SCHOOL OF
ECONOMICS AND
MANAGEMENT

3D Printing as a Path to Circular Economy: An analysis on the supply chain barriers

by

Alexander Reza Ramsey

Thiago Mazzeo Domingues de Castro

26/05/2021

Supervisors: Sotaro Shibayama & Joakim Winborg

Examiner: Anna Brattström

Word count: 17,868

Abstract:

Worldwide plastic production is expected to reach an amount of 34 billion tons by 2050, and a large portion of plastic used is for single-use packaging and low-cost consumer plastic products that are discarded. It is important to have a path to a circular economy by recycling and producing locally. The following potential research questions were identified to contribute to the existing knowledge in this field of study: How the supply chain barrier is impacting small and medium sized enterprises (SMEs) in the 3D Printing industry to migrate from a linear to a circular economy? Is it a stand-alone barrier or is it dependent on other barriers listed in the current literature? The purpose of this study was to contribute to the theoretical and practical knowledge on how the supply chain barriers correlate with five other barriers that could advance the path to a circular economy in the additive manufacturing sector within the EMEA region. The focus is on the five segments of additive manufacturing (3D printing) and if the barriers are interconnected. Empirical data was gathered by a qualitative method of six semi-structured in-depth interviews utilizing the grounded theory. The analysis of the grounded methodology facilitated the correlation between the data points of each barrier for attaining circularity. The theoretical and practical implications will be of interest to the chemical, producers, and waste industries, as well as to policymakers.

Keywords: Circular Economy, Additive Manufacturing, 3D Printing, Polymers Recycling, 3D Filament Recycling, 3D Printing Supply Chain Segments, Barriers to Circular Economy, Supply Chain Barrier.

Acknowledgments:

Firstly, we would like to thank the support of our supervisors Sotaro Shibayama and Joakim Winborg for the constant feedback and guidance during the supervisions and seminars throughout the program. A special thanks to our interviewees, Brian Houle from Markforged, Lasse Staal from Addifab, Löfgren Olof from Sysav, Mikus Upmalis from Tridos Design, Nicolas Mathian from Sculpteo BASF, and Pir Arkam Proto 21 3D Printing, who were generous to provide us with their time, insights and knowledge in the 3D Printing industry. Without them, this study would not have been possible. Furthermore, we would like to thank all our colleagues who have also provided feedback and suggestions that have contributed to the final result of this study. Finally, we would like to extend our gratitude to the administration of Sten K. Johnson Center for Entrepreneurship at Lund University for giving all the support and effort in making this course possible even during the COVID-19 pandemic.

Table of Contents

1. Introduction

1.1 Practical relevance

The increasing awareness of the circular economy concept in entrepreneurship is considered as an important combination of ecological and economic business models, which will drive public and private institutions to use new technology to reduce the side effects from traditional manufacturing, such as pollution and climate change in the near future (Moller, 2020).

As a result of the increasing extraction of natural resources to fulfill the need of the traditional linear business model over the past decades, and the inefficiency of dealing with waste management from this process, the circular economy model came as a great alternative for business owners and new entrepreneurs to provide more sustainability and efficiency in their processes (Patwa, Seetharaman, Arora, Agrawal & Mandalia, 2021).

Businesses are competing in a challenging global environment, where climate crises, shrinking resources, and environmental challenges are affecting business ventures. The circular economy shows us how to change our consumption and production by putting an end between economic profit and the consumption of natural resources. Companies need to rethink the traditional "take, make, dispose" linear approach in favor of producing longer-lasting products, that can have their materials reused at the end of the lifespan of the product, as a zero-waste value chain (Lacy, Long & Spindler, 2020).

The biggest challenge faced by companies working towards a circular economy is to create a framework that can find the balance between sustainability and profitability, as well as a good transition plan to assure companies go from their current situation to a profitable circular process (van Loon & van Wassenhove, 2020).

Despite the global awareness of sustainability and environmental concerns, plastic production and consumption of consumer goods are still gradually increasing (Zander, Gillan, Burckhard & Gardea, 2018). As demonstrated in Figure I (available in appendix A), worldwide plastic production is expected to reach an amount of 34 billion tons by 2050, a compound annual growth rate of 4.37% from 2017 to 2050 (Tiseo, 2021).

In addition to that, the consumption of plastics is also expected to increase 4.1% by 2030, as demonstrated in figure II (Garside, 2020) available in appendix A. Still, according to Garside (2020), the consumption of plastics seems to slow down from 2030 to 2050, representing only 2.4% growth. If compared to other materials in figure II, plastic is the one that raises most of the environmental concerns. Firstly, because it is largely used for packaging in several industries and is not always recycled, and secondly because it is the material that is registering the biggest growth rates over the years.

Considering the increase in plastics production and consumption, and also considering the sustainability and environmental concerns involved, many industries are trying different methods to reduce the use of single-use plastics, like adopting alternative plastics or using more recycled material.

The increasing awareness of resource efficiency has led several small and medium-sized enterprises (SMEs) to focus on achieving a circular economy model. According to EU (2015) a SME is an enterprise that has fewer than 250 employees, annual turnover less than 50 million euros and annual balance sheet below 43 million euros. Closing the loop in the process can bring several benefits for SMEs, however, entrepreneurs may face several barriers to achieve this business model. SME owners that are familiar with circular technologies have far greater chances of perceiving opportunities in these business models than owners without the technology know-how (Rizos, Behrens, van der Gaast, Hofman, Ioannou, Kafyeke, Flamos, Rinaldi, Papadelis, Hirschnitz-Garbers & Topi, 2016).

A very prominent industry that could be a game-changer in this scenario is the Additive Manufacturing (3D printing) industry. In figure III (Available in appendix A), it is possible to see that the 3D printing industry is expected to present rapid growth, going from a market size of USD 16 billion in 2020 to USD 40.8 billion in 2024 (Statista Research Department, 2021).

The accessibility of this technology, responsive manufacturing process, and the ability to produce complex products or prototypes directly, instead of using traditional production methods to produce the parts separately and then assemble the final product, are some of the benefits of additive manufacturing technology (Mueller, Elkaseer, Charles, Fauth, Rabsch, Scholz, Marquardt, Nau & Scholz, 2020).

1.2 Theoretical relevance

It is believed that additive manufacturing will be one of the disruptive technology components of Industry 4.0. While this could be debated between scholars, there is growing agreement that 3D Printing has added new capabilities to the manufacturing process and has the potential of changing the traditional manufacturing process, transitioning from an open-loop system to a closed-loop system (Garmulewicz et al. 2018).

The entire life cycle for 3D printed products shows lower energy use, CO2 emissions, and changes in the labor demand by shifting to a more digital and localized supply chain (Gebler, Uiterkamp & Visser, 2014). The 3D printing industry has the potential of being a great tool for the circular economy business model, since it is possible to produce and recycle the parts locally, instead of having manufacturing centers and logistics facilities to deal with importation and exportation.

Although scholars are still studying the circular economy as it is still considered a fairly new topic, many studies have been performed discussing the definitions of circular economy, as well as the challenges and opportunities, and in special, the barriers that companies face when pursuing circular economy (Elia, Gnoni & Tornese, 2020).

According to Jaeger & Upadhyay (2020), the main pressing barriers of manufacturing companies in closing the loop to a circular economy are related to the quality of the recycled materials, design and the production process, supply chain issues, disassembly of products being time-consuming, and costly, and high investment costs.

On the other hand, Kumar, Sezersan, Garza-Reyes, Gonzales & AL-Shboul (2019) have discovered through their study that the low public awareness and knowledge on the circular economy, lack of partner companies in the supply chain to collaborate, and lack of a proper waste management system is the most pressing barriers for manufacturing companies to implement a fully circular process.

With the growing interest in the circular economy and the increase in research to analyze and rank what are the most pressing barriers preventing business to go to a fully circular economy, Govindan & Hasanagic (2018) have examined 60 papers in their study, where they have recognized 39 different barriers to developing a circular economy, where the main takeaways were government play a key role in the implementation of a circular economy into a certain industry due to its high costs, and that companies still seek profit before considering sustainable solutions.

A great number of the studies relating to 3D Printing and circular economy have identified the supply chain as one of the main barriers of companies trying to implement a fully circular process (Elia, Gnoni & Tornese, 2020; Govindan & Hasanagic, 2018; Grafström & Aasma, 2021; Jaeger & Upadhyay, 2020; Kumar et al. 2019; Lahane, Kant & Shankar, 2020; Rizos et al. 2016). Furthermore, knowledge and research connecting circular economy and different segments of the supply chain, as well as the stages within the supply chain barriers like recovery, that comprises the pre-treatment process of collecting the waste and having technology for indicating the quality of the material, and the preparation stage, where the cleaning and sorting process occur, are still insufficient or express different points of view (Cruz Sanchez, Boudaoud, Camargo & Pearce, 2020; Elia, Gnoni & Tornese, 2020).

The circular economy is still considered a recent topic, and although there are several studies identifying barriers related to the implementation of circular economy, the knowledge of which barriers are sufficient or are necessary to be overcome so businesses can go fully circular is still a gap in the current literature (Grafström & Aasma, 2021).

1.3 Aim of the study

The aim of this research is to cover the gap in theory discussed in the theoretical relevance chapter above, to provide more knowledge and insights on the supply chain barriers that companies from the entire value chain within the 3D Printing industry face and identifying if this barrier alone is sufficient to implement a fully circular economy (Cruz Sanchez et al. 2020; Grafström & Aasma, 2021).

Covering all the value chain within the 3D Printing industry was one of the main priorities in this research since companies in different positions in the value chain might face different challenges when discussing the same points. To cover this, the study explored the entire supply chain of the 3D Printing industry by interviewing decision-makers from SMEs that have the potential to implement a fully circular economy process in their business.

Furthermore, this study analyzed how the supply chain barriers are correlated to other barriers. In order to achieve that, semi-structured interviews utilizing an inductive approach to provide more freedom for the interviewees to elaborate on their answers were conducted, and for this reason, a more general category of barriers that are listed by Rizos et al. (2016) will be utilized. Based on these discussions, the following potential research questions were identified to contribute to the existing knowledge in this field of study:

How the supply chain barrier is impacting SMEs in the 3D Printing industry to migrate from a linear to a circular economy? Is it a stand-alone barrier or is it dependent on other barriers listed in the current literature?

1.4 Outline

The next chapter will introduce and discuss the theoretical framework regarding the circular economy, barriers for adopting a circular economy model, additive manufacturing in the SMEs context, additive manufacturing as a step to the circular economy, and recycled filaments. Chapter three discusses the methodology of grounded theory and semi-structured interviews that were used in this study, as well as the sample studied. Chapter four discusses the empirical findings and analysis utilizing 1st order concepts and 2nd order themes identified throughout the interviews. To conclude, chapter 5 presents the conclusion with practical and theoretical implications of this study, as well as describing the limitations and recommendations for future studies.

2. Theoretical framework

The following section will introduce a theoretical framework of circular economy and sustainability, barriers for adopting a circular economy model, additive manufacturing in the SMEs context, and additive manufacturing as a step into the circular economy. Moreover, this chapter aims to bring discussions on the relevance of additive manufacturing technology and circular economy concepts, and how barriers are affecting the adoption of this business model.

2.1 Circular economy and sustainability

After analyzing 114 articles and their definitions of circular economy, Kirchherr, Reike & Hekkert (2017) have defined circular economy as an economic system framework developed to replace the end-of-life product cycle by reducing, reusing, recycling, and recovering products from the supply chain. Still, according to Kirchherr, Reike & Hekkert (2017), the circular economy framework is designed to generate economic growth and social equity while maintaining sustainable and environmentally friendly development.

Authors like Reh (2013) and Zhu, Geng & Lai (2010) have described the 3Rs (reduce, reuse and recycle) as key practices used to achieve a sustainable process, therefore these frameworks can be considered a core element to the circular economy definition. An additional R that stands for Recover is also mentioned in other studies, bringing the 3Rs to 4Rs. Moreover, some theories even subdivide the word Reuse into the following: Repurpose, Resale, Repair, Refurbish, Remanufacture, and Resynthesize (Sihvonen & Ritola, 2015).

Sihvonen & Ritola (2015) consider that the R frameworks, that they refer to as ReX, are an alternative solution to end-of-life strategies, and it can help companies to identify the strategy that is in place and examine the product life cycle to improve its efforts towards a more robust circular economy.

As stated by Bocken, de Pauw, Bakker & van der Grinten (2016), the closed-loop business models and design strategies should be complementary and used side by side in order to drive companies from the linear to the circular economy. The idea to slow down the resources loop is to extend the life cycle and utilization of products, on the other hand, closing the resources loop would connect both post-use and production, as recycling for example (Bocker et al. 2016).

Reaching a profitable circular model is still one of the most challenging aspects of circular economy, as well as challenges like understanding the demand for recirculated products, keeping costs low for operating a circular economy business model, access to quality products for recirculation, and technological evolution speed (van Loon & van Wassenhove, 2020).

For this study, it was defined that the concept of circular economy from Bocken, de Pauw, Bakker & van der Grinten (2016) should be adopted, since it covers all the aspects from closing the loop and pos-use of materials like recycling, which is one of the main points discussed throughout this research, due to the potential of local recycling 3D Printing filaments.

2.2 Barriers for adopting a circular economy model

The benefits of a circular economy can be demonstrated in the improvement of resource allocation, reducing carbon emissions, and reducing the usage of natural resources in order that future generations' resources are not depleted. Although these benefits are important for the environmental welfare of our society, there are also barriers for businesses to adapt.

In this section, the barriers to implementing the circular economy model by SMEs, that were identified by Rizos et al. (2016) will be examined, as described in the introduction. The barriers discussed in this chapter are the following: Supply chain, technical know-how, financial, company environmental culture, government legislation, and administrative.

Supply chain barriers are described by Rizos et al. (2016), as the lack of support from the suppliers and consumers to reach a circular business model. This refers to the dependency of SMEs on their partners' and customers' ideals and will of engaging in eco-friendly and sustainable solutions. For a successful implementation of a circular economy, a good collaboration within the entire supply chain must happen. Similarly, Jaeger & Upadhyay

(2020) and Kumar et al. (2019) recognize that the lack of appropriate partners is a supply chain barrier to implement a circular economy.

Technical know-how is another barrier that can prevent SMEs from transitioning to a circular economy model. According to Rizos et al. (2016), changing from a linear business as usual to a circular economy will require additional know-how. Whether by bringing in consultants or hiring a full-time Safety Health and Environment manager who will be needed to fulfill the knowledge gap. Grafström & Aasma (2021) on the other hand, describes technical know-how as a sub-barrier from technological barriers, not a stand-alone barrier. On the positive side, they all discuss the same issues, on the lack of expertise and knowledge required to migrate the business to a circular economy.

Financial costs are also considered a barrier to the circular economy according to Rizos et al. (2016). By shifting from a linear to a circular business model, additional costs are involved, where SMEs will have substantial costs such as time and labor in keeping their businesses green. For example, waste products will need to be sorted and disposed of properly, and there will be additional administrative costs associated with maintaining environmental certifications such as ISO14001 or eco-label. SMEs are more sensitive to additional costs and labor than larger enterprises. Kumar et al. (2019) also have a similar approach to financial barriers and adds that the investment itself is not the only pressing point, but also the slow payback period also affects companies that are willing to adopt this business model.

The next most prevalent barrier according to Rizos et al. (2016) is the **company's environmental culture**. This can be referred to the philosophy of the company culture mainly the company owners attitude and willingness to accept in adapting company resources to a circular economy. Resistance to change by owners and managers may influence the attitude of employees to fall under the same conventional thinking and prevent environmental initiatives. Kirchherr, Piscicelli, Bour, Kostense-Smit, Muller, Huibrechtse-Truijens & Hekkert (2018) have a similar approach for the company's culture, however, they consider the lack of consumers' interest and awareness on the circular economy also a pressing barrier related to social aspects. Grafström & Aasma (2021) go even one step further and consider three levels of social barriers, such as managerial resistance, circular economy initiatives isolated from the main activity, and low engagement in the business strategy.

Government legislation barriers towards a circular economy according to Rizos et al. (2016) can be considered as the lack of support or lack of legislation from local authorities, and also the fact SMEs have a harder time complying with environmental legislation than do large corporations. Jaeger & Upadhyay (2020) have a similar line of thought and believe that governments lack legislation on how to properly dispose of the waste, and they should create proper guidelines and pressure the industries to follow the guidelines. For Grafström & Aasma (2021), a top-down, bottom-up approach needs to be taken in order to have the attention and engagement from all pillars of the supply chain.

Administrative barriers to a circular economy can be costly and complex, such as monitoring and reporting environmental data (Rizos et al. 2016). In many cases, SMEs need to report the same data as larger corporations, which have more resources available. Besides that, SMEs are also required to upload the same information to several different authorities, and not usually in the same format, which increases the need for external consultants and consequently costs. Similarly, Grafström & Aasma (2021) also discusses administrative issues regarding reporting corsets and bureaucratic management as barriers to the circular economy.

2.3 Additive manufacturing in SMEs

Additive manufacturing (AM) or better known as 3DPrinting, is a process of producing materials layer by layer using digital design CAD programs and has the potential of disrupting the traditional manufacturing methods. The technology has been around for some years, with some companies using it for rapid prototyping and tooling. The additive manufacturing technology covers several production methods and materials, the most common 3D printing technologies are fused deposition modeling (FDM), stereolithography (SLA), selective laser melting (SLM), selective laser sintering (SLS), digital light processing (DLP), electron beam melting (EBM) and laminated object manufacture (LOM) (Petrovic, Vicente Haro Gonzalez, Jordá Ferrando, Delgado Gordillo, Ramon Blasco Puchades & Portoles Grinan, 2011).

Studies from Rayna & Striukova (2020) validate how 3D printing technology can help entrepreneurs to overcome challenges related to new product development issues, technical issues, market issues, financial issues, and last but not least, business model issues. Challenges faced by entrepreneurs, and the advantage of 3D printing technology compared with other means of production, connect the dots between the technology advances and benefits with the issues and problems faced by entrepreneurs.

The four main fundamental usage types of this technology are rapid prototyping, rapid tooling, direct manufacturing, and local fabrication. According to Rayna & Striukova (2020) the first two types of usage prototyping and tooling are fairly common, however, direct and local manufacturing still need to be explored and exploited.

In direct manufacturing, new product development (NPD) can be processed by rapid prototyping and the final products can be printed rapidly on demand. As an example of the capabilities of AM and direct manufacturing, the world faced exponentially growing cases of Covid19 in 2020 as the pandemic quickly spread, infecting millions of people around the globe. Along with the pandemic, the medical and health sectors had faced a great challenge, the shortage of personal protective equipment (PPE) for frontline workers. The SMEs working within the AM community made the Makersvirus movement and rose to the challenge of producing much-needed PPE (Mueller et al. 2020).

Compared to direct manufacturing, home fabrication has further advantages that SMEs can take advantage of, such as the 3D design models that can also be offered for sale online. A 3D printing marketplace is a website where people can buy, sell, or share 3D printable files. Just like IT developers were in high demand in building applications for the mobile industry, local fabrication will create an opportunity for entrepreneurs, consumers, designers, architects, and engineers who will be in demand for new innovative products (Rayna & Striukova, 2020).

2.4 Additive manufacturing as a step into the circular economy

The circular economy aims to boldly change the current “take, make, waste” linear model, and improve the resource efficiency of eliminating waste. While studies have demonstrated that the additive manufacturing processes are promising for sustainability and contribution towards a circular economy, there is no guarantee that it will reach this goal (Despeisse, Baumers, Brown, Charnley, Ford, Garmulewicz, Knowles, Minshall, Mortara, Reed-Tsochas & Rowley, 2017).

Gebler, Uiterkamp & Visser (2014) have assessed in their study, the sustainability implications of 3D printing in a holistic manner addressing the global impact by 2025, both in qualitative and quantitative methods. 3D printing manufacturing is expected to mature within the next decade and the authors explored the financial and energy resources, which will decrease production costs and CO2 emissions. There seems to be unreliability whether the adoption of the circular economy model will be widely accepted and adopted in the 3D printing community, or that an alternative and less eco-friendly manner of using virgin polymers and components will take rise to consumer demands (Despeisse et al. 2017).

Moreover, the study of Gebler, Uiterkamp & Visser (2014) demonstrates the first comprehensive assessment on the global perspective by using qualitative assessment and quantifying the CO2 emissions globally by 2025. The authors have identified a low volume and high value of production of Aeroespacial and medical components in the manufacturing supply chain. The entire life cycle for these products shows the lower energy use, CO2 emissions, and changes in the labor demand, which shift to a more digital and localized supply chain.

The study shows the opportunity of cost savings of 170 to 593 billion dollars in the model, and reducing the CO2 emissions by 130 to 525 metric Tons by 2025. The energy and CO2 can be reduced by 5% by using 3D printing technology by 2025. Furthermore, if 3D printing was utilized in larger productions such as consumer goods or automotive manufacturing, then the theoretical potential of reducing CO2 emissions would be even greater.

The influence of 3D printing on sustainability is rather small due to the current small production of the additive manufacturing community in high-value Aeroespacial and medical components. However, 3D printing holds the potential of reducing energy demands and CO2 emissions once it is applied to a larger production, which would significantly raise the sustainability potential by producing locally as opposed to importing products.

2.4.1 Recyclable filaments

The evolution of additive manufacturing has contributed a new opportunity for the circular economy, where the idea of Distributed Recycling via Additive Manufacturing (DRAM) is utilizing the recycled materials by mechanical and chemical processes (Cruz Sanchez et al. 2020).

Studies have been conducted for recycling polypropylene blends with other types of plastics as a novel 3D printing feedstock according to Zander et al. (2018). As plastic consumption continues to grow and places a strain on the environment, the recycling rate remains stagnant at 5% in the US, out of 32 million tons that are generated each year. The authors discuss the need for more efficient reprocessing techniques to change consumer demands for plastics. The process of collection, sorting, and reprocessing polymers remains challenging, however, it does have the potential of being a low-cost sustainable feedstock for fused filament fabrication in manufacturing processes, as the authors explore in their study.

With the rapid growth of the 3D printing industry, the sustainability and environmental aspects of this business model has also evolved, having different types of solutions to recycle this material and create new filaments to print new products. As an example, Zander et al. (2018) have concluded that a blend of polymers can be a great way to re-use this type of materials and reduce plastic waste in a very cost-effective manner, and it is a great material for creating 3D printing filaments, since it presents more tensile strength than traditional low-end commercial filaments, like the HIPS for example.

3. Research methodology

The following chapter describes the features of a qualitative research method by describing the relationship between ontological and epistemological assumptions. By combining ontology, epistemology and performing a systematic approach to new concept development of the grounded theory methodology the paper aims to present ‘‘qualitative rigor’’ to present an inductive research (Gioia, Corley & Hamilton 2013). The study aims to give a holistic understanding of how knowledge was gained and provide support for the formation of the research paradigm (Bell et al. 2019). The following sections will discuss the research design, instruments, limitations to sampling data collection, and the analysis of the findings.

3.1 Research paradigm, epistemological and ontological assumptions

In order to develop a research paradigm, the research addresses the three basic questions. The ontological question of what is the nature of the "knowable" or what is the nature of reality? The epistemological question, how do you know something? The methodological question: how should the inquirer go about finding out the knowledge (Bell et al. 2019)? Thus the research explores how supply chain barriers affect SMEs, and if they are independent of other barriers.

The research adopts the pragmatist perspective in gaining knowledge for the research paradigm, "pragmatists believe that reality is constantly renegotiated, debated, interpreted," (Patel, 2015, p.1). Therefore the research will adopt this methodology. The grounded theory method was utilized in order to gain insight from industry experts regarding the barriers to a circular economy in the 3D printing technology field. According to Bell et al. (2019), the popularity of abductive reasoning in business research is associated with interpretive epistemology.

3.2 Research design

This exploratory study adopts a cross-sectional design in order to capture the variables in this qualitative research. The study explores the relationship between supply chain barriers and the concept of circular economy mentioned by Patwa et al. (2020) by examining multiple case studies and performing a semi-structured interview to capture the variables and find a causal relationship.

The authors set the framework of the study by analyzing the findings of the interviews recognizing supply chain barriers that affect sustainable development as mentioned by Patzelt

& Shepherd (2011) and the findings from utilizing the grounded methodology according to Gioia, Corley & Hamilton (2013) and expert opinions.

The findings from this research are to explore variables that would help conceptualize the barriers to a circular economy by using 3d printing technology. The study captures the conceptual framework of the supply chain barrier that is impacting SMEs in the 3D Printing industry to migrate from a linear to a circular economy.

3.3 Sample

According to Gebler, Uiterkamp & Visser (2014), 3D printed products are now shifting the centralized production process to local production, also changing the labor demand and energy usage. Despite the upsides of having a local production, the supply chain is still one of the main barriers faced by entrepreneurs, and 3D Printing businesses are having issues with the feedstock to reach a sustainable and circular business model (Peeters, Kiratli & Semeijn, 2019).

Considering the low flexibility and power of bargain of SMEs with their supply chain, which is one of the main factors why small and medium companies do not fully reach a circular economy by themselves (Rizos et al. 2016), and the fact that researches on the circular economy should evolve on other areas than what most studies cover, such as waste management, natural resources and environmental impact (Grafström & Aasma, 2021), the ideal sample for this study would cover the entire supply chain within the 3D Printing industry. This would enable this research to get insights and the main pain points from different SMEs working towards a circular economy.

To cover the entire supply chain of the 3D Printing industry, 5 groups were considered:

- 3D Printer Producers
- 3D Filament Producers
- 3D Ecommerce Shops
- 3D Print on Demand Companies

- Waste Management Companies

The reason behind this division is to gather insights and learn from each part of the supply chain, and potentially to find an optimal way that SMEs could reach a circular economy process in collaboration with their suppliers and business partners.

In the table below, there is a selection of companies in the 3D printing industry, representing each of the segments from the supply chain as described above. This selection of SMEs in the EMEA (Europe, Middle East, Africa) region is the base sample of this study, and all companies were contacted to participate in a video call to discuss the barriers to implement a circular economy into their business model, however, only six companies (highlighted in the table I) have demonstrated interest and agreed to participate in this study.

(Table I)

3D Printer Producers	3D Filament Producers	3D Ecommerce Shops	3D Print on Demand	Waste Management
Markforged Addifab Prusa 3D	Sculpteo BASF Ultrafusefff Filamentone Treed Filaments	Tridos Design 3D Prima Printmaker 3D	Proto21 3D Printing Shapeways 3D Hubs Shop 3D	Sysav Avfall Sverige FTI Stenarecycling

3.4 Data collection and analysis

The hybrid research instrument that this study utilized for the cross-sectional design is semi-structured interview and case study. Interview questions relating to supply chain barriers and circular economy will be conducted on subject matter experts. The questions were charted in the data structure to capture 1st order concepts, 2nd order themes, and aggregate dimensions to identify relations (Gioia, Corley & Hamilton 2013). Interview questions will be carefully formulated and piloted according to the protocol by Castillo-Montoya, M. (2016).

Six interviews with experts representing different segments of the value chain for the 3D Printing industry were conducted, as discussed in chapter 3.3. To keep the transparency of this study, Table II provides a clear view of who was interviewed, their title, the company they work for or own, and the segment they belong to.

(Table II)

Name	**Title**	**Company**	**Segment**
Brian Houle	Vice President EMEA	Markforged	3D Printer Producers
Lasse Staal	CEO and Co-Founder	Addifab	3D Printer Producers
Nicolas Mathian	Product Manager	Sculpteo BASF	3D Filament Producers
Mikus Upmalis	CEO and Founder	Tridos Design	3D Ecommerce Shops
Pir Arkam	CEO and Founder	Proto21 3D Printing	3D Print on Demand
Löfgren Olof	Business Development	Sysav Industri AB	Waste Management

As part of the data collection process, a semi-structured interview method was used. In order to cover the main barriers to reach a circular economy, this research has used a set of questions detailed in Appendix A. The questions were adapted from the research of Hanohov, & Baldacchino (2018) and Peeters, Kiratli & Semeijn (2019) to better reflect the main focus on the research question, where the questions were segregated into three segments.

The opening segment was created with personal level questions to break the ice and to learn more about the interviewees' backgrounds and experiences in the industry. This segment ends with an open question on barriers faced by SMEs to implement a circular economy. The second segment contains a set of questions with the main focus of gathering data on specific barriers described by Rizos et al. (2016). To close the interview, additional open questions about other barriers not mentioned during the interview and some questions on the motivation side of entrepreneurship were also asked.

For this study, the grounded theory was applied to demonstrate the dynamic relationships from the data structure to emerging concepts (Gehman, Glaser, Eisenhardt, Gioia, Langley & Corley, 2018). "Theory is a statement of concepts and their interrelationships that shows how and/or why a phenomenon occurs" (Corley & Gioia, 2011, p. 12). Gioia methodology is designed so that emerging theory emerges from the rooted data. Therefore, theoretical contributions arise new concepts and relationships among the concepts that will help explain the phenomena.

3.5 Limitations of methodology

Using case studies to build theory is gaining popularity and is a very important research strategy to form the basis of relevant studies (Eisenhardt & Graebner, 2007). Although case studies are becoming more popular, those types of studies also present certain limitations and challenges.

Eisenhardt & Graebner (2007) discusses several challenges and opportunities regarding the use of case studies to create new theories, like justifying why theory building is better suited for the research question in place than theory-testing research, size and quality of the sample chosen, dealing with interview data, presenting empirical data and writing the emergent theory.

In order to mitigate these challenges and collect both retrospective and real-time information by people experiencing the factors studied in the research question, the authors of this study have decided to utilize the semi-structured interview method with multiple data sources, which almost all great qualitative research use to guide a well-specified research question (Gioia, Corley & Hamilton, 2013).

4. Findings and analysis

In this chapter, the findings and analysis will be presented in detail. Firstly, an overview of the findings will be presented for each individual segment within the 3D Printing supply chain, since companies from different segments might have different opinions and challenges to each of the barriers. Secondly, the findings will be structured per aggregated dimension, and further discussed by second-order themes, where first-order concepts, direct quotes, and theoretical papers will be used to ground each argument or finding presented. Lastly, a comparison between second-order themes from different barriers will be presented to test if the supply chain barriers are dependent on other barriers.

4.1 Overview per supply chain segment

4.1.1 3D Printer producers

Brian Houle, the Vice President EMEA at Markforged, agrees that there are currently supply chain barriers for 3D companies to reach a fully circular economy, however, he has also pointed that a pandemic like the COVID-19 has also created opportunities for the 3D Printing industry, since the supply chain was completely affected by the lockdown, and local producers made use of 3D Printing technology to produce PPE items to help hospitals, doctors and patients.

The CEO and Co-Founder of Addifab, Lasse Staal, believes that supply chain barriers will depend on the requirements and the industry that the company is currently working in. Lasse gave us an example of the medical industry, where they have to be very careful when choosing the supplier since they must be 100% sure of what is the origin of the recycled material to ensure that it will be contaminant-free for safety reasons when utilizing that material.

Lasse Staal also sees technical know-how as a barrier to a circular economy. As an example, he mentioned that just using recycled materials to create prototypes does not guarantee that you’ll have a green product, you must also make sure that the manufacturers can also use this material for mass production. Addifab works combining 2 different types of technology, 3D Printing, and Injection Moulding, to ensure that companies will be able to reach mass production with the advantage of local production, but for that, he also needs to educate his customers, so they realize what is possible to do with this technology.

Brian Houle, just like Lasse Staal, believes that the technical know-how barrier is closely related to the awareness of the technology, and for that Markforged has created the Markforged University, where it provides a great variety of digital courses and training to teach its customers of what their products are capable of, and how it could further help their company to reach their goals with the assistance of the 3D Printing technology to print complex metal parts.

When discussing financial barriers, Lasse Staal agrees that there are in fact financial barriers holding entrepreneurs to go green. As an example, Lasse mentioned that although there is a growing trend of companies going green, many customers still prefer cheaper products, and that affects small businesses going green.

On the other hand, Brian from Markforged believes that financial aspects should not be a barrier for entrepreneurs. According to him, 3D Metal Printing technology itself is already reducing the use of metals towards a circular economy process, since CNC and other techniques have a great amount of waste. This also resonates with Gebler, Uiterkamp & Visser (2014), that state that 3D Printed products lower energy usage, CO_2 emissions, and labor demand.

4.1.2 3D filament producers

During the interview with Nicolas Mathian, it was stated that BASF, which is the world's largest chemical manufacturer, is fully embracing the circular economy and adopting green economic opportunities. A large corporation such as BASF has fully committed its management and resources to the circular economy as also stated on their website. For BASF, a Circular economy means separating growth from consumption. BASF will maintain the resources as long as possible, minimizing waste and creating value from waste (BASF, 2021).

When management is supporting and financing a circular economy, the company environment culture shifts to a sustainability approach from top-down.

Nicolas Mathian mentioned the administrative barrier facing producers of 3D filament is that recycled materials can be more costly than using virgin polymers because of traceability challenges with waste plastic sources. Nicolas mentioned that the traceability will be challenging in complying with European Union regulation Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH). It is possible to see from the value chain that if sorting the post-consumer waste into recycled plastic doesn't have the incentives from government legislation the recycled plastics will be more expensive than virgin polymers because of the sorting and administration cost associated with it. There needs to be an incentive for the recovery of waste plastic from the governmental legislation in order for the use of more recycled polymers versus virgin polymers.

4.1.3 3D Ecommerce shops

Mikus Upmalis, the CEO and Founder at Tridos Design, states that there are supply chain barriers for entrepreneurs that are aiming to reach a circular economy, additionally, he points out that the main difficulty for SMEs is the accessibility of certain recycled materials, as ABS plastics in his case.

Mikus Upmalis explained that he still does not use recycled ABS filaments, mainly because he could not find them available in the market, and he also reinforces the technical know-how barrier by explaining why it is so difficult to recycle ABS plastics. In his brief explanation, the ideal scenario would be to recycle the same types of plastics and also from the same brands, in order to have a more reliable filament. However, sorting out the types of plastics is already a big challenge, even more by brand, so people would need to recycle random filaments from different sources, which would require great know-how to sort everything and utilize the proper processes to recycle them and turn them into a reliable product.

When discussing financial barriers, Mikus Upmalis could provide his own example, as an entrepreneur facing financial barriers to close the loop to a circular economy process.

Although Mikus could not find recycled ABS filaments to produce his products, Mikus was challenging himself to change the plastic packaging of his products to cardboard or other materials that are biodegradable or easier to recycle. The problem with that is that the plastic options for packaging are way cheaper than eco-friendly alternatives, and that would affect the bottom line of his business, maybe even the feasibility of his projects.

4.1.4 3D Print on demand

During the interview with Pir Arkam, the CEO and Founder of Proto21 3D Printing, it was mentioned that he believes that the technical know-how barriers are the most impactful of the barriers, and he recognizes that entrepreneurs might face challenges to reach a circular economy. He used an example of how challenging the logistics to collect the materials that will be used to start the recycling process is.

From all the companies interviewed in this study, Proto21 3D Printing is the only one using recycled filaments to this day. Pir Arkam mentioned that he purchases all the recycled 3D Filaments from a company based in the UK, however, if he had to create this business model from scratch, also producing the filaments, the knowledge behind recycling those filaments would be crucial to close the loop to a circular economy.

Pir Arkam believes that financial barriers are a great deal for entrepreneurs. He states that in Proto21 3D Printing, they only use recycled materials, but he has several clients that are willing to pay extra for eco-friendly solutions, but he also recognizes that this is not the case for most of the customers and entrepreneurs over the world.

4.1.5 Waste management

To cover all the chain, Löfgren Olof, business development at Sysav, a waste management company in Malmö, Sweden was also interviewed. Covering a waste management company was crucial for this study since the main pain point identified was within the supply chain barrier, where most issues come from sorting out the material before recycling. Olof was kind enough to confirm that their main difficulty is sorting and cleaning the material before recycling and that each municipality still sorts the trash in their own way, making it more difficult for waste management companies like Sysav to sort all the material in a proper way for recycling.

Löfgren Olof stated that some plastics and metal components are not being recycled in Sysav facilities, but they sort out and clean the materials before sending them over to other companies who have the expertise to recycle them.

When it comes to the financial barriers, there were some different answers and thoughts from the interviewees on how they work out for entrepreneurs and their SMEs. For instance, Olof believes that virgin materials should cost more than recycled materials, so people could consume more from recycled instead of virgin materials, but unfortunately, it is still the other way around. Since there are many costs involved in recycling materials, such as all the logistics behind it, sorting, cleaning, and the recycling process, it is difficult to compete with the virgin material prices, so the prices from virgin material should change to impact the consumption behavior. In the same line of thought, Jaeger & Upadhyay (2020) believes that the price of raw materials should increase due to the scarcity of virgin material and resources.

During the interview with Löfgren Olof, the aim of the interview was to find out the government regulatory barriers in the recycling of post-consumer plastics in a waste management company.

Although Sweden is a global leader in waste management, with less than 1% going to landfill, a large portion of plastics still goes to waste-to-energy (WTE). The sorting of waste from the 14 different municipalities that Sysav operates is a point where government legislative barriers are evident. Olof explained that since Sysav is collecting from different municipalities that have different local ordinances, it makes the sorting of the plastics even more challenging. Thus the plastic that could have been recycled ends up in incineration for energy recovery.

4.2 Grounded theory analysis of barriers

This study utilized the grounded theory to establish 1st order concepts and then 2nd order themes from all the quotes and data points that were gathered through the interviews (Corley & Gioia, 2011). The study has analyzed the 2nd order themes in order to be able to compare the different segments of additive manufacturing. The study ranked the 2nd order themes by a number of data points and unique interviewees that discussed the topic. For some 2nd order themes that were tied in ranking, the authors discussed the topics and voted for the most impactful of the 2nd order themes.

4.2.1 Supply chain

Table III demonstrates the 2nd order themes from the supply chain barriers that were narrowed down to six categories: Supply chain partnership, local manufacturing, external challenges, the unreliability of supply chain, lack of companies to collect and sort waste, and sorting and cleaning challenges.

(Table III)

1st Order concepts	2nd Order themes	Aggregate dimension
Collaboration within the value chain of additive manufacturing and injection molding to introduce more recycled materials to production.	Supply chain partnership	Supply Chain Barriers
Collaborations and partnerships in the value chain are needed to improve recycling performance.		
Collaborations within the value chain to address the waste material to better qualified or better know-how companies to recycle that item.		
Good collaboration within the supply chain may benefit the exploration of recycled materials and the customer with a better product.		
Missing supply chain partner to collect and sort materials		
Partnerships along the supply chain can help to overcome challenges		
Risk management by choosing a specific supplier with a quality management system in place		
Supply chain partnership as a business asset for expanding to other locations		

The importance of creating partnerships in the supply chain to trust other companies.		
machines and materials for local manufacturing	Local manufacturing	
Rapid response in localized manufacturing		
External factors like covid have provided an additional interaction within the additive manufacturing industry by sharing designs so people could locally produce PPE for a faster response.	External challenges	
External factors like the covid can easily create obstacles in the supply chain.		
External factors like the covid have created opportunities for the additive manufacturing industry		
Supply chain challenges during external environment issues		
Little to no supply of local recycled quality filaments	Unreliability of supply chain	
Unreliability of supply chain		
Lack of companies on the 3D Printing supply chain to collect and sort the polymers for recycling.	Lack of companies to collect and sort waste	
No proper companies to collect and sort different types of materials for recycling.		
Some polymers are advertised as eco-friendly because they can be recycled, but when they end up in the landfill due to a lack in the collection and sorting services, it does not decompose.		
Quality of materials and processes of sorting and cleaning might affect other partners in the supply chain and the ability to recycle.	Sorting and cleaning challenges	
Sorting and cleaning waste material is still one of the biggest challenges in the recycling industry.		
Sorting trash is still challenging in developed countries like Sweden.		

Supply chain partnership was the most discussed theme regarding the supply chain barriers, gathering eleven data points during the interviews. When discussing the importance of partnerships among the supply chain during a pandemic situation, Brian Houle said *"(...) it was really about trying to help solve the challenges that we saw, you know, first responders facing, if you will, some of it like locally started with a partnership"* to illustrate the fast response that additive manufacturing and partnerships with that technology gave to the local community. This also resonates with Peeters, Kiratli & Semeijn (2019) that discusses the benefits of 3D Printing shortening the supply chain.

On the other hand, Mikus Upmalis have raised a relevant point *“(...) companies that provide us services, and like products, we can't really control them, how they ship, how they package or ship their goods”* when he implied that to create partnerships you must first create valuable connections and trust with other companies that they will handle all the production and shipping of your products correctly.

Still, on supply chain partnerships, Lasse Staal said *“(...) For that reason, people usually choose specific suppliers with quality management systems in place”* when discussing the risks of choosing the right partners, giving an example in the medical industry that involves the risks of having contaminants in the recycled material, impacting lives and the entire company.

When talking about the accessibility of recycled materials, Lasse Staal said *“We've been working with Danish recyclers, UK recyclers trying to get our hands in as many different recycled materials as we can (...)”* reinforcing the importance of partnerships with companies from different stages of the supply chain.

On the same line of thought, Löfgren Olof, when discussing the recycling process of polymers, stated *“(...) I don't believe we shred it right now, maybe some kind of shredding or packaging, and then we send it up to this Dutch company (...)”*, and also when discussing metal recycling *“(...) when we take something to our facility, we will sort it out and we will send it to another company, and they will crush it and reuse it”*, which confirms that even recycling companies tend to rely on partnerships with other institutions that have the better technical know-how to recycle a certain type of material.

Local manufacturing was the second theme most discussed in the supply chain barriers, with four data points. This theme generated a discussion around the potential of local manufacturing, which can be identified more as an enabler rather than a barrier in the supply chain. Pir Arkam talked about how his company has helped the local community during the Covid-19 outbreak, where he stated *“(...) we ended up producing facial masks and providing for them”*, which also implies that local manufacturing could be an enabler to produce eco-friendly PPEs since he only uses recycled materials to manufacture his products.

Brian Houle has shared a similar view given the interaction between his company and the pandemic scenario by saying *“I think that the spotlight that it puts on supply chain issues has also led to opportunities for the additive manufacturing industry”*, where local manufacturing provided a great response in manufacturing PPE for hospitals in need.

In the same way, Lasse Staal mentioned *“Our business model is to supply the machines and materials that people would use for that localized manufacturing”*, implying the potential of local manufacturing given that the focus of his company is related to that.

External challenges were also very discussed among the interviewees, gathering four data points, and are very much linked to the local manufacturing topic mentioned above. Pir Arkam, for example, has produced face masks for local police during the pandemic as said during the interview *“I made three different facial masks for the police because the China supply was closed”*, which brings the factor of countries closing borders even for trade during the Covid-19 outbreak. If that was the case where he had no raw material in his inventory or the borders to the UK, where he buys the recycled filaments were also closed, his company would not be able to produce the PPEs for the police.

Brian Houle has described a similar situation during the pandemic, where he said *“(...) as a hardware producer, we're certainly subject to the same types of challenges that our customers can face”*, which he further explains by saying *“We've had internally, especially during COVID, a few challenges with securing the raw materials for the filament production (...)”*. This reinforces that his company has suffered from external factors like the pandemic, just like Pir Arkam could have suffered if he did not have recycled filaments in stock or the supply from the UK was interrupted during the pandemic.

Unreliability of supply chain was also a point discussed during the interviews, where Pir Arkam mentioned *"I will agree that the supply chain of recycled material filaments are not common (...)"*, confirming that recycled filaments are not so common in the market nowadays, restricting the circular economy adoption within the 3D Printing industry.

Mikus Upmalis also confirms that by saying *"(...) for ABS, I really haven't seen any advertisements like oh, this filament is like 30% recycled"*, where he states that from his knowledge, there are no companies selling high quality recycled ABS polymers in the market, and this is why he does not use them, otherwise, he would be happy to do so.

When discussing how additive manufacturing can help companies, Brian Houle also admitted that the traditional supply chain can be a barrier to certain industries *"(...) very small things can adversely affect that supply chain, (...) we have seen from time to time disruptions in the supply chain that has impacted our ability to produce our 3d printers, you know, to secure even materials and in some cases"*.

Lack of companies to collect and sort waste was another important issue identified and discussed by Mikus Upmalis, as he stated the insufficiency of recycling companies in Latvia for example: *"I haven't seen any services that are available to makers like me, where you, for example, where you can send, like, certain material parts for recycling"*.

In addition to that, Mikus also described how he was trying to sort the polymers from mistakes and errors in his production line for proper treatment and recyclability, however, he realized that all his efforts were for nothing as he mentioned: *"There is like printing supports you basically have to throw away. For some time I was gathering them in separate boxes and sorting them, but then I realized there's no real way or place where I could hand those parts in. There's just no information, there's just no none of the big companies that are going to do the recycling, are going to bother with your few kilograms of plastic"*.

Even though systems are not yet in place as stated by Mikus, the European Commission in 2018 approved a plastic strategy as a means of achieving UN Sustainable Development Goals by transitioning towards a more circular economy (EU, 2020).

Sorting and cleaning challenges, just like the insufficiency of recycling companies to deal with waste management, is also a big barrier for industries implementing a fully circular business model. Löfgren Olof mentioned that: *"So I believe there's a challenge for the future, and also the cleanliness of the material, because even though Sweden is, I believe, in many senses, a bit ahead of other countries (...) you still find things within fractions that, you know, how did this garbage end up here? It's supposed to be paper, or it's supposed to be plastic, or are supposed to be metal."*.

In the European Union, the recycling of post-consumer plastic waste faces several regulatory barriers. The main barrier is lacking implementation of the waste hierarchy resulting in a large portion of post-consumer plastics waste ending up in incendiary facilities and landfills instead of being recycled (Duque-Ciceri, Fischer, Gama, Scheidt, Schäfer & Fischer, 2016).

Although companies are trying their best to collect and sort out their trash, Löfgren Olof mentioned that after sending out the trash sorted out to their final destination for recycling, e cleanliness of the products can still be a barrier for some companies or technologies to proceed with the recycling process, as he mentioned: *"(...) a lot of the things that we send to them are being rejected from them for the time being, they're not too happy with the quality and the cleanliness of the material, etc"*.

4.2.2 Technical know-how

Table IV demonstrates the 2nd order themes from the technical know-how barriers that were narrowed down to four categories: Technology relevance, challenges from production with recycled materials, lack of technology, and lack of knowledge.

(Table IV)

1st Order concepts	2nd Order themes	Aggregate dimension
3D Printing is not suitable to replace injection molding in mass production.	Technology	Technical

3D Printing technology is limited to production scalability when compared with injection molding.	relevance	Know-how Barriers
Challenges in technology and know-how to properly recycle different polymers and still assure the quality of the filaments and end products.		
Different manufacturing technologies are better for each individual scenario, depending on your needs and the parts requirements.		
New technologies and know-how are still necessary to make 3D Printing more competitive compared with injection molding.		
Technical know-how and technology are necessary to recycle polymers locally.		
Challenges of recycling different sort of polymers	Challenges from production with recycled materials	
Industries face challenges implementing more sustainable manufacturing patterns, where the prototyping phase must be aligned with the production phase so recycled materials can be used in both phases instead of only in prototyping.		
The quality of recycled materials can be tested in alternative methods without incurring big risks for the company by using comparative tooling.		
The quality of recycled materials might be an issue for the purpose of that polymer.		
Quality of the materials and knowledge on polymers to ensure the end result of the products are restricting the recyclable material usage.		
Lack of technology to automate the sorting and cleaning of the waste material before recycling.	Lack of technology	
lack of technology to manufacture quality recycled materials		
Lack of knowledge on the production processes and sources of materials may affect the performance of the company	Lack of knowledge	
Smaller companies may lack the knowledge and know-how on what types of polymers can be recycled or how to recycle them.		

Technology relevance was the most discussed theme around the technical know-how barriers to implementing circular economy, with six data points. These points brought some barriers, but also enablers into these discussions. Lasse Staal for example has discussed the applicability, potential, and limitations of additive manufacturing in becoming a green technology, where he stated: *"We quickly discovered that 3d printing as a production* *technology is limited by a very, very low selection of materials, and by an equally low scalability (...)"*.

With this statement, Lasse mentions that 3D Printing on its own is not the answer for scaling the production in a sustainable way, as he states: *"3d printing is not a technology that is suitable for replacing production capacity. You cannot expect 3d printers to produce the injection-molded components of this world"*.

However, injection molding is also not a good option for sustainable and green mass production, as Lasse Staal recognizes: *"Also if you want to create a more sustainable manufacturing pattern, you just need to think about reducing waste from injection molding because the amount of materials that are moved through injection road toolchains is 1000 times larger than 3d printing is doing"*. This led Lasse and his company to start combining 3D Printing with injection molding for better sustainable production processes.

Mikus Upmalis on the other hand sees great potential for 3D Printing as a local and sustainable source of production, but he recognizes that technology is still a barrier to local recycling 3D Printing filaments with good quality: *"Because those whole machines don't really provide neither the consistency not nor the quality, that's required for like, if you say if you're actually a company manufacturing products with 3d printing is going to be a problem"*.

Just like Mikus, Pir Arkam also sees great potential in local sustainable production, since he only uses recycled filaments from a company in the UK, and he also mentions another great potential technology to recycle plastic bottles: *"when it comes to material, (...) the UK is out there, and as I know, some companies here in Dubai (...) have a contract for recycling stuff in Dubai. So they reached me out, and I told them that, you know, you can invest and get a machine out, which can convert the plastic bottles into filaments, and use them for manufacturing stuff"*.

Challenges from production with recycled materials were very important in the discussions, and have gathered five data points during the interviews. Lasse Staal brought a great example within the medical industry, and the risks of using recycled materials that you are not secure of its origins and the difficulty of assuring it is contaminant free by saying: *“I mean, if you thought you were making your device and somebody, right out of a sudden add something to that, probably makes it behave differently in a biochemical level, then you're in trouble”*.

Mikus Upmalis for example works mainly with ABS polymers due to their resistance to temperature, so his products don't meltdown or deform whenever exposed to sunlight, however, he mentions that the main reasons he doesn’t introduce recycled materials to his production line are: *“ So I think, I think number one is materials. And number two is accessibility to recycle those materials”*. Furthermore, he explains the reason he believes is causing this current situation by saying: *“(...) ABS is not really well suited for recycling”*.

Also discussing the difficulty in assuring the quality of recycled materials, Löfgren Olof said: *“(...) depending on what you're trying to achieve, when you are doing a 3d printing, probably you might know this better, you would need in some cases, maybe better material”*, which implies that producing with recycled materials might add an extra barrier to the circular economy in case the company is aiming for precision and quality.

Lasse Staal also discusses that these challenges also extend to the prototyping phase, because the engineers must be able to recognize what type of material to use, how to work with it to create a functional prototype, and also check the applicability of this material for mass production. *“So in order to bring recycled materials into the product space, we needed to find a way to get them available for prototyping. But to ensure that manufacturers could work with them also for manufacturing, recyclers on one side want to get the materials into the hands of developers, developers want to get their products launched”*.

Lack of technology is another point that was brought up in the discussions. Mikus Upmalis for example considers that there is still not a good solution for people to recycle their own filaments at home, when he said: *“there's not enough high-quality devices out there that could enable us to do this”*, implying that if there was a good solution where he could recycle his own material and still have a high-quality filament, he would introduce that to his business.

Löfgren Olof spoke from the recycling companies' perspective, where he was able to visit the facilities from different partners recycling companies and realized that the processes are still lacking the technology to improve and speed the processes. *"(...) I met them once I was there seeing their facility, and it's a lot of sorting going on manually"*.

Lack of Knowledge was also mentioned during the interviews as a pressing point. When discussing the knowledge to recycle materials locally with new technologies, Mikus Upmalis mentioned: *"First of all, I don't know if nylon is properly recyclable"*, referring to his knowledge and ability to recycle his own waste. This could also be applied to other SMEs in the 3D Printing industry that does not have a material expert to deal with the processes or 3D Printer hobbyists that are willing to recycle their own waste to create new filaments.

Lasse Staal also reinforces that the lack of knowledge might be a great barrier to a circular economy and that it could bring negative results for your business. *"Because if you don't understand the processes, you will either end up having crossed a lot of barriers, and that will hit you as soon as you start wanting to test your device in the clinic. Or alternatively, you will launch a product in the market that has not been properly prepared. Both may end up with severely negative results"*.

4.2.3 Financial

Table V demonstrates the 2nd order themes from the financial barriers that were narrowed down to four categories: Premium price for green products, consumer behavior, patents restricting SMEs financially, and recycled materials risks vs costs.

(Table V)

1st Order concepts	2nd Order themes	Aggregate dimension
Customers usually do not see a financial barrier in adopting 3D Printing after seeing the benefits of the technology.	Premium price for green products	Financial Barriers

Recycled materials tend to be more expensive due to the technical know-how or the technology applied to recycle that material.		
Virgin stocks are more expensive than recycled or green products		
Consumer mindset and consumption behavior	Consumption behavior	
Nowadays, only limited consumers are willing to pay extra for green solutions.		
Patents in the 3D Printing industry, like metal 3D Printers, can restrict the growth and financial accessibility of the technology for SMEs.	Patents restricting SMES financially	
Contaminants in the recycled polymers may affect production and increase the costs for small local producers and affect the production line time frame.	Recycled materials risks vs costs	

Premium price for green products was the most debated theme for financial barriers, with five data points. Mikus Upmalis has raised a flag for how technology, technical know-how and efforts in recycling can raise the prices for sustainable products. *"Okay, we are taking this extra time and effort to try to figure out how to recycle these things. And that's why we're putting our know-how and that's why these things cost a little bit more than normal materials"*.

In the same way, Pir Arkam discusses that recycled products should cost less because the manufacturer is not spending money on the raw materials, however, it is not how things work, since there are all the costs related to collecting, sorting and recycling the materials. *"(...) it sounds that using recycled material, it's going to be cheaper because you're not paying for the material, but it's the other way around (...)"*.

On the other hand, Brian Houle considers that additive manufacturing on its own is already a great benefit for the circular economy, since it is saving virgin material compared to other means of production and reduces the carbon footprint by having a local production. So investing in this technology would already be the premium price barrier, but it should not be a problem for his clients when they see a clear ROI as he stated: *"You can do that in house quicker, more affordably and with reduced inventory, then that ROI can be pretty clear."*.

Mikus Upmalis have also discussed the fact that he is trying to replace his packaging with a more sustainable and eco-friendly solution, however, he states that the costs for doing that are still an issue: *"(...) there definitely are financial barriers on how to match non-plastic or more recycled goods, and they definitely cost more than their plastic counterparts. And that's a big issue"*.

Consumption behavior was the second most discussed theme in the financial barriers, which has gathered four data points. By discussing the adoption of circular economy processes, Lasse Staal has brought the consumer perspective into a very important barrier: *"But I think as long as consumers would prefer the cheaper product and consumers usually do, you're faced with a challenge of only a smaller portion of people being able to invest in going greener"*. This means that before implementing a circular economy, companies need to check the acceptance of those solutions among their targeted audience, and also to see if they would be willing to pay extra for those types of products.

Pir Arkam has a similar view as Lasse, and believes that most of the customers in the market are not willing to pay a premium price just for the fact that the product is more sustainable than the competition, as he mentioned: *"I mean, those are my clients when I tell them these stories, they appreciate it, and they can afford to pay for the environment. But the market won't"*.

This point is also backed up by Kumar et al. (2019) study, where they concluded that lack of awareness and understanding of the principles of the circular economy was considered as one of the main barriers.

Lasse also adds that the same applies to packaging, and governmental initiatives should be created to improve the consumption behavior of the population. *"For that reason, also, you need the right political incentives because if you don't have those, then people will not change their behavior. They will still buy the cheap packaging"*.

Patents restricting SMEs financially was a serious problem mentioned by Mikus Upmalis. During the interview, Mikus stated: *"So generally I feel like having metal printing is at a stage where expensive companies are using high, high precision printers successfully, like buying and stuff. And they're doing it very successfully, just because they can produce parts that are impossible to create otherwise, so they can reduce weight, reduce material waste and stuff"*, to describe that 3D Printing for manufacturing metal parts are still not as accessible as the plastic printers, and only companies with a larger budget can invest on them. This is a big barrier that patents bring to SMEs since they usually can not afford new technologies such as 3D metal printing.

Mikus has emphasized that it is the price point of patents that restrains the usage of those technologies by mentioning: *"But the good thing is that I think the patents on metal printing similar in style to SLS expired a few years ago. And I think there are quite a few up-and-coming proper 3d metal printing companies coming up that are allowing you to print in a similar style to SLS. And I think those are going to be a big game-changer."*, implying that new opportunities will emerge for SMEs in this industry to adopt the technology at an affordable price once the patents expire and new companies start manufacturing cheaper solutions.

Recycled materials risks vs costs is another important comparison that happened during the interviews. For example, Mikus Upmalis has stated: *"There's, first of all, there are contaminants that can block your nozzle. Every maintenance check that you have to do in your printers when something's not working, is costing you time and money. It's just a huge pain point"*. This sentence explains that the risks of using a recycled material that has not enough quality to deliver a good end product will cause financial damage to SMEs, where budgets are not so flexible compared to large corporations where they can afford to try new methods and materials without hurting themselves financially.

Lasse Staal when discussing an example in the medical industry has also stated: *"(...) it has a lot to do with risk analysis when you develop a medical device, you look at all the things that can go wrong. And getting material that is not what you thought it would be is a risk for* *everybody. (...) For that reason, people usually choose specific suppliers with quality management systems in place.”*. Besides the risks of putting people's lives in danger, this could also hurt a company financially, and this is the reason why companies should choose carefully their business partners as suppliers as was mentioned in the quality of recycled materials (Jaeger & Upadhyay, 2020).

4.2.4 Company environmental culture

Table VI demonstrates the 2nd order themes from the company environmental culture barriers that were narrowed down to four categories: Efforts going green, recycled materials usage, waste reduction, and efforts to recycle.

(Table VI)

1st Order concepts	2nd Order themes	Aggregate dimension
Bigger industries are committing in the long term to increase the usage of recycled materials in their products.	Efforts going green	Company Environmental Culture Barriers
The effort to implement recycled or green materials in products and packaging.		
Efforts to implement recycled materials or plastic alternatives in the products and packaging and other green technologies in the business.		
Efforts to implement recycled materials or plastic alternatives in the products and packaging.		
Efforts to reduce waste, building unnecessary inventory, and shipping products long distances		
Still no clear signs of a fully circular business in the 3D Printing industry, but companies are trying.		
The company still doesn't recycle filaments for quality standards but is willing to do so in the future.	Recycled materials usage	
Cooperation with other companies to implement the use of recycled materials in the production process		
To keep accuracy and quality, the company has still opted for using virgin instead of recycled materials.		

Usage of recycled filaments in the 3D Printing production line.		
Efforts on waste reduction and product lifecycle extension	Waste reduction	
Efforts on waste reduction and recycling		
Efforts on waste reduction through a new combined technology		
Private companies are working on communities to start local recycling centers and providing low investments for people interested in collecting, sorting, and recycling materials in those communities.	Efforts to recycle	
The recycling industry tries to use as much of the waste material as possible, but still a great part is burned.		

Efforts going green were the most discussed category by three of the six interviewees, Lasse Staal, Mikus Upmalis, and Pir Arkam had seven data points from the 1st order concepts. Bigger industries are committing a long-term strategy in using recycled materials in their products in efforts of going green. Lasse Staal stated: "*It means that we reduce waste in the development part of a product life cycle, it means that we provide manufacturers with access to materials that are either recycled or bio-based or a combination.".* Pir Arkam reflected on their company's efforts going green and stated that: "*So when again, when I look at producing it from solar panels, it might add a cost, you know, so that's another story (...)"*. He reflected about everyday tasks that he and his company could do in going green. Although there are still no clear signs of a fully circular business in the 3D Printing industry, Mikus Upmalis is dedicated to going green. Mikus states that: *"I've been putting a real emphasis on trying to get rid of any plastic packaging I have in my products. So that's been actually a tough, tough thing to do. Because like, it's super hard to replace a plastic bag that costs me half a cent with something that costs me 20 cents per unit."*.

Recycled materials usage was the second-ranked order theme discussed by Brian Houle, Lasse Staal, and Pir Arkam and had four data points. Although companies want to encourage going green the emerging theme is that companies want to keep accuracy and quality, the company has still opted for using virgin instead of recycled materials. Brian informed us that: *"because of the precision and uniqueness of our products, we decided from a very early stage that we want to ensure high reliability and accuracy for our customers and that we want to* *control the material processes as well (...)"*. The company does plan to use recycled materials in the future. In contrast, Pir Arkam informed us that for their printing operations of some forty 3D machines they do use recycled filaments: *"(...) from a company called filament of UK now this is the only company in the world right now. That is using industrial recycled plastic to produce those filaments"*. Similarly in the waste management segment cooperation with other companies to implement the use of recycled materials in the production process is taking place as Lasse has mentioned: *"We've been working with Danish recyclers, UK recyclers trying to get our hands in as many different recycled materials as we can, (...) So that's very much a part of what we do"*.

Waste Reduction is the third-ranked order theme and two interviewees Lasse Staal and Mikus Upmalis had four data points related to this category. In efforts to reduce waste during the product life cycle, companies need to provide the tools and convenience to achieve this. Lasse mentions that: "(...) *if you want to create a more sustainable manufacturing pattern, you just need to think about reducing waste from injection molding because the amount of materials that are moved through injection road toolchains is 1000 times larger than 3d printing is doing"*. This means that waste reduction is planned in the development part of a product life cycle, which the company can provide manufacturers with access to materials that are either recycled or bio-based such as PLA or a combination. Mikus' views on waste reduction are also aligned with Lars and he adds that: *"(...) the company culture is me and I'm for recycling wherever it's possible"*. He favors working with suppliers that are also conscious of needless waste and it upsets him when his suppliers are wasteful.

Efforts to recycle was the fourth-ranked order theme out of the eight 2nd order themes that were initially categorized. Löfgren Olof and Mikus Upmalis had two data points addressing their company's efforts to recycle. The recycling industry tries to use as much of the waste material as possible, but still, there is a large amount of waste that is transformed to energy by incineration. Olof said that in Sweden *"(...) we are actually reusing everything that we can, as much as we can also. So there are not so many, you know, materials that we don't try to reuse in some way"*. On the other hand, in Latvia, there are companies that are making efforts to recycle without having the infrastructure. Mikus mentioned that private companies are working on communities to start local recycling centers and providing low investments for people interested in collecting, sorting, and recycling materials in those communities.

4.2.5 Government legislation

In this segment government legislation had twenty-five data points making it the third relevant topic by the interviewees. Table VII demonstrates the 2nd order themes from the government legislation barriers that were narrowed down to four categories: Lack of legislation, government initiatives, and funding, recycling companies' dependency on governments, and government guidelines.

(Table VII)

1st Order concepts	2nd Order themes	Aggregate dimension
Clear rules and legislations would help the recycling industry	Lack of legislation	Government Legislation Barriers
Governmental legislation still needs to evolve to bring in more sustainability requirements to the manufacturing industry.		
Lack of legislation or governmental action on standardization of waste management		
Political action is imperative to change industrial and consumption behavior		
The political process is needed for a transformation in sustainable processes		
Stricter legislation should be put in place to punish people who are not sorting the trash properly.		
Change is driven by resources, and investments might be impacted by the lack of political initiatives to foster the industry.	Government Initiatives and Funding	
Governmental efforts to promote local additive manufacturers to help in covid times.		
Governmental funding is also a great tool to incentivize companies to go green.		
Governmental initiatives on 3D Printing and sustainability can bring great impact for manufacturers by empowering the local production on demand.		

Government legislation supporting and encouraging local manufacturers		
Government support 3D Printing technology		
Not enough government incentives for using recycled polymers		
Political actions have been playing an important role to make companies from different sectors like the Packaging and automotive industry commit to use more recycled materials in their products.		
Dependency of recycling companies on municipalities and governmental legislations.	Recycling companies' dependency on governments	
European Union is starting to push countries to sort trash		
Municipality and government decided the destination for the waste material to be recycled.	Government guidelines on recycling	

Lack of legislation was the top-ranked 2nd order theme in government legislation barriers with ten data points and three interviewees Brian Houle, Lasse Staal, and Löfgren Olof discussing the category. Governmental legislation still needs to evolve to bring in more sustainability requirements to the manufacturing industry. Brian stated that: *"(...) any government or legislative barriers are more about, you know, product certifications, and safety, compliance, (...)"*. While the US approach to legislation regarding sustainability is lacking, the European approach to legislation appears to be better aligned. Lasse stated: *"I think political action is an absolute imperative. We saw what happened in the US while they stepped away from the Paris Agreement. I mean, they went a lot blacker, just because the political pressures ceased to exist"*. Furthermore, Lasse mentioned: *"(...) You need to build the right incentives and the right incentives in order for industries to change their behavior, otherwise, nothing's going to happen"*. An example of how insufficient legislation affects local Swedish waste management companies is what Olof stated regarding local municipalities: *"(...) when it comes to recycling, I believe that a country let's say in the Swedish government if they would point out the direction and create rules. This is the way we want it, Buster, it would be easier for all the actors in the recycling industry also to adapt and to know how to do it. Now it's kind of fragmented (...)"*.

Government Initiatives and Funding was the next top-ranked 2nd order theme with eight data points and four out of six interviewees were Brian Houle, Lasse Staal, Nicolas Mathian, and Pir Arkam. Governmental initiatives for additive manufacturing and sustainability can bring great impact for manufacturers by empowering the local production on demand in fact a good example was the Diamond project mentioned by Brian: *"(...) one of our biggest successes from last year was a big initiative in the Midwest of the US a project called diamond, were leveraging some government initiative there to both empower (...) manufacturers and additive capabilities, but also was built in a way that will allow them to respond to future pandemics (...) Diamond, for example, even though the hardware has effectively been granted to all of these manufacturing companies if the state or the government needs to use those for different purposes, can effectively commandeer them for printing, ppe or whatever other you know, emergency response equipment is, is needed (...)"*.

In a different industry, Lasse stated that government initiatives and funding have been impactful in the energy industry and he stated: *"(...) wind turbine industry in Denmark has also been profiting a lot from Danish funding. I see the Danish government also putting in 25 billion DKK. (...) I mean, it's definitely setting up solid incentives for moving in a green duration"*. This statement is aligned with Govindan & Hasanagic (2018) that the government plays a key role in the implementation of a circular economy into a certain industry due to its high costs. Pir Arkam also agrees that government initiative was a driving factor for Dubai after China's supply chain got delayed and Pir's company received funding to produce three different masks for the police department. "(...) *So the government of Dubai is too much supporting the 3d printing strategy"*. On the other hand: *"(...) Not enough government incentives for using recycled polymers (...)"* was mentioned by Nicolas whose company makes 3D printed filaments.

Recycling companies' dependency on governments was the third-ranked 2nd order theme with three data points and two interviewees Löfgren Olof and Mikus Upmalis. As the European Union is mandating countries to sort out the trash there are local government municipality challenges that will need to be resolved. In discussion with Olof, he mentioned: *"(...) we are a company that is owned by 14 different municipalities in the southwest of Sweden, which makes things like this challenging in the way that we have admitted that we* *have to do certain things. And we are not like a normal commercial company. (...) we just have to go in the direction where the municipality says that this is what we need to do"*. Where else in the Baltic countries Mikus stated: "(...) *I haven't seen any push happening. So obviously, as of lately, since we're in a part of Europe, European Union there has been a push for sorting out the trash"*.

Government guidelines on recycling were tied with three other 2nd order themes that didn't make it to the final four. The researchers voted on this theme based on the discussions they had with the interviewees. There was one data point and one interviewee that discussed local municipality decisions for the waste material that was recognized as relevant. Olof mentioned that: *"(...) when it comes to the normal household plastics, it's this FTI collection that is going around in the different municipalities (...), you see those small green boxes in our municipality, where you collect paper, plastic, etc., they are actually the ones taking care of the plastic that never reaches us"*. The issue of having standard guidelines set by the federal government is apparent where each region manages their recycling a bit differently from other local municipalities thus creating challenges with sorting and recycling.

4.2.6 Administrative

In this segment, administrative barriers had eight data points out of 154 total data points making it the least talked about segment by the interviewees. Table VIII demonstrates the 2nd order themes from the Administrative barriers that were narrowed down to four categories: Material traceability and combined with EU REACH (EU, 2020), cultural resistance at the managerial level, and safety using virgin material.

(Table VIII)

1st Order concepts	2nd Order themes	Aggregate dimension
Waste material quality traceability challenge	Material traceability	Administrative Barriers

Cultural resistance in adopting new technologies or changing processes to get future better results	Cultural resistance at the managerial level	
Lack of acceptance of new procedure and technology		
EU REACH places the burden of proof on companies	EU REACH Impact	
Virgin stocks are still safer for producing certain items, this is why management should be challenged to change to sustainable and recyclable materials.	Safety using virgin material	

Material traceability and EU REACH Impact were the top-ranked 2nd order theme with five data points and Lasse Staal and Nicolas Mathian discussed the pain points of material traceability. The challenge of recycling polymers (plastics) is that in order to get a good quality filament you can't mix certain plastics together and it's important that you know the source of the waste polymers are non-toxic. Lasse informed us that *"(...) if we want to start implementing recycled plastics and medical devices for whatever type of fabrication, we need to be absolutely sure that we can trace the history back to the origins for some types of recycled materials (...)"*. On that note, he further elaborated that even if they are not sure about the history of the waste, what impact would that have on the device? He stated that: *"(...) there is a bit of analysis going on behind the scenes to ensure that we can answer all these questions"*. Nicolas also agrees with remarks made by Lasse that the main challenge of recycling polymers is the original source. He had concerns regarding the waste that is imported from non-EU countries regarding the origins and safety and stated: "*(...) EU REACH places the burden of proof on companies (...)"*.

Cultural resistance at the managerial level was the next top-ranked 2nd order theme with two data points and two interviewees Brian Houle and Pir Arkam discussing the challenges and resistance in adopting new technology or procedures from management. Brian agrees that there are barriers from the top-down as he stated: *"(...) we certainly see at a high levels (...) change is hard for everyone and particularly people who've made decisions and are often in a business position to try to defend those decisions, if you will, it's, it's not broke so why do we need to fix it (...)"*. Furthermore he added: *"(...) even if it can be more efficient, more* *cost-effective, more environmentally friendly, etc.., in general, people are often resistant to change"*. Certain industries are even more reluctant to change how they do things and he added that on the positive note, additive manufacturing is more open to change. Pir had similar discussions regarding purchasing new equipment that was better, faster, and more sustainable, however, management thought he was going too fast adopting new technology.

Safety using virgin material was the last ranked 2nd order theme with Lasse Staal giving discussions regarding the administrative barrier. Although recycled polymers are safe for producing materials, there is a mindset from management that there could be risks and safety issues using recycled materials. Lasse mentioned that: *"(...) virgin stocks are still safer for producing certain items, this is why management should be challenged to change to sustainable and recyclable materials (...)"*.

4.3 Correlation and dependence of barriers

For the correlation and dependence of the supply chain barriers to other barriers, an analysis of the second-order themes was conducted to verify any possible connection between the barriers, with quotes from the interviewees to back up the discussions. The criteria for this analysis was set to one or more connections found, categorizing the barrier as correlated and dependent.

4.3.1 Supply chain and technical know-how

After analyzing the first-order concepts and second-order themes from both supply chain and technical know-how barriers, a clear connection between those barriers was found. The first second-order theme with a clear connection was technology use for performance in the technical know-how barriers, with the (2nd order theme) from supply chain barriers. The idea behind this connection is that by using know-how and technical abilities, it is possible to disrupt supply chain issues, however, if no technical know-how is available in the SMEs, the entrepreneurs will have to rely on the traditional supply chain, which still has several challenges for implementing a fully circular economy.

To cover this connection, Brain Houle interestingly states: *"The standard process, if you will, for something inevitably breaks with machinery, so their customers have either had to maintain, you know, in some cases, warehouses of spare parts and such, or, or the, the vendors had to do that. And now with 3d printing, they can just put that printer on-site and print the spare or replacement parts on demand. So you think about the efficiency and the, you know, the inventory savings, inventory savings, the lack of waste, if you will, it really is changing the way that companies are manufacturing".* This clearly demonstrates that technology and know-how can enable companies to produce items locally and on-demand, reducing waste and risks from relying on the traditional supply chain.

The second connection found was technical know-how and new technologies with the second-order themes of local manufacturing and sorting and cleaning challenges. The rationale of this connection comes from new machines that enable SMEs and hobbyists working with 3D Printing to locally recycle filaments, optimizing the production line and reducing waste.

This point was mentioned during the interview with Mikus Upmalis, where he clearly mentioned this technology: *"for recycling, I think the next big challenge, so you basically have to shred the material back to pellet form, and then reshape it back to a filament form. And there have been definitely attempts at making such small devices that you can plunk at home that have a shredder that has a melting chamber, and that has the spooling mechanism. And they keep improving those things (...)".* Although promising, Mikus recognizes that this technology still needs to improve a lot so people can produce high-quality recycled filaments at home or for small-scale production in SMEs.

Similarly, Nicolas Mathian also states another new technology that has just been released to the market, called Chemcycling®. This technology is another great link from the technical know-how barriers with the second-order theme of sorting and cleaning challenges from the supply chain barriers.

During the interview Nicolas Mathian mentioned *“BASF is innovative in the process of recycling all plastics using chemcycling® and capturing the pyrolysis oil used for new polymers”*, meaning that this new technology allows companies to recycle plastics without the need of sorting the different types of plastics and reducing the efforts in sorting waste that is still considered one of the main challenges for recycling companies to this day.

4.3.2 Supply chain and financial

During the analysis of the financial barriers, a few links to the supply chain barriers were identified. The first point is brought up by Mikus Upmalis when discussing the usage of recycled filaments without high standards of quality, and the financial impact. During the interview Mikus has stated: *“First of all, there are contaminants that can block your nozzle. Every maintenance check that you have to do in your printers when something's not working, is costing you time and money. It's just a huge pain point”*. This statement clearly demonstrates a link of financial barriers to the supply line of recycled filaments and partnership with companies providing those products, which is linked to the second-order themes of the unreliability of supply chain and supply chain partnerships from the supply chain barriers aggregated dimension.

The second connection found was the link between the premium price for green and recycled products with the second-order themes of sorting and cleaning challenges from the supply chain barriers. This point was debated in multiple interviews, for example, Nicolas Mathian has stated that: *“It's expensive to buy Polyamide 12 compared to virgin stock”*, meaning that this component is a more sustainable material, and therefore has a premium price. Pir Arkam, when discussing the price of recycled materials and the challenges of recycling those materials has also stated that: *“(...) it sounds that using recycled material, it's going to be cheaper because you're not paying for the material, but it's the other way around (...)”*. Similarly, Mikus Upmalis makes a similar comment regarding the price and challenges of recycled materials *“(...) these things cost a little bit more than normal materials”*.

Another connection found was the financial impact in SMEs of patents in the 3D Printing industry and the local manufacturing second-order theme from the supply chain barriers. When discussing the patents' impact on SMEs, Mikus Upmalis stated: *"But the good thing is that I think the patents on metal printing in a similar style to SLS expired a few years ago. And I think there are quite a few up-and-coming proper 3d metal 3d printing companies coming up that are allowing you to print in a similar style to SLS. And I think those are going to be a big game-changer. I think the Markforged where they are now with the FDM style printers, where you can rebuild the I mean, put that thing in the oven and then wait for it to solidify and stuff. Those are like, as a stepping stone. But I think the big change is gonna happen when the actual affordable metal SLS versions arrive"*. This shows not only a connection with the financial accessibility impact for SMEs and local manufacturing, but it also connects with new technologies and technical know-how barriers.

4.3.3 Supply chain and company environmental culture

Continuing with the analysis of company environmental culture correlated with supply chain there is a clear correlation between the two barriers. For example, the top-ranked 2nd order theme in company environmental culture such as efforts going green and recycled materials usage can be connected with the 2nd order theme. Lasse Staal stated that: *"It means that we reduce waste in the development part of a product life cycle, it means that we provide manufacturers with access to materials that are either recycled or bio-based or a combination (...)",* which has similarity to the 2nd order theme Supply chain and 1st order concept collaborations and partnerships in the value chain are needed to improve the recycling performance. This means that companies such as Lasse's company are aware and striving to help their partners meet the European Union Corporate Social Responsibility (CSR) goals. Similarly, Mikus Upmalis said: *"I'm happy to see that I'm, for example, ordering a lot of parts from China. And, and I'm definitely happy to see when some of the companies use paper, like paper wraps instead of plastic wraps (...)"*. Although this is just a snapshot of the data source there are more examples in the data code which the study finds correlation evidence with efforts going green and supply chain partnership.

4.3.4 Supply chain and government legislation

During the analysis on the government legislation, the study had identified several links to the supply chain barriers. The most obvious correlation is the lack of government legislation in the 2nd order theme and the connection to supply chain partnership. For example, since government legislation is lacking or ambiguous companies have barriers that are interconnected. For example, Olof stated that: "*the plastics in our company are causing us a lot of problems. Due to the household waste, of course, we do not want to burn it, of course. So we try to collect all the plastics that we can (...)"*. The implication is that the 14 different municipalities sort their waste just different enough that it is challenging downstream to sort it out properly due to the lack of homogeneous federal legislation giving guidance on how this should be done.

Another 2nd order theme in government legislation that is also correlated with supply chain partnership was Government Initiatives and Funding. Lasse mentions this with the example of the Danish incentives for going green in the energy sector: *"I see the Danish government also putting in, I think it's 25 billion DKK. So that will be over 3 billion euro into green research lately. I mean, it's definitely setting up solid incentives for moving in a green duration",* and the importance of initiatives that have direct effects on the supply chain. The most interesting initiative was the government incentive during the Covid19 pandemic to get local producers to make PPE because of supply chain issues from China. Without government interventions and the 3D maker movement, the supply chain for PPEs could have been further delayed as was observed during the pandemic.

4.3.5 Supply chain and administrative

The last analysis on the administrative barriers didn't have as many data points as the other barriers, however, one correlation that was compelling: the 2nd order theme traceability barrier in administrative and the 2nd order theme lack of companies to collect and sort waste in the supply chain are interconnected. Lasse Staal stated: "(...) *for medical applications for* *food-grade applications, recyclers may be challenged, because they will have to demonstrate that they know the origin and the history of the materials that they supply. Otherwise, they cannot guarantee that they are free from contaminants or whatever"*, which has both administrative and Supply chain implications. Furthermore, management would prefer to take the high ground and use virgin polymers instead of taking the risks. In addition, when using recycled materials in the use of additive manufacturing the company is responsible to comply with the EU REACH mandate to ensure the protection of human health and the environment (Combes, Barratt & Balls, 2003). For this reason, mechanical recycling is cumbersome and challenging which drives the cost and impacts the supply chain as previously mentioned in the financial section.

5. Conclusion

This chapter concludes the main research findings on how supply chain barriers impact SMEs in the 3D Printing industry in implementing a circular economy model and the correlation of supply chain barriers to other barriers listed by Rizos et al. (2016). The conclusion is presented first as implications for practice, where the practical relevance outcomes within the 3D Printing industry and recycling industry are discussed, followed by the implications for theory, where theoretical relevance outcomes from circular economy and barriers to achieving circular economy are stated. Finally, the authors present the limitations of this study and provide a suggestion for future research on this topic.

5.1 Implications for practice

Several findings from this research have practical implications. The first implication regards that none of the companies interviewed have fully implemented a circular economy into their processes, indicating that even with the potential of additive manufacturing technology in sustainability perspectives, the market might still not be ready for its full implementation.

However, the limitations on the sample size should be considered in this scenario, and therefore, this should be further studied on a larger sample.

Another practical implication from this study is that even developed countries like Sweden, still have plenty of opportunities for improvements in the waste management and recycling processes, since a great amount of waste is still incinerated and transformed into energy instead of recycled. Furthermore, based on the interview with Löfgren Olof, it was possible to identify the need of companies pursuing a circular business model to gather lobbying efforts on government legislation. The ideal legislation should provide guidelines for a national homogeneous policy for sorting and cleaning the waste, which would increase not only the volume of material to be recycled but also the overall quality of the recycled end product.

A new variable has been unearthed while conducting the empirical evidence during the interview with Nicolas Mathian, the theory of using chemcycling®. Through this process, most plastic waste can be chemically broken down to pyrolysis oil, which can be processed into new virgin plastics. This is a very important milestone achieved by the chemical recycling industry, however, this process alone might not solve all the supply chain issues. For this reason, the private and public sectors need to work together to find solutions on how to spread this new technical know-how and technology to as many waste management hubs as possible, improving the chances of other SMEs to achieve a circular economy.

5.2 Implications for Theory

This study has evaluated the findings that support the existing theory regarding the circular economy as mentioned in the previous chapters, where studies in cleaning and sorting are still insufficient (Cruz Sanchez, Boudaoud, Camargo & Pearce, 2020; Elia, Gnoni & Tornese, 2020). The findings from this study revealed the theoretical transition from an open-loop system to a closed-loop system would require a methodological theory in transitioning waste materials to a virgin stock material. The study found the current system as insufficient in achieving a closed-loop system. The study found that although the waste material for recycling is getting sorted at the point of the collection there is an insufficient method of transitioning it to a true virgin stock material by using mechanical process therefore the waste gets outsourced or is used for waste to energy. Furthermore, there needs to be a change in consumer behavior as mentioned by subject matter experts and in theory, if consumers change their behavior on how they consume, use and dispose of products then there could be advancements in a circular path.

The next theoretical implication that this study achieved was to investigate the supply chain barriers with the five other barriers discussed in previous chapters in order to find out whether or not these barriers are connected or independent (Grafström & Aasma, 2021). The study found that there were correlations with different barriers affecting the supply chain. The study concluded that in order for the supply chain barrier to be resolved, other correlated barriers such as administrative or governmental for example should be addressed simultaneously.

Empirical evidence from interviewing Löfgren Olof from Sysav also suggests that waste management companies still have many issues to be resolved in order to sort, clean, and recycle materials, that are the core principle of the circular economy that are the 3Rs (Reh, 2013; Zhu, Geng & Lai, 2010), instead of incinerating the waste transforming it in waste to energy. In theory, based on our findings in closing the loop, the researchers suggest that waste management facilities could utilize the chemcycling® process and change their business model from collect, sort and incinerate to collect, process and produce all in one location.

5.3 Limitations of the study and future research

As mentioned in chapter three, this study also has limitations by utilizing the grounded theory and semi-structured interview methodology. The sample size of this study, as well as other qualitative papers, is not enough to draw conclusions for the entire industry, therefore a similar study utilizing a quantitative approach to test these findings with a larger sample is suggested.

The 3D Printing waste disposal is still a topic that needs to be further studied, comprising both the individual and the companies in this industry behavior in order to capture ways that the recycling process of those materials could be incentivized and facilitated (Peeters, Kiratli &

Semeijn, 2019). This also goes in line with what Mikus Upmalis, CEO of Tridos Design said during his interview, where he tried to separate the filaments to properly dispose of them, however, there were no good alternatives for disposing of them in his country or companies he could send the waste for proper recycling.

The study also found a novel recycling method Chemcycling® developed by BASF that could be the breakthrough technology to facilitate the waste management industry by closing the loop for waste plastics. Future research will be needed to determine whether municipality waste management facilities can also be producers of virgin stock polymers by incorporating the checmcycling® process.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this thesis.

References

BASF (2021), Circular Economy, Available online: https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy.html [Accessed 20 April 2021]

Bell, E., Bryman, A & Harley, B (2019) Business Research Methods, 5th edn, Oxford University Press.

Bocken, N. M. P., de Pauw, I., Bakker, C. & van der Grinten, B. (2016). Product Design and Business Model Strategies for a Circular Economy, *Journal of Industrial and Production Engineering*, vol. 33, no. 5, pp.308–320, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 2 April 2021]

Castillo-Montoya, M. (2016) Preparing for Interview Research: The interview protocol refinement framework, Qualitative Report, 21(5), pp. 811–831, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 5 April 2021]

Combes, R., Barratt, M. & Balls, M. (2003). An Overall Strategy for the Testing of Chemicals for Human Hazard and Risk Assessment under the EU REACH System, *ATLA Alternatives to Laboratory Animals*, [e-journal] vol. 31, no. 1, pp.7–19, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 May 2021]

Cruz Sanchez, F. A., Boudaoud, H., Camargo, M., & Pearce, J. M. (2020). Plastic Recycling in Additive Manufacturing: A systematic literature review and opportunities for the circular economy. *In Journal of Cleaner Production*, vol. 264, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021]

Despeisse, M., Baumers, M., Brown, P., Charnley, F., Ford, S. J., Garmulewicz, A., Knowles, S., Minshall, T. H. W., Mortara, L., Reed-Tsochas, F. P. & Rowley, J. (2017). Unlocking Value for a Circular Economy through 3D Printing: A research agenda, technological forecasting and social change, vol. 115, pp.75–84, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021]

Duque-Ciceri, N., Fischer, T., Gama, M., Scheidt, L., Schäfer, L. & Fischer, S. (2016). Regulatory Barriers for the Circular Economy Lessons from Ten Case Studies. Available online: https://www.technopolis-group.com/wp-content/uploads/2020/02/Regulatory-barriers-for-the-circular-economy.pdf [Accessed 20 February 2021]

Eisenhardt, K. M. & Graebner, M. E. (2007). Theory Building from Cases: Opportunities and challenges, *Academy of Management Journal*, vol. 50, no. 1, pp.25–32, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 4 March 2021]

Elia, V., Gnoni, M. G. & Tornese, F. (2020). Evaluating the Adoption of Circular Economy Practices in Industrial Supply Chains: An empirical analysis, *Journal of Cleaner Production*, vol. 273, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 11 May 2021]

EU (2015). User Guide To The SME Definition, Available online: https://ec.europa.eu/regional_policy/sources/conferences/state-aid/sme/smedefinitionguide_en.pdf [Accessed 15 May 2021]

EU (2020). Review No 04/2020: EU Action to Tackle the Issue of Plastic Waste, Available online: https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=55223 [Accessed 21 April 2021]

Garside, M. (2020). Materials: Global consumption growth rate by type 2050, *Statista*, Available online: https://www-statista-com.ludwig.lub.lu.se/statistics/1114860/global-consumption-growth-rate-selected-materials/ [Accessed 2 February 2021]

Gebler, M., Schoot Uiterkamp, A. J. M. & Visser, C. (2014). A Global Sustainability Perspective on 3D Printing Technologies, *Energy Policy*, [e-journal] vol. 74, pp.158–167, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 1 February 2021]

Gehman, J., Glaser, V. L., Eisenhardt, K. M., Gioia, D., Langley, A. & Corley, K. G. (2018). Finding Theory–Method Fit: A comparison of three qualitative approaches to theory building, *Journal of Management Inquiry*, [e-journal] vol. 27, no. 3, pp.284–300, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 13 May 2021]

Gioia, D. A., Corley, K. G. & Hamilton, A. L. (2013). Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia methodology, *Organizational Research Methods*, vol. 16, no. 1, pp.15–31, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 4 April 2021]

Govindan, K. & Hasanagic, M. (2018). A Systematic Review on Drivers, Barriers, and Practices towards Circular Economy: A supply chain perspective, *International Journal of Production Research*, vol. 56, no. 1–2, pp.278–311, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 18 May 2021]

Grafström, J. & Aasma, S. (2021). Breaking Circular Economy Barriers, *Journal of Cleaner Production*, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 8 May 2021]

Hanohov, R. & Baldacchino, L. (2018). Opportunity Recognition in Sustainable Entrepreneurship: An exploratory study, *International Journal of Entrepreneurial Behavior &*

Research, [e-journal] vol. 24, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 21 March 2021]

Jaeger, B. & Upadhyay, A. (2020). Understanding Barriers to Circular Economy: Cases from the manufacturing industry, *Journal of Enterprise Information Management*, vol. 33, no. 4, pp.729–745, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 8 May 2021]

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A. & Hekkert, M. (2018). Barriers to the Circular Economy: Evidence from the european union (EU), *Ecological Economics*, vol. 150, pp.264–272, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 19 May 2021]

Kirchherr, J., Reike, D. & Hekkert, M. (2017). Conceptualizing the Circular Economy: An analysis of 114 definitions, *Elsevier B.V.*,[e-journal], Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021]

Kumar, V., Sezersan, I., Garza-Reyes, J. A., Gonzalez, E. D. R. S. & AL-Shboul, M. A. (2019). Circular Economy in the Manufacturing Sector: Benefits, opportunities and barriers, *Management Decision*, vol. 57, no. 4, pp.1067–1086, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 8 May 2021]

Lacy, P., Long, J. & Spindler, W. (2020). The Circular Economy Handbook, *Palgrave Macmillan UK*, Available online: https://link-springer-com.ludwig.lub.lu.se/content/pdf/10.1057/978-1-349-95968-6.pdf [Accessed 21 February 2021]

Lahane, S., Kant, R. & Shankar, R. (2020). Circular Supply Chain Management: A state-of-art review and future opportunities, *Journal of Cleaner Production*, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 12 May 2021]

Moller, Di. P. F. (2020). Enhancement in Intelligent Manufacturing through Circular Economy, *IEEE*, Vol. 2020, pp.87–92, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021]

Mueller, T., Elkaseer, A., Charles, A., Fauth, J., Rabsch, D., Scholz, A., Marquardt, C., Nau, K. & Scholz, S. G. (2020). Eight Weeks Later-the Unprecedented Rise of 3D Printing During the COVID-19 Pandemic: A case study, lessons learned, and implications on the future of global decentralized manufacturing, *Applied Sciences (Switzerland)*, [e-journal] vol. 10, no. 12, pp.1–14, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 30 January 2021]

Patel, S. (2015). The research paradigm: Methodology, epistemology and ontology explained in simple language, Available online:

http://salmapatel.co.uk/academia/the-research-paradigm-methodology-epistemology-and-ontology-explained-in-simple-language/ [Accessed 21 February 2021]

Patwa, N., Seetharaman, A., Arora, A., Agrawal, R. & Mandalia, H. (2021). Circular Economy: Bridging the gap in sustainable manufacturing, *The Journal of Developing Areas*, vol. 55, no. 1, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021]

Patzelt, H. and Shepherd, D. A. (2011) Recognizing Opportunities for Sustainable Development, *Entrepreneurship Theory & Practice*, vol. 35, pp. 631–652, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 21 March 2021]

Peeters, B., Kiratli, N. & Semeijn, J. (2019). A Barrier Analysis for Distributed Recycling of 3D Printing Waste: Taking the maker movement perspective, *Journal of Cleaner Production*, [e-journal] vol. 241, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 3 April 2021]

Petrovic, V., Vicente Haro Gonzalez, J., Jordá Ferrando, O., Delgado Gordillo, J., Ramon Blasco Puchades, J., & Portoles Grinan, L. (2011). Additive Layered Manufacturing: Sectors of industrial application shown through case studies, *International Journal of Production Research*, vol. 49, pp. 1061–1079, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 21 February 2021]

Rayna, T. & Striukova, L. (2020). Assessing the Effect of 3D Printing Technologies on Entrepreneurship: An exploratory study, *Technological Forecasting and Social Change*, [e-journal] p.120483, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 31 January 2021]

Reh, L. (2013). Process Engineering in Circular Economy, *Particuology*, [e-journal] vol. 11, pp.119–133, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021].

Rizos, V., Behrens, A., van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M. & Topi, C. (2016). Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and enablers, *Sustainability (Switzerland)*, vol. 8, no. 11, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 11 March 2021]

Sihvonen, S. & Ritola, T. (2015). Conceptualizing ReX for Aggregating End-of-Life Strategies in Product Development, *Elsevier B.V.*, Vol. 29, 2015, pp. 639–644, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 21 February 2021]

Statista Research Department. (2021). Global 3D Printing Industry Market Size, *Statista*, Available online: https://www-statista-com.ludwig.lub.lu.se/statistics/315386/global-market-for-3d-printers/ [Accessed 2 February 2021]

Tiseo, I. (2021). Plastic Cumulative Production Globally 2050, *Statista*, Available online: https://www-statista-com.ludwig.lub.lu.se/statistics/1019758/plastics-production-volume-worldwide/ [Accessed 2 February 2021]

van Loon, P. & van Wassenhove, L. N. (2020). Transition to the Circular Economy: The story of four case companies, *International Journal of Production Research*, vol. 58, no. 11, pp.3415–3422, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021]

Zander, N. E., Gillan, M., Burckhard, Z. & Gardea, F. (2018). Recycled Polypropylene Blends as Novel 3D Printing Materials, *Elsevier B.V.*, [e-journal], Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 2 February 2021]

Zhu, Q., Geng, Y. & Lai, K. hung. (2010). Circular Economy Practices among Chinese Manufacturers Varying in Environmental: Oriented supply chain cooperation and the performance implications, *Journal of Environmental Management*, vol. 91, no. 6, pp.1324–1331, Available through: LUSEM Library website https://www.lusem.lu.se/library [Accessed 20 February 2021]

Appendix A: Figures I, II & III

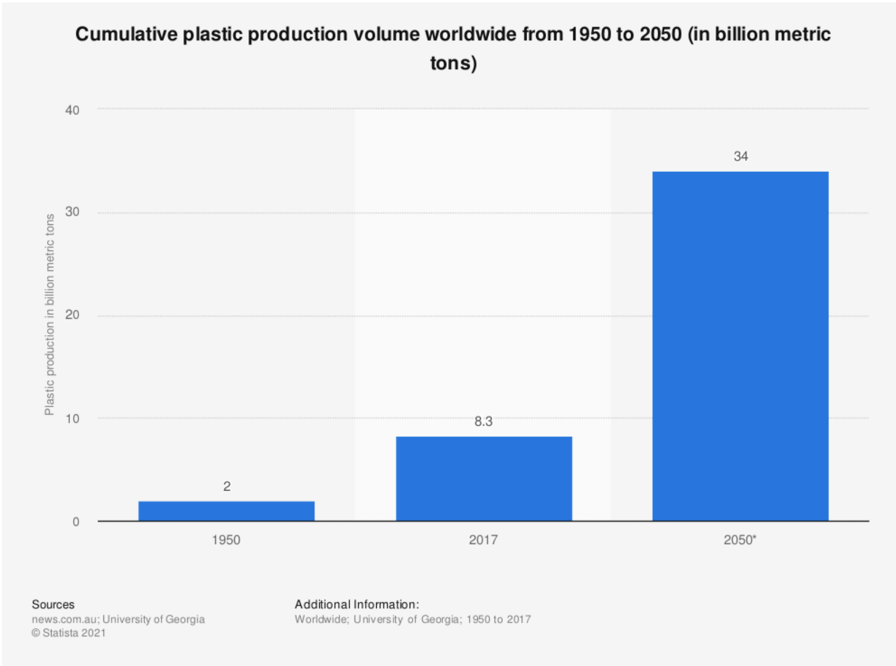

Figure I (Tiseo, 2021)

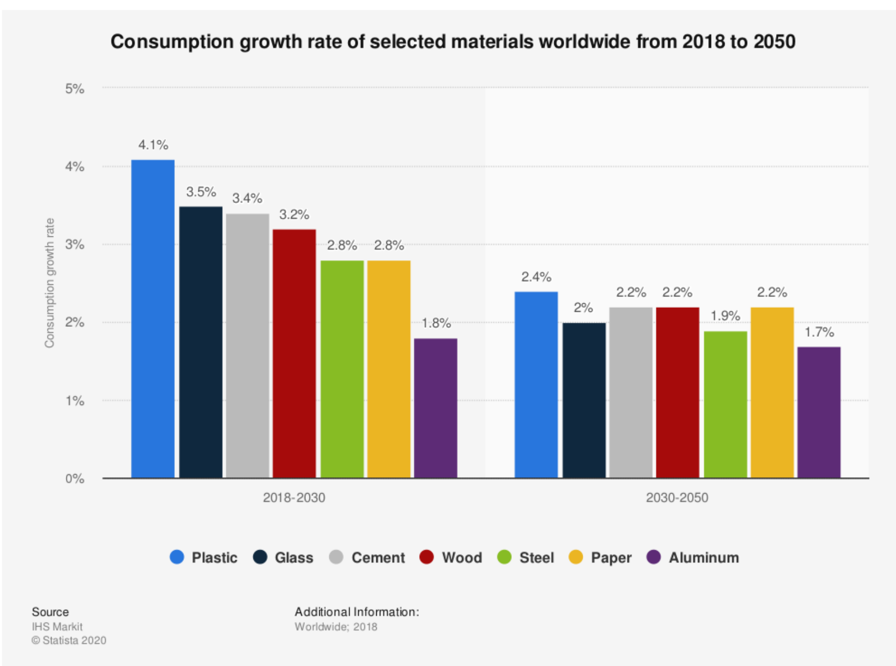

Figure II (Garside, 2020)

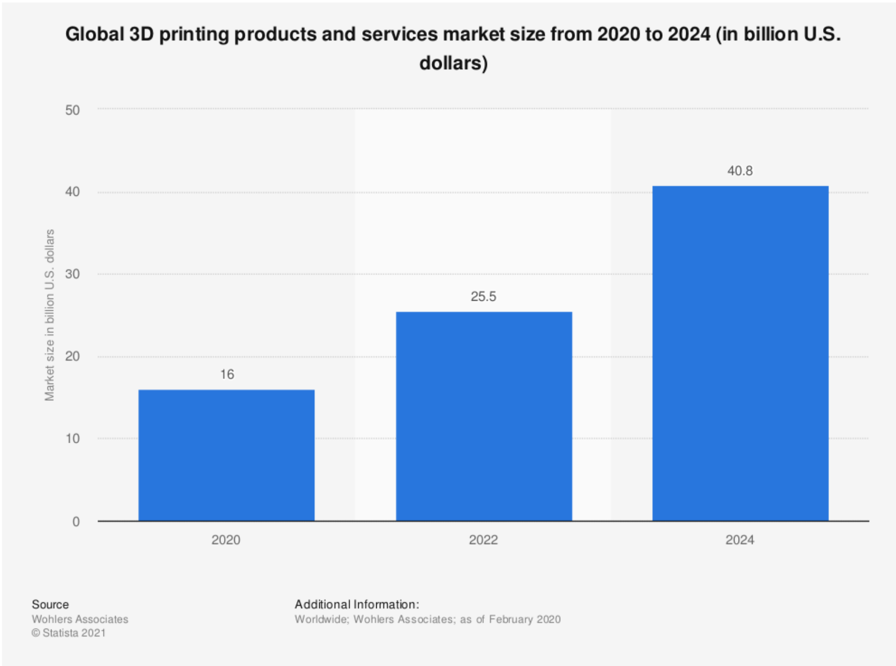

Figure III (Statista Research Department, 2021)

Appendix B: Semi-structured interview guide

<u>Opening segment</u>

1. Introduction of participants with background information on education and work experiences.
2. What is your current job and function?
3. Why did you choose to work in this field?
4. What does sustainability mean to you?
5. Do you consider yourself as a sustainable entrepreneur or working for a sustainable company? Why or why not?
6. In your opinion, which circumstances have contributed for you or your company to become sustainable?
7. Are you familiar with the term circular economy?

8. In your opinion, what benefits do you think a circular economy process brings to a company?
9. What are the main challenges companies face when reaching a circular economy?

Middle segment

Supply chain barriers:

10. Do you or your company have experienced any Supply Chain barriers to close the loop to a circular economy process?
11. If yes, what was the issue? Could you please provide us with more details?
12. What opportunities have you or your company discovered to overcome this barrier?
13. How have you recognized that opportunity?

Technical know-how barriers:

14. Do you or your company have experienced any technical know-how barriers to close the loop to a circular economy process?
15. If yes, what was the issue? Could you please provide us with more details?
16. What opportunities have you or your company discovered to overcome this barrier?
17. How have you recognized that opportunity?

Financial barriers:

18. Do you or your company have experienced any financial barriers to close the loop to a circular economy process?
19. If yes, what was the issue? Could you please provide us with more details?
20. What opportunities have you or your company discovered to overcome this barrier?
21. How have you recognized that opportunity?

Company environmental culture:

22. Do you or your company have experienced any environmental culture barriers to close the loop to a circular economy process?
23. If yes, what was the issue? Could you please provide us with more details?
24. What opportunities have you or your company discovered to overcome this barrier?

25. How have you recognized that opportunity?

Government legislation barriers:

26. Do you or your company have experienced any government legislation barriers to close the loop to a circular economy process?
27. If yes, what was the issue? Could you please provide us with more details?
28. What opportunities have you or your company discovered to overcome this barrier?
29. How have you recognized that opportunity?

Administrative barriers:

30. Do you or your company have experienced any administrative barriers to close the loop to a circular economy process?
31. If yes, what was the issue? Could you please provide us with more details?
32. What opportunities have you or your company discovered to overcome this barrier?
33. How have you recognized that opportunity?

<u>Closing segment</u>

34. Are there any additional barriers you or your company have identified?
35. If yes, what barrier? Could you please share more details with us?
36. Did awareness or knowledge on sustainability and circular economy have led you to recognize any of the opportunities mentioned in this interview?
37. Before becoming a sustainable entrepreneur or started to work for a sustainable company, were you in any way connected with the field where you have recognized this opportunity?
38. Have you felt responsible to act in this field to create benefits for other people than for yourself or for the company you work for?
39. What level of knowledge in this field did you have before working with this opportunity?

Appendix C: Interview quotes and grounded theory analysis

Since the interview quotes tables with the categorization of the 1st order concepts and 2nd order themes, plus the pivot table grouping them bu aggregated dimension and ranking are too large to be present here at the appendix, the authors of this study have create a Google Sheets file containing all the information that was used during the analysis of this study. The Google sheets can be found in the following link: https://docs.google.com/spreadsheets/d/11LrkqSpJEDfEh7MaSpR2Y9CEtnGfi8LDMwWmwUW0oFw/edit?usp=sharing