flow diagram maps out where they are and what they should pay attention to, in order to overcome the challenges and barriers within the three main perspectives. It furthermore provides data-driven approaches and strategies for each circular business model element and their characteristics that ultimately allow those companies to become more circular and gain competitive advantages. Furthermore, this research also gives researchers and educational institutions a comprehensive and structured insight into the studies that have been carried out to date. In which the researchers can set up a follow-up study based on the results of this study. To further improve the phenomenon of digital data technology and circular economy.

6.2 Limitations

The scope of the research topic is limited to the technology manufacturing sector, with the aim of improving the technology manufacturing companies' business models to become more circular. However, the transition itself also depends on the policymakers and their decisions, financial sectors that are opening up resources to these companies, in order for them to realize the business model transition to circular business model. As well as on the open-mindedness of the technology manufacturing companies about introducing circularity and implementing digital data technologies into their business models.

Although, this research has established a flow diagram to help technology manufacturing companies towards circular business models, but at the end, it is unfeasible to have a certain fixed sets of challenges and barriers or strategies for every technology manufacturing companies. Because in practice, every company is unique, therefore every company has their own specific challenges and barriers.

Nevertheless, the flow diagram that is generated from this research is remarkably extensive; therefore many potential challenges and barriers already have been included in the analysis. Comprehensive digital data technologies approaches and solutions with unique characteristics have been generated to help those technology manufacturing companies to overcome all those challenges and barriers. This ensures that the flow diagram can still be of unique value for

each individual company. Ultimately allowing those technology manufacturing companies to successfully make the transition towards circular business models and gain competitive advantages. This research also gives researchers and educational institutions a comprehensive and structured insight into the studies that have been carried out to date. In which the researchers can set up a follow-up study based on the results of this study. To further improve the phenomenon of digital data technology and circular economy.

6.3 Recommendations for future research

For future research, it is necessary to apply the flow diagram in practice. Many literature studies, on which the flow diagram has been created, are based on theories of the literature and case studies that have been done during this research. Further research in practice and more case studies should be conducted to further develop the flow diagram to refine and make more reliable.

When the combination of digital data technologies and circularity is being applied more by technology manufacturing companies, it is worth to conduct more case studies and thorough analysis at those companies to get a good insight of the challenges, barriers, strategies and key drivers of a circular business model to further refine the flow diagram and even have the flow diagram applied by technology manufacturing companies at a later stage.

Furthermore, this research has been focusing on the digital data technologies as the driver, and how it can help the technology manufacturing companies towards circular business models. For the further completion of literature, further research can also be done by focusing on the drivers besides digital data technologies that can help technology manufacturing companies towards circular business models, for example the internal managerial structure of a technology manufacturing company, or external structure effect for example the government that influences the regulations and legislation about circularity in a certain way or the technology change (enabling technology), or is it a technology effect and customer perspective.

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Appendices

Appendix I: Overview of all the studies done about digital data technologies helping technology manufacturing companies towards circular business model

This appendix gives an extensive overview of all the studies that have been done about the digital data technologies helping technology manufacturing companies towards a circular business model.

Author	Digital Data Technology Type	Sample	Research Methodologies	Performance attributes	Limitations
(Antikainen, Uusitalo, & Kivikytö-Reponen, 2018)	- Digital collaboration platforms	- 62 participants 26: Industry 22: Academia and Research 7: Governmental organizations 6: NGOs	- Exploratory study Data collection through a workshop event	Virtualization: 1. Reduce costs 2. Saving resources 3. Providing an accurate and trustable data The whole ecosystem has to close the loop. Efficient networking Collaboration and co-creation	This study is just an exploratory study, further studies on real company cases has to be done
(Bressanelli, Adrodegari, Perona, & Saccani, 2018)	- Internet of Things - Big Data and Analytics	- Companies in the household appliances sector, a sector particularly promising for the adoption of the CE paradigm	- Exploratory research - Qualitative case study - Preliminary questionnaires - Semi-structured interviews	Implementing IoT , big data and analytics into the Product-Service Systems Business models that enables the: 1. Monitoring users' activities 2. The provision of advanced services such as maintenance or optimization of the usage phase 3. Digital upgrade 4. Estimation of products and components residual life. In order to overcome the CE challenges like: operational risks, loss of ownership, users' willingness to pay, technology improvement and return flow uncertainties.	Just one case study has been performed, not all the digital technologies highlighted by Industry 4.0 have been explored. Further research has to be done based on the economic and environmental impacts
(Bressanelli, Adrodegari, Perona, & Saccani, 2018)	- Internet of Things - Big Data and Analytics	- Alpha, a household appliance retailer in the Northern Europe. This company has less than 10 employees	- Case study - Preliminary questionnaires - Semi-structured interviews	1. Enhancing product design 2. Enhancing marketing activities 3. Allowing the monitoring and tracking of product activity 4. Enhancing the provision of technical support 5. Allowing the provision of preventive and predictive maintenance 6. Optimizing the usage of the product 7. Enhancing product upgrading 8. Enhancing the execution of renovation and end-of-life activities	Just one case study has been done. The findings of this paper should further validated with qualitative data. Further research focus has to be done on product-focused and result focused business model types.

(Pagoropoulos, Pigosso, & McAloone, 2017)	- Internet of Things - Big Data to improve the Product/ Service Systems,	- 12 articles	- Systematic Literature review	1. Optimizing forward material flows 2. Enabling reverse material flows These digital data technologies can help to further develop the Product/service system	Further research has to be done by focusing on obtaining observational results by appraising the application of digital technologies in actual case studies
(Parida, Sjödin, & Reim, 2018)	- Internet of Things - Digitalization - Industry 4.0 - Remote monitoring - Smart factory	- 106 articles, all are publication between 2012 and 2018. All are related to digitalization and business models and focused on production, marketing, and innovation management	- Systematic Literature review	Based on the review and analysis, this paper organized the studies into a framework that shows the linkages between digitalization, business model innovation, and sustainability industry. The important links between digitalization and the three main elements of business model innovation value creation, value delivery, and value capture are described	
(Bianchini, Pelligrini, Rossi, & Saccani, 2018)	- Internet of Things - Big Data - Data analytics - Cyber-Physical systems	- Four companies: 1. Reduction of raw materials: Papermaking 4.0 2. Reduction of residual waste: AMP Robotics 3. Asset recovery: IBM, IT and consulting service company 4. Tires-as-a-service: Michelin	- Case studies	1. A more productive and sustainable circular business model. The new circular structure is based on a further: - Reduction of raw materials and energy consumption. - Increases the flexibility and productivity that results into reduction of raw material use and energy consumption. 2. The network between machines, products, and logistics through the supply chain, creates the opportunity for continuous monitoring of the movements, and therefore the optimization of waste collection, energy, material, and logistics efficiency. The paper came up with a new business model based on circular economy principles. The strategies include involvement of the all stakeholders of the entire supply chain, from suppliers to end-users, in order to be able to share the information	
(Okorie, Salonitis, Charnley, Moreno, Turner, & Tiwari, 2018)	- Digital sensors - Cyber-physical systems - Cloud Manufacturing - Internet of Things - Additive Manufacturing	- 174 papers selected based on: Circular economy, circular approaches, geographical distribution, and subject area.	- Systematic literature review, descriptive analysis of the papers	1. Enabling automation, monitoring and control of processes and objects in real time 2. Virtual portals that create shared networks of manufacturing resources and capabilities offered as services 3. A computational system that collects and exchanges data acquired from electronic devices 4. Connected prototyping of parts of products on a	

				large scale, enabling customization	
(Alexandris, Katos, & Hatzivasilis, 2018)	- Blockchain Technology		- Study to tackle the shortcoming by proposing a concrete application of a collaborative circular economy network	1. Value creation 2. Value proposition. 3. Data sharing, transparency and control; it enables new decentralized systems and applications	This paper is more focused on the perspective of governmental regulators and environmental policy, and less focused on the circular business models of companies.
(Jabbour, Jabbour, & Sarkis, 2017)	- Large-scale data (Big Data)		- Research to propose a framework that shows and capture the complexity of the relationships between circular economy and large-scale data	1. Positive influence on the stakeholders within the supply chain 2. Data sharing of usage of products and materials creates new knowledge and skills from suppliers and producers	The framework is based on theory, so it is necessary to apply and test it in real practices.
(Del Vecchio, Di Minin, Petruzzelli, Panniello, & Pirri, 2017)	- Big Data to support open innovation strategies	- Small medium enterprises and large corporations	- Systematic Literature review	Three ways to create new opportunities to sustain an open innovation strategy: 1. Creation of new opportunities to sustain an open innovation strategy 2. The spin-out asset and the secondary markets 3. Organizational changes	Further in-depth observational studies have to be done to examine the outcomes of the application of big data to refine the innovation process through the open innovation paradigm. It is also not enough systematic research done about the implementation of big data to fully understand its performances
(Bolier, 2019)	- Blockchain Technology	- Circularise, a company that is part of the TU Delft's university business incubator Yes!Delft	- Systematic Literature review	1. Distributed nature, immutability that provides security and trust, transparency, it leads to high security and immutability of the data 2. Integration into the supply chain to allow the exchange of material and product information that can be trusted between the parties. Recovering old materials, and products.	Should be implemented in practice.
(Lieder & Rashid, 2016)	- Internet of Things - Big Data Analytics	- 136 research articles	- Systematic literature review	1. Close the material loop 2. The End of Life (EoL) 3. The link to production 4. *Economic benefits*: In order to secure profitability and a competitive edge, companies need an integrative approach towards business models,	

			product design, supply chain design and choice of materials *5. Resource scarcity*: Circularity of resources is necessary in the realization of circular economy *6. Environmental impact*: Minimum environmental impacts are an important factor in order to reduce solid waste, landfill and emissions through reuse, remanufacturing and recycling
(Ramadoss, Alam, & Seeram, 2018)	- Artificial Intelligence - Internet of Things -Big Data Analytics	- Systematic literature review	1. Device-to- device interactions 2. Human-to-device interactions 3. Enhancing the operational efficiencies through automation, connectivity and analytics 4. Proof for data authentication and integrity autonomous functioning of smart devices without the need for centralized authority 5. Big data analytical tool combined with Artificial intelligence will be employed to derive conclusion, examine raw with the purpose of finding patterns by deep learning algorithm 6. Understanding of the information/data from the sensor / things connected and running through several data sets to look for meaningful correlations between each other to positively impact businesses

Appendix II: Overview diagram of the challenges and enablers of circular business model

In order to develop a flow diagram, it is necessary to identify a structured overview diagram of the subject area of the study.

The key aspects are circular business models, digital data technologies and the challenges and barriers. In this case, the main aspect is the circular business model, because this is also the aspect that must ultimately be achieved. Another aspect is the challenges and barriers; this aspect stands on its own and could not be affected by any external factors. The third aspect that changes the strength, direction or relation of the effect between those two aspects is the digital data technologies.

An overview diagram of the challenges and enablers of circular business model is shown below, which represents a representation of the system made of the different variables with the specific components of each variable that has been emerged from the literature review.

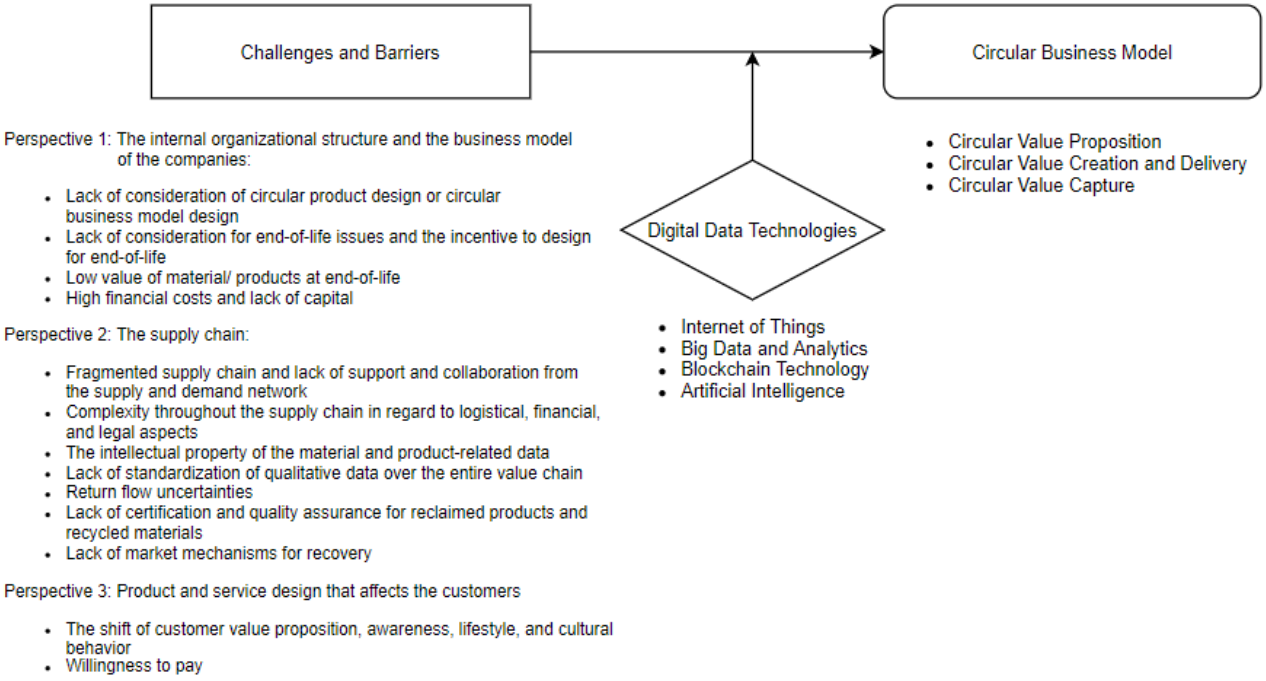

Figure A - Overview diagram of the challenges and enablers of circular business model

Appendix III: Transcript: Interview with Circularise

On the 17th of April 2020, I had the opportunity with my supervisor Hanieh Khodaei and lecturer for entrepreneurship Victor Scholten to have a video interview with one of the co-founders of Circularise. In this appendix, you can find the full transcript of the video interview with the questions and answers.

During the interview we will go through five main topics, those topics are:

- General overview of the company related to circularity
- The company business model
- The stakeholders, partnerships, and customers of Circularise
- The challenges towards circularity
- Driver and enabling factors of specific technologies to overcome the transition

1. General overview of the company related to circularity

~Could you tell us something about your company?
In answer to this question, the interviewee had given us a short 7-minute presentation about the company's background, progress, their customers and their goals.

~Right now as i understand, Circularise is using the blockchain technology are you also including other technologies into your business model?
We relay a lot on technologies that keep your data safe, so think for example on, subscriptions, so it is not specifically blockchain, because blockchain is just a way for us to ensure that everyone is on the same page, so to say. But other than that, we are using everything that is available to us. In the end, it's more focused on the problem that we want to solve. And not like other companies you could see, for example in Yes!Delft, that are focused on one specific technology and trying to market their product.

2. Company business model questions

~How is Circularise structured and how does Circularise work? In other words, what is your business model?
For the structural part, we are right now a Dutch BV, limited liability company, we are now transitioning in a part to become a 'foundation', a 'stichting', we are trying to get an ANBI status, that's available in the Netherlands. This means basically for our core technology, we want to sit down with all of these companies, and together we want to develop a new standard that we could push the industry and the regulation, that is our next step.

For the business model, it was a long journey to get here. It's definitely something that you will learn when you are an entrepreneur. In this case it wasn't really cut and drives, because just doing like normal size, normal for instance subscription doesn't really work with blockchain,

because it is all transaction based, volume based, et cetera. So in the end, actually by talking to our customers we found out that basically the plastic manufacturers, they sell a commodity and right now that is just commodity process, because there is no lead way for that. But if they work with us, and give all those information to us, it basically becomes something like what you would call a smart commodity for instance. That means that it is an option for them to charge a premium, because it saves a lot of money and risk actually from people that are buying it. So that meant for them that it is a way to earn more profit for them, we are happy for them, but we want to share an upside, we want to make sure we also get a piece of that what ever you are earning on top of your commodity right now. So it is very straight forward now, we charging a certain price for a kilogram, and the price is based on market price of the material that we are creating, its basically volume based, so how more volume in a single transaction the price will go down. The good thing about that from a business point of view is that our cost and our profits are decoupled from each other. So when we push a transaction through our system for 10 kilos for a million kilo's, the cost and the effort for us will be still the same, but we are earning obviously a lot more, with a higher amount of kilo transactions.

~I have understood that last year, Circularise were aiming for the companies within the textiles, plastic and metals industry. In other words, Circularise were focusing on material manufacturers that have a specific product, and using them as a sales channel to get to the other main brand companies. So our question is: Could you explain what the current progresses are, and is Circularise still focusing on this industry, did Circularise got the big fish? Or did Circularise expand its customer segment by aiming for other industries?

This is all our strategy, we talk with people and companies as a way at the beginning of the value chain, that creates some kind of materials, that somehow is more sustainable or somehow is having missions to become more circular, and we basically work with them and do the whole thing I just presented. They will go to their customers and sell this, and from that we get from instances the other industries where they use a lot of assets, so they will say well this is really great, so now we have one supplier that we get a lot of data. So it is basically on one side it is successful, once we did a successful pilot. However, there are two questions popping up about that: 1. Can you do this for our other suppliers of the same materials? Of course that is easy for us. And 2: could you do this for our other materials? That takes a bit more time, because actually we can imagine the supply chain are operating very differently from each other. So we need to adapt to some certain steps into our programs. But in the end that is how we scale. So we go, basically with them to their customers, so our customers actually help us in scaling our business.

~Could you describe in more detail how the circular approach helps you in creating value and take us along the lines of your business model?

The interesting things we should keep in mind for sure, and the others also, if we make the transition to a circular economy, this means that there is new value to begin with, for sure. I mean everyone understands that, but also we need to make sure that the values go to the right people. So right now, everyone, or at least even the people in my business talks about material

manufacturers now earning more, but then again they are completely reliant on secondary pit stock right? So why are we not having that discussion, why are we not saying well maybe these sorts of recyclers should earn more, because again, they are going to giving us those pit stock we need, and well we can keep go down that loop and backwards. So in the end, I think besides the business model we have right now, we need something so we can make sure that every single step in this supply chain gets their right value out of it.

~Circularise is a company that helps other companies to become more circular, by using a circular approach. In other words, you are applying a circular approach within your business model to create value.

However, could you explain if you are also applying a circular approach (digital data technologies) within your own company structure? For example, using the blockchain system to improve your company's process or to make things more convenient?

Well it depends. Directly, no, because there is no way we can really use a digital technology just by ourselves during the position we are in right now. But then, we have for instances we also participated in a blockchain event last year, that we have won. So we took the challenge to something that was not our core business, so we looked at different funding mechanisms for open source blockchain projects, and from there we created a new funding mechanism. And actually a part of that we did used to close some new contracts with companies that we have right now. Also, whatever you do in digital spaces you could do contracts of course, physical contracts. And for instances, my co-founder is working right now on the COVID-19 app, also to get some of our technology in there, because if we can provide security for things, then why not for people as well.

~The value creation/delivery dimension: How are activities and processes employed to deliver the promised value? For example, what technologies and capabilities are needed?

To answer that, on the practical side we use agile development, we have a certain options that a company can choose which sides digital data business that which we use the normal business model for, we can do like a piece of study or other pilot projects. We even have projects on the other side of the world with companies that have want to use what we are building today, but something that we are less related to it, so for that we have a certain package that we offer, and those are all based on what we know in the software industry in terms of workshops.

~The value capture dimension: What are the additional cost structures and changes in revenue streams, and is the revenue model financially viable?

That is tough to answer, I mean, we are really good at doing pilots, we have done a lot of them. But it doesn't necessary say anything about our business on scale. I think we are right now on the transition period, so I don't think we could give you a good answer for this question.

3. The stakeholders, partnerships, and customers of Circularise

~Who are your main customers and partners?

So we have obvious materials manufacturers, most notably are the plastic and textiles industries, but then we also work it up with knowledge institutes on different European projects, like TU Delft, and also others. Also, we are right now actually working a lot on the customers of our customers basically. Currently we are trying to scale that around the European institutes that we try to work with as well. Especially at the regulatory side, so we see that there is a travers being made, the new green deal, so we are trying to make sure that we can deliver that and probably some more as well for other industry.

~Is Circularise also trying to focus on the industries with a known brand for example, Volkswagen and BMW?

The nice thing about our partners is that I am sure that you can not buy a car anywhere in the world without their materials. So we are automatically talking will all of those companies through the plastic and metal industries.

4. The challenges towards circularity

~What are the challenges that you think that your company and other companies have during this transition towards circularity?

For Circularise back then, the biggest challenge was that we were way too early, so we are now almost four years old as a company. I think the first 1,5 to 3 years, we spend just on educating people. We were just going to customers to tell them about circular economy, because although they have heard about it, but they didn't know what it means, what it does for them. Now we are finally through that stage where the world knows what we are talking about, they understand the value. But now we have that same problem with 'blockchain', although they have heard about it, but they didn't know what it means, what it does for them. There is still a lot of miss understanding there about what it actually is, so now we see ourselves still fulfilling that role, in that aspect we are now basically doing pilot projects, this means that we are getting people to this technology and we are trying to push it in the way we want. But obviously it takes a lot of time. So I think now, since January we got the first customers that understands circular economy and blockchain, and understand what we are doing, and want our service what we are selling. But basically, until now it was kind of a big struggle to get here. But to be honest, I see that in all aspects of innovation, this was always a problem.

~So as I understand, the main challenges are that the technology is still a very new phenomenon, and therefore, customers are not familiar with that and also don't trust and share the data?

To condense it, when you are doing it in an innovation by yourself, doing an innovation is really exciting. But then if you want to purchase an innovation from someone else, it could be very scary. And that's what we are now seeing and experiencing. Our strategy to mitigate that, what

we are doing for a while now is that we are co-creating a bit more with customers. Internally they get the knowledge and materials to convince the other members of their team et cetera. And that really makes our growth quicker and quicker.

~Do you also experience the challenges of your clients? For example, while during the implementation of the technology into their company structure?

Well it takes a lot of time. For instance, one of the plastic manufacturer we are working with, imagine that we are helping them in moving to a integrated services, so fast forward a couple of months, imagine we have to have the integrated solution ready. If we then want to implement that into their system it takes about 9 months at least as a minimum before they can actually use it, because all of the security checks and all the other stuff we have to go through, because it is a very big company. So we understand it, but imagine to a startup being told that 'this is really great, but we will think about that' but that is how it goes. So my suggestion for other new startups is to go for small companies first, although big companies are good as well, but it will take a lot of time to make everything work.

~Do you experience that the companies to implement it into one specific department first and thereafter slowly expand it into other departments, or is it implementing the whole system all at once?

Yes for sure, it is always step by step, especially with the big companies, we are talking about a tiny part or one specific part of their structure.

~Are the challenges mostly lying in the system implementation phase (for example for the employees to settle down and get used to the system) or during the system usage phase? (For example, maintaining the system, and keeping it working in an efficient way?)

The understanding of regulatory aspects, we have some crazy experiences where for example an aircraft, if you say 2 years from now, this aircraft will be out of use, in our perspective, from that moment on it is already a waste. It is just too difficult right now, to use the plastic from the aircraft and recycle it to a better plastic for other aircrafts.

5. Driver and enabling factors of specific technologies to overcome the technology

~Could you explain, what are the drivers of the enabling technologies to help you and the other companies to overcome those challenges?

I think its biggest driver is probably their mindset, people are asking questions now, and those questions are uncomfortable and that is what we try to change, because everyone wants to have a good answer for those questions are not getting easier. The biggest one, we see regulations as well, but it is always that follows, because it is not the first thing that happens, which I think drives back to our strategy. Let's say well we can serve a small percentage of the

market with our technology, and we at least showed that it is possible for future regulators to take it as: well these are already possible, and maybe let's go one step further.

~So do you actually think that the government regulation changes are a big driver?
I would suggest divide the circularity word up, so when we talk about Circularity, it is a concept that we understand, but in a lot of places in the world they do not mention that word as a whole, instead they talk about recycling, which is a part of circularity. Dividing it in parts makes it more understandable and it might also be different drivers. Might for instances, we have also conversations with multiple stakeholders about recycling associations, they want to recycle as much as possible, but then from the circularity point of view, other options might be better to be first. So you also have to divide it up a bit.

6. The questions Hanieh and Victor asked

~Hanieh: How did your company came to the idea of circular economy?
My co-founder originally when he was investigating what he is going to do for his master thesis. Right before that he had some lectures, about critical materials, his choice was go to the entrepreneurship route with me together, or do something for Yes!Delft. So at the end, we thought well for entrepreneurship is really my passion so we really started with this problem, why are we doing nothing about those critical materials, because apparently we keep throwing those materials away everyday, while they are critical, and can be recovered. So we went through all the recyclers in the Netherlands of electronics and we just interviewed them and asked them: why are you not doing this? The short answer was: Well, we don't know. At the end we find out it is mostly an information problem, and it turns out some companies have information of recycling guides about how to recycle products properly. Which was basically a manual about how to disassemble a product, but nobody has time to read the manual there. That was basically the start that we found out more problems of the same topics about this and tried to come up with technologies how to overcome those. And that basically has built the business. So it was from the 'problem first', instead of the 'technology first' perspective.

~Hanieh: Is that company became your client later on?
Yes and no, we did a couple of pilots in recycling spaces, but through a recycler, in order to use what we are doing, we need to have a lot of value on the production side, so basically adding QR codes to products when they are produced, and we have the electronic products with a lifespan of 7 to 10 years. So even when we are able to track everything today, recyclers still can not really use it, because it takes a lot of time.

~Hanieh: I think that it very depends on the mindset and decisions, those two factors are really important for the beginning of the startup, of the founders of the entrepreneurship.
Yes I agree, and also like for the students, it is really important to understand, if you really want to go to the entrepreneurship route, it is not always fun, it has a lot of high surface area's with happy moments, but you also have a lot of negative moments, for example we have months

that we just could not pay our salaries, so we were technically bankrupted. However, we decided to just give it a go, because we believed in this, but that is also a part of the story.

~Hanieh: How do you see the future of Circularise, within 5 years or 10 years from now?
I hope it will be good. But basically, our grand vision is that we really enabled this change, and that is our focus right now. Although we are right now focused on the business side, but our primary role will be always to enable this change, this means that if something is about open source, or something that we need to give to others and that is fine.

~Victor: In order to enter this market, it has other challenges it might be interesting to have a comparison of a value chain and supply chain in which it works very good and there is a lot of benefits that we can see. But it might be also very challenging to those of the next one, which might be more difficult, but it might really depends on the supply chain to have a feeling of that, that would be interesting.
Yes, indeed. The biggest challenge is that digitally, the sky is the limit, although it will take a lot of time and resources, but the hardest part is to make the link work between physically and digitally. So for instance, textiles are working with a customer that really embeds a tracer into the yarn. For example, at a clothing store, we can use a QR scanner to validate it that it is exactly that specific yarn, and that's great because now there is validation to the claims that I am making. But if you talk about metals in general, how do you add a tracer? That is not really possible, because you are losing all the information somewhere in between. So there, the questions is about the link between digitally and physical, see everything in bags or locking mechanisms, which is not our core business. How can we make sure that everything that happens in physical spaces matches with the digital spaces?

~Victor: Indeed, but I think this also comes a lot with the people that are involved, who has to work with you?

Yes, especially at the beginning of the value chain. For example, the labor, in some countries that are not as good connected compared to here in the Netherlands. There are all challenges for sure. So that is why we talk about different supply chains, we sort of cherry pick them now, for example those are still difficult cases, but they are probably easiest to do right now. Now we have to see how we can bring that back to other cases.

Appendix IV: Transcript: Interview with Deloitte

On the 23rd of April 2020, I had the opportunity to have a short telephone interview with the director technology strategy at Deloitte. In this appendix, you can find the full transcript of the telephone interview with the questions and answers.

~What is your opinion about the potential of digital data technologies to help technology manufacturing companies in their business model transformation?

Digital data technologies, for instance: big data, data analytics, blockchain, artificial intelligence and robotics indeed have great potential to help the technology manufacturing companies in their business model transformation.

But not every digital data technology can be applied in every company. In practice, it therefore depends very much on each specific company and what they need. Each individual company has its own specific solution that is totally designed based on their structure and problems.

~What do you think about the technology manufacturing companies that are working on their business model transformation towards circularity?

From the technology manufacturing companies perspectives and actually from every company, no matter which sectors it comes from, their ultimate goals are always to ultimately gain market share, to make their business process more effective and optimized, or to maximize their profit. It is actually naïve to expect the companies to think, care, or even worrying about the environmental well being, and therefore spend money to circularity as a result.

However, circularity can be an intermediate step for those companies to achieve their main goal, and that is to gain market share, to make their business process more effective and optimized, or to maximize their profit.

If companies see the potential that circularity can help them improve their profit. Only then will there be a business model transformation based on circularity.

~From your experiences as an advisor, what are the most common challenges and barriers that the technology companies have during this transition towards circularity? And what are the key drivers to overcome those challenges and barriers?

In practice, with my experiences of all those years being an advisor, each company and sector all have their own unique challenges and barriers and key drivers. Therefore, each single individual company has its own specific organization, structure, vision, process, problems and challenges.

So in other words, it is difficult or even impossible to just mention the most common factors.

Appendix V: Data analysis: Fairphone

On the 4th of May 2020, I had the opportunity to contact the Co-Founder and Circular Innovation Lead of Fairphone. Due to the lack of capacity of the company, He was not able to conduct an interview; instead he provided some company documents. In this appendix, you can find the full data coding summary of the company documents that he had provided, which summarizes the most important and relevant points of the documents.

~ Fairphone's business model and structure

Fairphone is a technology manufacturing company that currently is applying the B2C for-sales business model in which the company loses ownership and control of the device after it is sold.

However, to reach a more circular mobile solution, Fairphone is currently working on the business model transition between linear and circular by moving from B2C product sales business model to offer a B2B business model that is based on Fairphone-as-a-Service. This means that Fairphone's proposition is based on giving access to functioning Fairphone devices for the customer's employees. This business model requires businesses to pay a mixed monthly fee, maintenance services, device updates and take-back of devices when the devices reach their end-of-life phase.

~Key enabling factors for the business model Fairphone-as-a-service model

The key enabling factor of the Fairphone-as-a-service proposition is that Fairphone will retain the ownership of the devices. This gives the opportunities to increase the value created as Fairphone can deploy circular strategies for instance maintenance, repairs, refurbishment and recycling to extend the lifetime of devices and therefore optimizing the value creation.
Furthermore, the latest Fairphone devices consist of several modules. The modules can be taken out and repaired or replaced without the need to return the whole device. The strength of the modular nature ensures for the financial viability of the proposition as circular value creation can be structured around the individual characteristics of the modules, instead of having to focus on the aggregate performance of the whole device.

~Challenges of the transition to a Fairphone-as-a-service model:

Product challenges:

Due to the ongoing nature of the Fairphone-as-a-Service proposition and the fast-moving nature of the smartphone market, a key challenge is to provide and service devices at an appropriate technology level.

Organizational and financial challenges:

Organizational and financial complexities: Initial investments in the fleet of assets against a backdrop of longer payback periods, which puts pressure on the cash-flows.

Robust contracts are required to stipulate the terms and conditions between customers, end-users and the product supplier.

Supply chain challenges:
Circular supply chains require cooperation and coordination between all the parties. This leads to high administrative costs, need of trust, transparency and long-term agreements between the chain partners.

***Privacy challenges*:**
Data privacy: Retaining ownership of the devices gives interesting opportunities to access user data; however the use of those data is subject to strict privacy considerations

- Tracking devices, components, resources
- Failure data
- Behavioral data

~Strategies to overcome the challenges

Product challenges strategies:
Fairphone has to provide smartphones that are on 'the generally accepted technological level' to its customers, which does not require that Fairphone provides state-of-the-art or latest generation devices. Also, Fairphone retains the right and responsibility of the smartphone to take the functionality and circularity together into account. Therefore, allowing Fairphone for the use of refurbished modules means the smartphone does not become outdated when new hardware becomes available.

Operational challenges strategies:
Hardware management (in particular, the improvement of precautionary maintenance solutions and off cost-effective module management solutions).

- Preventive maintenance
- Module management

Financial challenges strategies:

- Estimate the service fee
- Define a realistic scenario
- Model cash flows
- Identify financing solutions
- Model profit & loss statement
- Model balance sheet

Contracts: development of a financeable business model and a corresponding contract.

Supply Chain challenges strategies:
For the supply chain, the solution is to structurally generating, gathering and storing of the existence of data regarding material composition, condition, location, maintenance, supply chain actors, asset use and corresponding revenues and costs.

~Key drivers of overcoming the challenges and barriers to circular business models

- One of the key drivers are the company's openness for experimentation with the new business models. The concept of 'learning by doing' curves can help to improve the development of its new business models and even unravel additional potential values of the circular economy.

- Collaboration and transparency are the other key drivers to create synergies between different fields of expertise, for instance, business, legal, operational and financial.

Appendix VI: Data analysis: Signify (Philips Lighting)

On the 11th of May 2020, I had the opportunity to contact the Senior Director Sustainability at Signify. Due to his busy schedule it was not possible to conduct an extensive interview; instead he provided some company documents. In this appendix, you can find the full data coding summary of the company documents that he had provided, which summarizes the most important and relevant points of the documents.

~ Signify's business model and structure

Signify is a technology manufacturing company that focuses on producing light sources. Signify was traditionally a division of Koninklijke Philips Electronics N.V. This division focuses on the philosophy of circular economy by bringing as many materials as possible back into the production loop and to keep products and materials on its highest utility and value for as long as possible.

Instead of selling products, Signify adopts the strategy of B2B product-as-a-service business model that includes the manufacturing, installation, maintenance, upgrades, reuse and recycling of the lighting products and equipment. This strategy allows Signify to create value by retaining the ownership of its products and selling product-as-a-service to optimize its use of resources. This strategy comes together with the possibilities for data-driven solutions, this means that the lighting systems can be linked to its data network to manage and optimize the lighting infrastructure on a system-wide level.

As a leader in innovation, Signify believes in an approach which integrates systems thinking and regenerative product design, new business models, reverse logistics and enabling communication technologies.

~Key enabling factors for the business model product-as-a-service model

According to Signify, there are four key enablers for the product-as-a-service model:

- Business models
    - Attractive value propositions that enables an optimal capture of the economic opportunities.
    - Scale up the service business.
    - Development of sales tools for circular value proposition.
- Product design
    - The product designs that enable multiple lifecycles of products and materials with minimal loss of value, energy impact and quality.
    - Expanding the portfolio of circular products.
- Collaboration

    - The collaboration across the value chain and sectors is necessary. Therefore, networks and knowledge sharing platforms are essential to facilitate the large scale establishment of circular economy. Also, policy regulations are important.
    - Enhance relationships with customized solutions
- Reverse logistics
    - The operations related to the recovery and reuse of materials and products. Furthermore, the processes, strategies and infrastructure are from necessity to enable a cost-effective collection, treatment and redeployment of the materials and products.
    - Extend the possibilities for take back and recycling.
    - Enhance collaboration with recyclers and distributors

~Challenges of the transition to a product-as-a-service model

- Legal ownership and use
    - One of the challenges is the ownership of the product. In the product-as-a-service model, the product remains the property of the company, the user may be less careful with the product compared to when the user really owns the product.
    - Legal ownership issues are another challenge, the product-as-a-service model. In this business model, data flow between the customer and company is a crucial factor. The free flow of data are caused by the legal uncertainty surrounding the emerging issues on 'data ownership' or control, reusability and access to or transfer of data and liability arising from the use of data.
- Adaptive logistics
    - The company's flexibility and quickness to fully adapt to the operations related to the recovery and reuse of materials and products. Furthermore, the processes, strategies and infrastructure are from necessity to enable a cost-effective collection, treatment and redeployment of the materials and products.
- Financial strategies
    - The company has to adapt to longer payback periods because of the product-as-a-service model; the cash flows of the company are therefore different from the normal product-sale business models. Therefore, a well thought out financial strategy must be applied based on this business model.

~Key drivers of overcoming the challenges and barriers to circular business models

- Big data
    - Big data shifts the approach in which the problems can be solved, it provides deeper market knowledge and increase the opportunities of customer- focused solutions. Furthermore, it enables the intelligence and knowledge where the

resources are within the economy, the product properties and status. This makes the manufacturing process more optimized and additive.

- Government regulations and legislation
  - Government regulations and legislation are crucial factors to positively influence and accelerate the business model transition toward a more circular business model.
- New business models of consumer consumptions
  - Customers' product interests are starting to shift toward the concept based on access and performances rather than ownership. In contrast to goods, services also help the companies to redefine their relationship with the consumers.
- Online platforms
  - Online platforms allow companies to improve their relationship with their customers through new levels of engagement and connectivity's.

Appendix VII: Table of Coding - Case study Circularise

The findings of the case study with Circularise are coded and described in the table shown below. The findings are categorized into the family code, codes, description and specific quote taken from the interview transcript.

Family code	Codes	Description	Quotes
Challenges	Quite new and unknown	Companies have no understanding or knowledge of the new digital data technologies	"The first 1,5 to 3 years, we spend just on educating people. We were just going to customers to tell them about circular economy, because although they have heard about it, but they didn't know what it means, what it does for them."
	Trust	Companies have no trust, because it is a new technology	"When companies are doing it in an innovation by themselves, it is really exciting. But then if you want to purchase an innovation from someone else, it could be very scary. And that's what we are now seeing and experiencing."
	It takes time	Implementation of digital technologies take a lot of time, especially in big companies	"Imagine we have to have the integrated solution ready. If we then want to implement that into their system it takes about 9 months at least as a minimum before they can actually use it, because all of the security checks and all the other stuff we have to go through, because it is a very big company."
	Link between physically and digitally	This is necessary within a company structure to make it work effectively and the performances optimal	"The hardest part is to make the link work between physically and digitally, in some specific sectors, how do you add a tracer? That is not really possible, because you are losing all the information somewhere in between."
Strategies	Target small companies	It takes less time to implement the systems	"My suggestion for other new startups is to go for small companies first, although big companies are good as well, but it will take a lot of time to make everything work."
	Target big companies	Start with a tiny part within a company structure	"In order to implement our system into our customer's company's structure, it is always step by step, especially with the big companies, we are talking about a tiny part or one specific part of their structure."
	Target the companies at the beginning of the value chain	Those companies lead to the big fish	"Circularise talk with people and companies at the beginning of the value chain, that creates some kind of materials, that somehow is more sustainable or is having missions to become more circular, and we work with them. They will go to their customers and sell this, and from that we get from instances the other industries where they use

			a lot of assets."
	Target knowledge institutes	To get access to their network and target new potential customers	"We also work with knowledge institutes on different European projects, like TU Delft, and also others. Also, we are right now actually working a lot on the customers of our customers basically. At the moment, we are trying to scale that around the European institutes that we try to work with as well.
	Focus on agile development	An iterative approach to project management and software development that helps teams to deliver value to their customers faster and with fewer headaches	"To deliver the promised value we use agile development, we have a certain options that a company can choose which sides digital data business that which we use the normal business model for, we can do like a piece of study and offer them a certain package."
	Focus on pilot projects	Small scale preliminary study conducted in order to evaluate feasibility, duration, cost, adverse events, and improve upon the study design prior to performance of a full-scale research project	"To deliver promised value we also use pilot projects. We have projects with companies that want to use what we are building today, but something that we are less related to it, so for that we have a certain package that we offer, and those are all based on what we know in the software industry in terms of workshops."
	Co-creating with customers	Through this partnership and sharing knowledge, the customers can be convinced and to gain the trust	"What we are doing for a while now is that we are co-creating a bit more with customers. Internally they get the knowledge and materials to convince the other members of their team et cetera. And that really makes our growth quicker and quicker."
Key Drivers	New attractive value	Every single party in the supply chain has to get their value before they decide to implement digital data technologies	"If we make the transition to a circular economy, this means that there is new value to begin with, for sure. I mean everyone understands that. So in the end, we need something so we can make sure that every single step in this supply chain gets their right value out of it."
	Mindset	Customers are lacking trust, because their lack of knowledge	"People are asking questions now, and those questions are uncomfortable and that is what we try to change, because everyone wants to have a good answer for those questions are not getting easier."
	Regulations	It can accelerate the transition to circularity. However, it must be divided into parts to make it more understandable, because circularity is a big general word	"Regulations are a key driver as well, but it is always that follows, because it is not the first thing that happens."

Table B - Overview findings of the case study with Circularise

Appendix VIII: Table of Coding - Case study Deloitte

The findings of the case study with Deloitte are coded and described in the table shown below. The findings are categorized into the family code, codes, description and specific quote taken from the interview transcript.

Family code	Codes	Description	Quotes
Limitation of implementing circularity into the business models	Every company is unique on its own	Digital data technology can be applied in every company, but each company has its individual specific structure and problems.	"Not every digital data technology can be applied in every company. In practice, it therefore depends very much on each specific company and what they need. Each individual company has its own specific solution that is totally designed based on their structure and problems."
Potential	Implementation of digital data technologies	Digital data technologies, for instance: big data, data analytics, blockchain, artificial intelligence and robotics indeed have great potential	"Digital data technologies, for instance: big data, data analytics, blockchain, artificial intelligence and robotics indeed have great potential to help the technology manufacturing companies in their business model transformation."
Challenges	Every company is unique on its own	Based on the business model, structure and problems, each individual company has its own specific solution	"In practice, each company and sector all have their own unique challenges and barriers and key drivers. Therefore, each single individual company has its own specific organization, structure, vision, process, problems and challenges."
Drivers	Gaining and maximizing profits	The main goal and drivers of a business is to gain market share, having an effective and optimized business, and to maximize profit	"Every company, no matter which sectors it comes from, their ultimate goals are always to ultimately gain market share, to make their business process more effective and optimized, or to maximize their profit. The environmental well being, and therefore spend money to circularity as a result is not the main goal of a company. However, circularity can be an intermediate step for those companies to achieve their main goal, and that is to gain market share, to make their business process more effective and optimized, or to maximize their profit."

Table C - Overview findings of the case study with Deloitte

Appendix IX: Table of Coding - Case study Fairphone

The findings of the case study with Fairphone are coded and described in the table shown below. The findings are categorized into the family code, codes, description and specific quote taken from the document analyses.

Family code	Codes	Description	Quotes
Product-as-a-service	The product-as-a-service proposition	This will retain the ownership of its products. It gives the opportunities to increase the value created as the company can deploy circular strategies for instance maintenance, repairs, refurbishment and recycling to extend the lifetime of its products and therefore optimizing the value creation.	"Fairphone-as-a-service enables the company to retain the ownership of its products."
	Product consisting of several modules	Products that consist of various modules have the advantage of becoming circular	"The modules can be taken out and repaired or replaced without the need to return the whole product. The strength of the modular nature ensures for the financial viability of the proposition as circular value creation can be structured around the individual characteristics of the modules, instead of having to focus on the aggregate performance of the whole product."
Challenges	Product challenges	The main product challenge is to remain at the desired technological level when time passes	"Due to the continuing reuse nature of the product-as-a-Service proposition and the fast-moving nature of the products nowadays, a key challenge is to provide and service products at an appropriate technology level."
	Organizational and financial challenges	The product-as-a-Service business model gives organizational and financial complexities. While products are normally sold and the company immediately earns its turnover to earn back its investments, in this case there is an additional backdrop of longer payback periods; this puts pressure on the cash- flows of the company. Additional contracts are required to stipulate the terms and conditions between customers, end-users and the product supplier.	"Initial investments in the fleet of assets against a backdrop of longer payback periods, which puts pressure on the cash-flows." "Additional contracts are required to stipulate the terms and conditions."
	Supply Chain	Circular supply chains require	"Moreover, circular supply chains

	challenges	cooperation and coordination between all the parties. This leads to high costs, need of trust, transparency and long-term agreements between the parties.	require cooperation and coordination between all actors, leading to high administrative costs and need for trust, transparency and long-term agreements between chain partners."
	Privacy challenges	Retaining ownership of the devices gives interesting opportunities to access user data; however the use of those data is subject to strict privacy considerations.	"The legal and privacy aspect is a challenge, with respect to data privacy and contractual agreements in the circular value chain in order to align incentives of all stakeholders."
Strategies	Product challenges solutions	The company has to provide products that are on 'the generally accepted technological level' to its customers, which does not require the company to provide state-of-the-art or latest generation products. Also, the product-as-a-service business model allows the company to retain the right and responsibility of the product, which enables the opportunity to take the functionality and circularity into account. Therefore, allowing the company for the use of refurbished modules, means the product does not become outdated when new products becomes available.	"For Fairphone, state-of-the-art hardware management is critical to optimize the use of individual modules, ensure high quality services and maximize circular value." "Fairphone retains the right and responsibility allowing the use of refurbished modules, which enables the opportunity to take the functionality and circularity into account."
	Operational and financial challenges solutions	Hardware management for effective module management solutions Extensive pre- calculations in order to prevent unexpected situations Financeable business model and corresponding contracts	"Hardware management. In particular, the improvement of precautionary maintenance solutions and off cost-effective module management solutions." "Before the company realizes the business model, make an extensive calculation of the estimations of service fees, realistic scenarios, modeling the cash flows, financial solutions, profit and loss statements and balance sheets to be fully prepared with all scenarios and not to face unexpected situations. "Development of a financeable business model and corresponding contracts."
	Supply Chain challenges solutions	Structurally generating, gathering and storing of the existence of data	"For the supply chain, the solution is to structurally generating, gathering and storing of the existence of data

			regarding material composition, condition, location, maintenance, supply chain actors, asset use and corresponding revenues and costs."
Key Drivers	The openness and flexibility	In order to be able to experiment with new business models	"The openness and flexibility of the company to be able to experiment with new business models. The concept of 'learning by doing' curves can help to improve the development of its new business models and even unravel additional potential values of the circular economy."
	Collaboration and transparency	Cooperation between different fields of expertise, for instance, business, legal, operational and financial leads to new opportunities	"In order to create synergies between different fields of expertise, for instance, business, legal, operational and financial."

Table D - Overview findings of the case study with Fairphone

Appendix X: Table of Coding - Case study Signify

The findings of the case study with Signify are coded and described in the table shown below. The findings are categorized into the family code, codes, description and specific quote taken from the document analyses.

Family code	Codes	Description	Quotes
Product-as-a-service	Value creation	Creation of value by retaining the ownership of its products and selling product-as-a-service to optimize its use of resources.	"In a circular economy, the more effective use of materials enables to create more value, both by cost savings and by developing new markets or growing existing ones."
	Possibilities for data-driven solutions	The lighting systems can be linked to its data network to manage and optimize the lighting infrastructure on a system-wide level.	"The emergence of connected lighting is creating more possibilities for data-driven solutions."
Challenges	Ownership of the product	The product remains the property of the company, the user may be less careful with the product compared to when the user really owns the product.	"Attractive value propositions that will enable an optimal capture of the economic opportunities of a circular economy – for example through further emphasis on access over ownership."
	Legal ownership issues	Data flow between the customer and company are a crucial factor. The free flow of data are caused by the legal uncertainty surrounding the emerging issues on 'data ownership' or control, reusability and access to or transfer of data and liability arising from the use of data.	"We also need to refine concepts of legal ownership."
	Adaptive logistics	The company's flexibility and quickness to fully adapt to the operations related to the recovery and reuse of materials and products. Furthermore, the processes, strategies and infrastructure are from necessity to enable a cost-effective collection, treatment and redeployment of the materials and products.	"We also need to refine concepts of adaptive logistics, trying to extend possibilities for take back and recycling and enhancing collaboration with recyclers and distributors."
	Financial strategies	The company has to adapt to longer payback periods because of the product-as-a-service model; the cash flows of the company are therefore different from the normal product-sale business models.	"We also need to refine concepts of financing strategies."
Key Drivers	Big data	Shifts the approach in which the problems can be solved, it provides deeper market knowledge and increase the opportunities of customer- focused solutions.	"The emergence of big data has shifted the approach in which problems can be solved, providing deeper market knowledge and increasing consumer-focused solutions."

		Enabling the intelligence and knowledge where the resources are within the economy, the product properties and status. This makes the manufacturing process more optimized and additive.	
	Government regulations and legislation	Those are crucial factors to positively influence and accelerate the business model transition towards a more circular business model.	"Regulation and legislation is an important driver for recycling WEEE as it ensures that all producers are committed to managing collection and recycling in a professional way."
	New business models of consumer consumptions	Customers' product interests are starting to shift towards the concept based on access and performances rather than ownership. In contrast to goods, services also help the companies to redefine their relationship with the consumers.	"We have seen the emergence of a different type of consumer, who is interested in different ownership and business models. These consumers are more driven by access and performance rather than ownership. Services and not goods are helping to redefine the relationship between objects and consumers."
	Online Platforms	These allow companies to improve their relationship with their customers through new levels of engagement and connectivity's.	"The multi-channel world has also led to new levels of engagement and connectivity with consumers looking for relationships with brands that go beyond the transactional."

Table E - Overview findings of the case study with Signify

Appendix XI: Case studies summary overview table

In this section an overview of the case studies is shown with the summary of all the important findings.

Case Study	Digital Data technologies	Business model	Challenges and barriers	Strategies	Key drivers	Limitations
Circularise	Providing an open-source protocol and a decentralized network that is based on Blockchain technology	- B2B - Providing product and service that help other companies towards circularity	- Digital data technologies are still a quite new phenomenon - Customers have no trust or knowledge - The implementation of the digital data technologies takes a lot of time - The link between physically and digitally within a company structure to make it work effectively	- Target small companies to implement digital data technologies - Aim for companies at the beginning of the value chain, for example material industries - Target knowledge institutes to get access to their network and target new potential customers - Focus on agile development to create value, an iterative approach to project management and software development that helps teams deliver value to their customers faster and with fewer headaches. - Also focus on pilot projects, this is a small scale preliminary study conducted in order to evaluate feasibility, duration, cost, adverse events, and improve upon the study design prior to performance of a full-scale research project. - Co-creating with the customers, through partnership and sharing knowledge, the customers can be convinced and gain the trust.	- New attractive value to the companies and parties within the supply chain - Mindset, customers are lacking trust, because their lack of knowledge - Regulations can accelerate the transition to circularity	
Deloitte		- B2B - Consultancy company	- Every technology manufacturing companies have their own unique challenges and barriers and key drivers.			- From the technology manufacturing companies'

			Therefore, each single individual company has its own specific organization, structure, vision, process, problems and challenges.			perspectives, their goals are always to ultimately gain market share, to make their business process more effective and optimized, or to maximize their profit. - Circularity can actually be an intermediate step for those companies to achieve their main goal, and that is to gain market share, to make their business process more effective and optimized, or to maximize their profit.
Fairphone	- Fairphone is looking for opportunities and trying to implement big data and blockchain into their business models to obtain usage data to increase its circularity.	- B2C - Product for-sales business model - Selling sustainable smartphones to customers. - B2B - Product-as-a-service business model that is based on circularity - Allows companies to pay a mixed monthly fee for maintenance services, device updates and take-back of	- Providing services and products at an appropriate technology level that also remains at the desired technological level when time passes. - Organizational and financial complexities, there is an additional backdrop of longer payback periods; this puts pressure on the cash- flows of the company. - Cooperation and coordination between all the parties. This leads to high administrative costs, need of trust, transparency and long-term agreements between the chain partners. - The data is subject to strict privacy considerations.	- Providing products that are on 'the generally accepted technological level' to its customers. - Retain the right and responsibility of the product, which enables the opportunity to take the functionality and circularity into account. Therefore, allowing the company for the use of refurbished modules and not become outdated when new products becomes available. - Extensive calculations of the estimations of service fees, realistic scenarios, modeling the cash flows, financial solutions, profit and loss statements and balance sheets to be fully prepared. - Make corresponding contracts.	- Openness and flexibility of the company to be able to experiment with new business models. The concept of 'learning by doing' curves can help to improve the development of its new business models and even unravel additional potential values of the circular economy. - Collaboration and transparency to realize co-working between different fields of expertise, for instance, business, legal, operational and financial.	

		devices when the devices reach their end-of-life phase.				
Signify (Philips Lighting)	- Signify is looking for data-driven solutions, using big data and data sharing. The lighting systems can be linked to its data network to manage and optimize the lighting infrastructure on a system-wide level	- B2B - Product-as-a-service business model that is based on circularity - That includes the manufacturing, installation, maintenance, upgrades, reuse and recycling of the lighting products and equipment.	- Ownership of the product, the product remains the property of the company, the user may be less careful with the product compared to when the user really owns the product. - Legal ownership issues, data flow between the customer and company are a crucial factor. The free flow of data are caused by the legal uncertainty surrounding the emerging issues on 'data ownership' or control, reusability and access to or transfer of data and liability arising from the use of data. - Adaptive logistics, the company's flexibility and quickness to fully adapt to the operations related to the recovery and reuse of materials and products. Furthermore, the processes, strategies and infrastructure are from necessity to enable a cost-effective collection, treatment and redeployment of the materials and products. - Financial strategies, the company has to adapt to longer payback periods because of the product-as-a-service model; the cash flows of the company are therefore different from the normal product-sale business models.		- Big data shifts the approach in which the problems can be solved, it provides deeper market knowledge and increase the opportunities of customer- focused solutions. Enabling the intelligence and knowledge where the resources are within the economy, the product properties and status. This makes the manufacturing process more optimized and additive. - Government regulations and legislation are crucial factors to positively influence and accelerate the business model transition toward a more circular business model. - New business models of consumer consumptions. Customers' product interests are starting to shift toward the concept based on access and performances rather than ownership. In contrast to goods, services also help the companies to redefine their relationship with the consumers. - Online platforms that allow companies to improve their relationship with their customers through new levels of engagement and connectivity's.	

Table F – Overview summary of the findings of all the case studies

Appendix XII: Research planning

This appendix shows the research planning that was included in the research proposal, as well as the target date to deliver the thesis and to have the Green Light meeting. At the end, I managed to work according to the schedule throughout the whole research and complete the research according to the dates described.

1. Timeline

The thesis will be carried out in a period of 5 months and starts officially after the Kick- Off Meeting, when the Kick- Off form is confirmed by the student administration of TU Delft.

The table below shows a planning that includes the target dates, deadlines and meetings.

Research phase	Objectives	Deadline
Background Research, Literature Review and Research Design Planning	Arrange supervisors and chair Submit literature review Submit research proposal	24-01-2020
Kick-Off Meeting	Discuss master thesis project plan Sign Kick-Off form	18-02-2020
Structured literature analysis	Carrying out the structured literature analysis, collecting data	13-03-2020
Flow diagram	Carrying out the research analysis and coming up with solutions and a flow diagram	10-04-2020
Case Studies	Doing case studies, as a goal to improve and refine the flow diagram. By collecting primary sources by conducting interviews. Thereafter, analyzing the data and refining the flow diagram	29-05-2020
Writing	Write the discussion and results chapter Complete thesis draft Submit the thesis draft	08-06-2020
Green Light Meeting	Discuss thesis draft Submit Green Light form	17-06-2020
Revision	Revise based on feedback supervisors Proof read Print and submit the thesis	30-06-2020

Graduation Presentation	Graduate	30-07-2020

Table G - Planning of the research, including target dates, deadlines and meetings.

2. Table of Contents

The draft of the final table of contents can be found in the table below.

	Chapter	Content
	Abstract	
1.	**Introduction** 1.1 Background 1.2 Problem Statement 1.3 Research Approach 1.4 Research Question	Revised version the project proposal
2.	**Literature Review** 2.1 Circular Economy 2.2 Business Model 2.3 Digital Technologies 2.4 Findings 2.5 Conclusion	Answering the sub-questions 1 and 2
3.	**Research Methodology** 3.1 Flow diagram and Solutions 3.2 Case Studies 3.3 External Confirmation	Answering the sub-questions 3 and 4
4.	**Conclusion and Recommendation**	Answering the main research question
5.	**Acknowledgement**	
6.	**References**	
7.	**Appendices**	

Table H - Expected table of contents of the final thesis.