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Sustainable Supply Chain With 3D-Knit Technology For Ekornes AS and Devold of Norway

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Preface and acknowledgements

This thesis marks the end of a 2-year long journey of the Master of Science in logistics degree programme at Molde University College. The knowledge gained during these years has helped us grow tremendously as academics. We alone could not accomplish this master thesis without the help of the individuals working at the University college.

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Thank you to you Jessie for believing in my abilities and being a supporting soul.

Thank you to you Jonas for always being supporting, calm and encouraging to me to be a better human being.

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Abstract

The textile-based industry struggles with sustainable production, due to an industry wide overproduction, overconsumption, questionable cheap labour production and a focus on fast fashion trends. This thesis explores 3D knitting technology in the client companies (Ekornes AS and Devold of Norway) current supply chain, to gain integration of supply chain activities and increase sustainability in their production.

This thesis aims to explore how 3D knitting technology can enable changes in the supply chain, and sustainability improvement by switching from the traditional fabric manufacturing to 3D knitted garments. This research also explores how the technology helps to move from a linear to a circular economy and critically assess the potential supply chain challenges.

As the client company Ekornes had already started to explore this technology, a clinical management research approach was applied, to help guide them as researchers to figuring out the sustainability potential of the technology. Data were collected from interviews with professional from the two client companies. Supplemented with observation at Ekornes and an external 3D Knit lab in addition to email inquiries, web search and relevant document study.

Based on a clinical management methodology, this thesis builds on existing literature within Supply chain management topics and the connection to 3D Knit technology and aims to amplify and further develop the literature. A Practical approach of applying 3D Knit technology from a Supply chain perspective is attempted within Ekornes.

The findings of this study contribute to a mapping of the current supply chain and the challenges the client companies are facing when implementing 3D knit technology. Ekornes gets practical suggestions from this research on how they could maximise the potential of the technology. While, Devold of Norway established a subsidiary named Nansen by Devold, where this research suggests a potential approach for the company. The research found that the technology makes it possible to integrate supply chain activities, enabling a mass customization approach to the market. Some of the main barriers for technology adoption is the lack of education and stakeholder willingness to share data. However, the research suggests potential Circular business models for Ekornes and Nansen by Devold (subsidiary of Devold of Norway). The outcome of this thesis proves managerial implications and suggestions for future research on this topic.

Abbreviations

AM	Additive Manufacturing
B2B	Business – to – Business
B2C	Business – to - Customer
CE	Circular Economy
CEBMs	Circular Economy Business Models
CMR	Clinical Management Research
NRBV	Natural Resource – Based View
PLM	Product Lifecycle Management
RBV	Resource-Based View
SC	Supply Chain
SCM	Supply Chain Management
SLR	Systematic Literature Review
SME	Small and Medium sized Enterprises
TBL	Triple Bottom Line
VC	Value Chain

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1. Introduction

This chapter presents the background of this thesis along with the relevance of our clinical study. Additionally, the fundamental of the research, the research object and corresponding research question are clarified, along with the structure of the thesis.

1.1.Background of the thesis

The textile-based industry has over the decades faced major challenges and concern regarding sustainable production. These challenges occur from elevated demand and uncertainties from the supply side (Wen, Choi, and Chung 2019). The industry has a dynamically fluctuating trends and suppliers. The reason behind is the inefficacy to forecast what the consumers requires in advance of sales. Vaagen, Wallace, and Kaut (2011) states that the strategic behaviour of suppliers elaborates challenges as periodic establishment of inexpensive products, especially ideal/second-rated replacement. Hence, such strategy is called fast-consumption strategies to assure that the customers get several alternatives to purchase from. According to Vaagen and Wallace (2008), and Agrawal and Smith (2009), the mentioned challenges evolves into a tremendous overproduction. Additionally, the articles specify that the overproduction is present in approximately around 50% of the textile-based industry (Vaagen and Wallace 2008; Agrawal and Smith 2009). Vaagen (2022) stated that *"Resource (in)efficiency through overproduction and low resource utilisation -6% global average, with recycled textile-based products less than 1%- is one of the greatest challenges for sustainability."* As overproduction is the ingrain of the obstacle, Greenpeace International, Cobbing, and Vicaire (2017) features that circular economy declines to acknowledge overproduction. Different academically research points out different challenges that textile-based industry is facing, and one of the challenges that was emerged was lacked proactive attempt and theoretical knowledge to scale down the quality and growth rate (Vaagen 2022; Klepp 2015).

EU has made a strategy for sustainable and circular textile: *"EU consumption of textiles has, on average, the fourth highest impact in the environment and climate change, after food, housing and mobility. It is also the third highest area of consumption for water and land use, and fifth highest for the use of primary raw materials and greenhouse gas emissions."(European Comission 2022)* A consequence of the above-mentioned statement from the European Commission, they created "The Commission`s 2030 Vision for Textile" that is illustrated in Figure 1. This figure illustrates the objectives and actions that can elaborate to a sustainable and circular textile. Also, the EU`s Sustainable Product Policy program stated that the design decisions utilizes 80% of the environmental footprint (Vaagen 2022). However, the statement is confirmed by Vaagen, Kaut, and Wallace (2017) that increased level of environmental impact of design decision within plan and performance is recognizable.

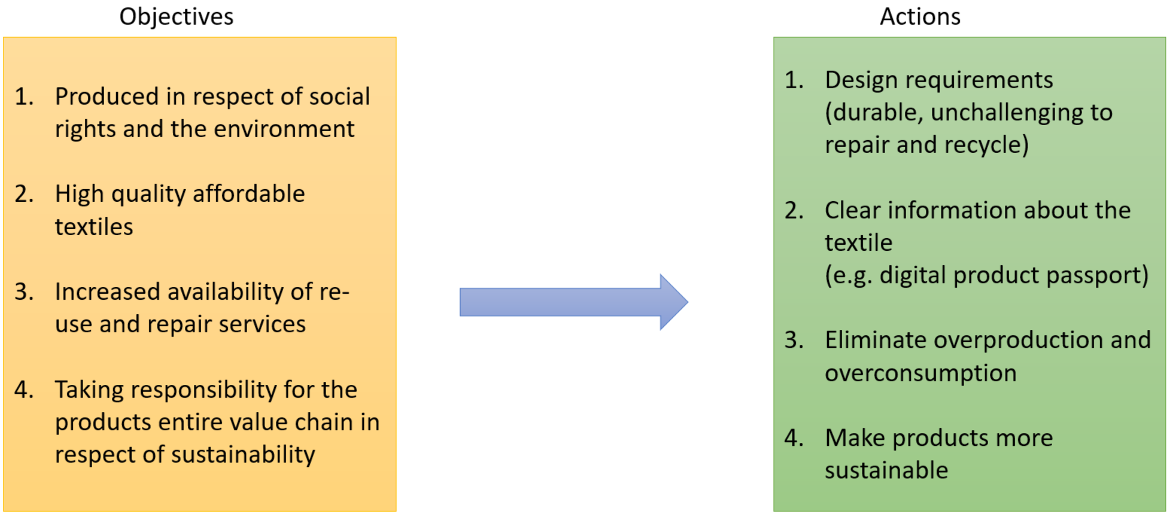


Figure 1 Objectives and actions to elaborate sustainability and circular textile. Adopted from European Commission (2022)

With the EUs Commissions actions in mind a feasible solution is adoption of an integrated 3D knitting technology approach. This kind of technology make it possible to connect links in the SC that traditionally could not be connected. For example, customers' needs can be transferred directly from customer to design and production seamlessly. This is with a prerequisite that the different links (actors) are willing to share information (Vaagen 2022).

3D Knitting technology enables the industry to move from a mass production approach and aims to provide mass customization and on-demand production instead. Additionally, the technology enables individuals to turn into co-designers for their desired products they want to purchase. This enables customers to have ownership to their products and not only be passive consumers. Supplementary, the technology lowers the utilization of raw materials that lead to "zero-waste" production and fast duplicability. Vaagen (2022) stated that the technology *"eliminated the manual-labour intensive step in furniture and textiles production, sewing (which has led to outsourced production), and enables reduced time-to-market (which is so important in consumer industries)."* A question that arises along with the arguments are how sustainable are these design innovations with such technology? Is such technology more sustainable compared to the current designs?

This thesis will focus on investigating a sustainability potential by utilizing innovative 3D Knitting technology design and production for Norwegian industry leaders Ekornes AS (furniture industry) and Devold of Norway (textile/apparel industry). The main features of the technology are virtual design potentials, product life-cycle management that is driven by data and computerized 3D manufacturing. This can be applied to wearables, interior, and other applications.

1.2. Applied research and the client companies

To clarify what this research/thesis contributes to, an understanding of the difference between basic research and applied research is established (Fomunyam 2020). Cherry (2020) states that basic research finds a topic based on scientific knowledge, to increase the knowledge in a broader picture around a particular topic. In contrast, applied research goes into depth toward solving a particular problem. Hence, Cherry (2020) states that basic and applied research are closely intertwined regarding *"the information learned from basic research often builds the basis on which applied research is formed."*(Cherry 2020) The study reported in this thesis can be classified as applied research, because it tries to solve a problem for two companies (Ekornes AS and Devold of Norway). Therefore, with help of applied research approach, this thesis answers the specific questions related to a practical problem presented by the two companies (Fomunyam ; Hedrick, Bickman, and Rog 1993).

Utilizing applied research in this thesis, a focus has been on two separate firms. According to Karlsson (2016), when a research project involves an organization that seeks a solution to a specific problem, the organization becomes a "client" to the researcher(s) addressing the problem. Thus, in the remainder of this thesis we will refer to Ekornes AS and Devold of Norway as the "client companies" who want to explore how 3D Knit technology drives changes in their Supply Chain. Specifically, to get an overview of critical aspects and challenges involved of how they can achieve sustainable industrial advantages in a supply chain and system perspective.

1.3.The client companies

Ekornes AS, one of the largest furniture producers in Norway (Trondstad 2019) produces brand names such as Ekornes®, Stressless®, Svane® and IMG. Established in 1934, with 3 employees and one machine the company now has expanded to 10 factories, making it a vast enterprise (Ekornes 2022a). Half of these factories are located outside of Norway, with two in Vietnam, and one in Lithuania, Thailand and USA. The one in USA is an assembly plant basing production on components from Norway to reduce lead time for customers. In Norway, one factory is producing beds in Fetsund outside of Lillestrøm. But the most well-known brand name Stressless® is produced in 4 out of 5 of the Norwegian factories. Two of the Stressless® factories are producing Stressless® components, while the remaining two focus on finished goods. These last two factories are further divided where one is focusing on reclining and dining chairs, while the other is focusing on sofas. During this research the focus will be on the factory located at Ikornes in Sykkelven, producing the reclining and dining chairs. This factory is supported by access to both sea and land transport, where ships load finished goods 3 times a week, destined to harbours such as Rotterdam and Hamburg. Trucks leaving the factory making transport locally from the supporting component factories as well as on a national basis. According to Ekornes, their passion is innovation and sustainable thinking, to achieve comfort in their products. This is attained through constantly looking to develop optimal patterns of smart functionality and to have attractive design (Ekornes 2022b).

Ekornes has also started to explore the 3D knitting technology, along with the traditional way of producing the cover on the stressless dining chairs. They have also launched their first 3D-knitted dining chairs at Møbelringen. The prototypes they have produced is illustrated in Appendix C.

The other client company presented in this thesis is Devold of Norway. Ole Andres Devold established the company in 1853, and is one of the oldest textile companies in Norway (Tobiasson 2020). The company has a more decentralized structure, where the headquarter is in Langevåg, Ålesund. Design in Skøyen, Oslo and production in Panevezyz in Lithuania. The office in Oslo mainly produces drawings and designs for new collections. While in Langevåg, further developments are made to the drawings to make patterns for the knitting machines. This process is based on vector drawings from design and cutting patterns. Here recipes for handling the garment, what accessories are necessary, yarn type to use and colours for each product is determined. All this information is put into a PLM system, that production workers have access to. The production factory (UAB Devold) processes several product groups, including knitted sweaters that will be the chosen product group the of this thesis. These are more costly than comparable brands, as Devold has a goal of producing high quality garments. Having a retail price of NOK1000-2000 also qualifies the garment as a part of luxury products, but according to Devold, the consumer makes a bond with their product, compared to cheaper alternatives. Devold of Norway informed us that the 3D-knitting machine would be used by their subsidiary company called Nansen by Devold (Devold of Norway Interview 1 2022).

2. Research objective – and questions

2.1. Research objective

As this thesis is based on an applied research approach, the research problem is based on the needs of the client companies. Where the companies are requesting what impacts the technology may have on their current supply chain structure and the coherent challenges. The sustainable advantages they can gain by implementing 3D Knit technology and if this type of technology is enough to move from a linear towards a circular economy.

Overall, this thesis aims to explore how 3D knitting technology can enable sustainable design-production. Based on a clinical management methodology, a systematic literature review approach to the technology and supporting relevant theoretical literature, the goal is to suggest a potential approach for the clients.

2.2. Research questions

Based on the thesis objectives, the three research questions were formulated. These questions would guide the thesis to collect the information that is required to understand the challenges of the client companies, and further come up with relevant suggestions.

RQ1: How would the traditional supply chain be affected by the implementation of 3D knitting technology?

The first research question would help the thesis to identify the current SC, and how implementation of 3D knitting technology would affect Ekornes and Devold`s current SC.

This research question aims in finding out if such implementation would affect the client companies` current stakeholders.

RQ2: What barriers would the companies face when implementing 3D- knit technology compared with the traditional supply chain?

The second research question contributes to compare the current SC against the SC with 3D knitting technologies. Which barriers and drivers arise by implementing such technology. It is more profitable for the company to implement the technology or is it better for them to have the current production process.

RQ3: How can 3D knitting technology help Ekornes and Devold move from a linear economy towards circular economy?

Sustainability is a focus area for many companies, along with Ekornes and Devold. Today both companies use linear approach. Would an implementation of 3D knitting technology help the client companies to move towards the circular approach? In addition, this thesis suggests (some) approaches that can be applicable for the client companies' production.

The following research questions in figure 2 provides the clear restrictions to our approach.

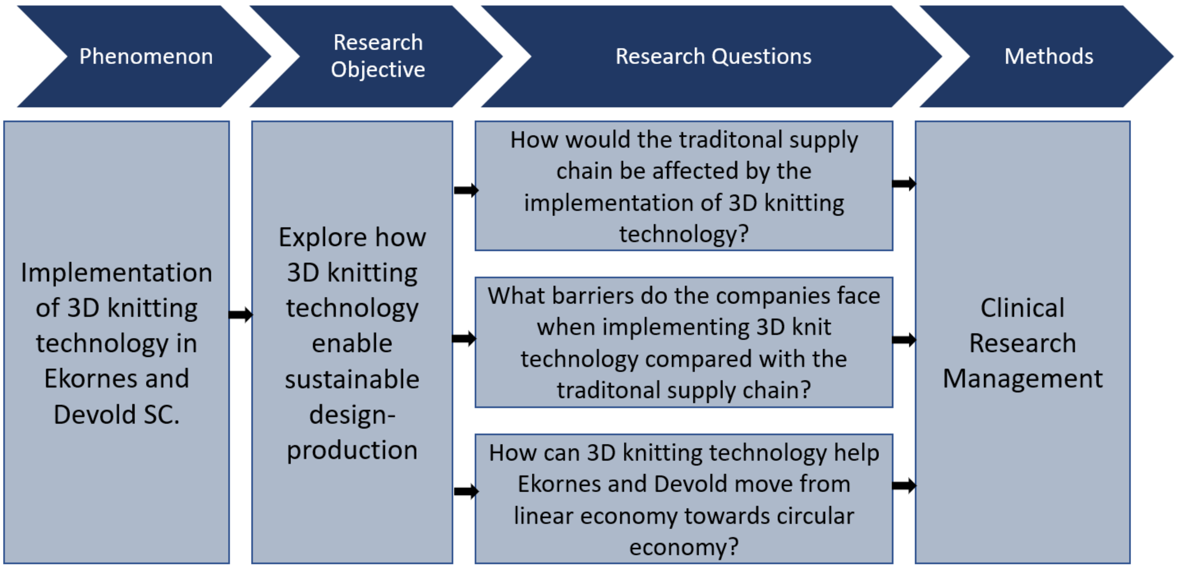


Figure 2 Overview of the research approach. Adopted from Petersen (2017).

2.3. Structure of the Thesis

The thesis is organized into eight chapters: introduction, literature review, methodology, findings and analysis, discussion, conclusion, references, and appendices. Hence, each of the chapters contain corresponding subchapters. However, the thesis includes two companies with the same project and technology. The factor that differs the companies is the industry type, since Ekornes is a furniture industry and Devold is a textile industry. Additionally, the output would be two different transfer variables. As a result, the thesis has increased number of pages.

Chapter 1 lays the foundation on what the thesis involves. *Chapter 2* presents the existing literature, acknowledge relevant concepts and gaps. The chapter is divided into two sub-chapters, background of the field and SLR. *Chapter 3* describes the research methodology and reasoning of our chosen methodology. *Chapter 4* presents the findings deriving from conducted interviews with the clinical companies, observations, e-mail inquiries, and documents. *Chapter 5* contains a discussion of the finding form the data collection in chapter 4, comparing it with relevant review before proposing suggestions. Lastly, *Chapter 6* conducts the conclusion, managerial implications, and limitation(s) along with suggestion for future research. Figure 3 illustrates the structure, including the introduction. A large, printable version can be found in appendix D.

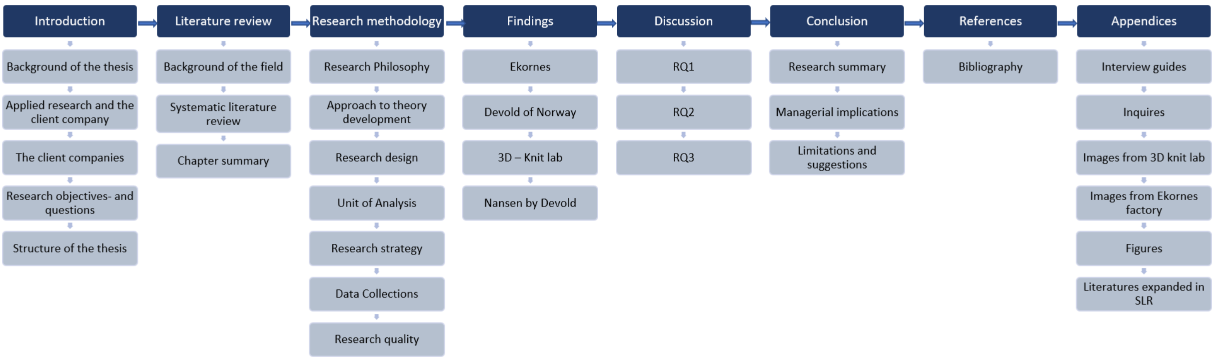


Figure 3 A holistic overview of the structure in the thesis.

3. Literature review

This chapter is divided into two sections, where the first part includes literature that indicates the background of the field. The second part include a systematic literature review for 3D-knit technology. Both sections are illustrated in figure 4. (A large, printable version can be found in appendix D.) Further, following recent scholarly works of Mahood, Van Eerd, and Irvin (2014), both sections will include peer reviewed publications and grey literature. Recent studies show that including grey literature in the research can enable broader scope to more relevant studies. This again can give a more complete view of what kind of evidence that are available.

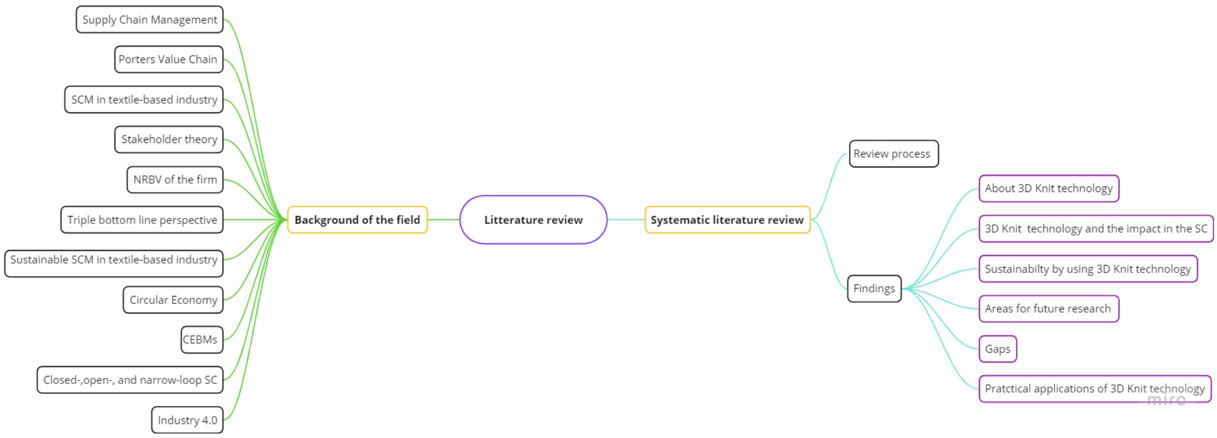


Figure 4 Overview of the different sections in the literature review.

3.1.Background of the field

This sub-section contains literature review on different topics regarding supply chain management, the current situation of the textile-based industry, the sustainability potentials within the field, and the 3D Knit's relevancy as an industry 4.0 technology.

Academic search engines such as Google Scholar and Oria are used to cover the existing literature regarding background of the field. Since the two previously mentioned companies differ from each other, it was found necessary to use several search words. To cover significant number of researches within the industry, search words such as textile-based industry, consumer-based industry, consumer businesses, furniture industry, textile industry, and fashion industry where used. However, the clinical study reviled that textile-based industry is the most collective concept and relevant term to use during the literature review.

3.1.1. Supply Chain Management

Supply Chain Management (SCM) has become more scientific in nature and a term that numerous companies are seeking more knowledge about (Mentzer et al. 2001). SCM was first introduced in the 1980s, and later became an attractive term for many researchers. Today it is difficult to find any periodical within distribution, customer relationship, suppliers, or transportation without getting into articles regarding SCM (Douglas M. Lambert and Cooper 2000; Hugos 2018; Mentzer et al. 2001). Since the day SCM was introduced, academics have aimed to give a composition to what SCM is. Some definitions are shown in table 1.

Table 1 Various SCM definitions in the literature.

Author	Definition
Mentzer et al. (2001, 18)	*"the systemic, strategic coordination of the individual business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as whole."*
Douglas M Lambert, Cooper, and Pagh (1998)	"*integration of key business processes from end user though original suppliers that provides products, services, and information that add value for customers and other stakeholders.*"
Croxton et al. (2001)	"*is being recognized as the management of key business processes across the network of organizations that comprise the supply chain.*"
Mangan and Lalwani (2016)	"*the management, across and within a network of upstream and downstream organizations, of both relationships and flows of material, information, and resources. The purposes of SCM are to create value, enhance efficiency and satisfy customers."*

Based on the definitions given by Mentzer et al. (2001); Douglas M Lambert, Cooper, and Pagh (1998); Croxton et al. (2001) and Mangan and Lalwani (2016), this thesis defines SCM as a strategic collaboration in key business processes across a network of individual business functions, within or outside of the focal firm, both upstream and downstream. Where the flow of materials, information and resources create value to the involved stakeholders and produces long term improvements to the supply chain as a whole.

The explanation about SCM provides the readers a principle understanding of SCM. The review of SCM lays the foundation of the literature review. In addition, it proposes the advantages by mapping the companies supply chain. It will be relevant to see how supply chain adapt new technologies and how changes affect the composition of the SCM.

3.1.2. The value chain

The supply chain is somewhat of an extension of the value chain and according to Christopher (2016) there has been done significant work to gain access to strategies that gives businesses significant competitive advantage over the last three decades. This is largely credited to Harvard Business school professor, Michael Porter, who brought up different focus areas to gain competitive advantages in a business environment. He was also the pioneer for the term, "value chain", which has been widely adopted by scholars as a basis to understand where value is created. The description he proposed starts with how competitive advantage is understood, and then states the definition of value chain as follows:

"Competitive advantage cannot be understood by looking at a firm as a whole. It stems from the many discrete activities a firm performs in designing, producing, marketing, delivering, and supporting its product. Each of these activities can contribute to a firm's relative cost position and create basis for differentiation…

The value chain disaggregates a firm into its strategically relevant activities in order to understand the behaviour of costs and the existing and protentional sources of differentiation. A firm gains competitive advantage by performing these strategically important activities more cheaply or better than its competitors."(Porter 1985) (Definition found in Christopher (2016, 10)

The activities of the value chain are split into two different categories of primary and support activities. as illustrated in the figure below**.**

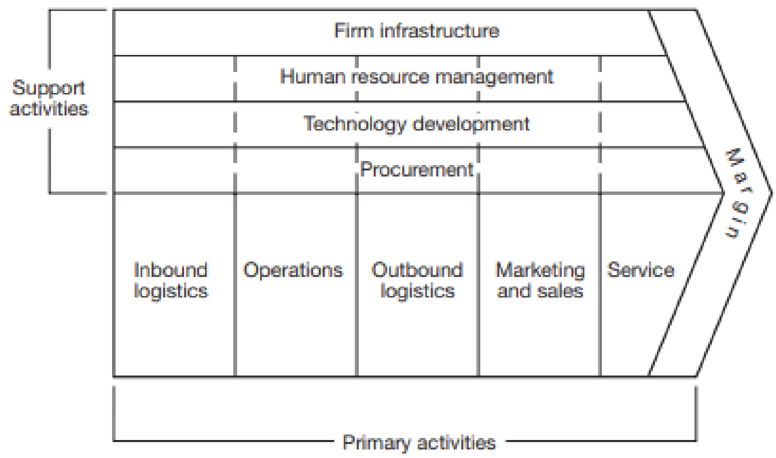


Figure 5 Illustration of primary and support activities in a value chain perspective. Source: (Porter 1985)

The primary activities contain inbound logistics, operations, outbound logistics, marketing and sales and service. Whereas the support activities are comprised of the infrastructure of the firm, human resource management, technology development and procurement (Porter 1985). This is also described as value chain in a micro perspective, as it is a focus of business processes view within the firm itself. A common label of this focus is the work of the company's operational management (Walters and Rainbird 2004). According to Walters and Rainbird (2004) the notion of value chain also operates at two levels, namely macro and micro levels.

With this view on the value adding activities of a firm, the idea of outsourcing is brought up, when an activity is not bringing an advantage by either reduced cost or increased value. The value chain is then extended outside of the firm itself and supply chain is formed as the value chain of the firm (Christopher 2016). With this way of bringing activities outside of the firm, it may also increase the complexity of the supply chain itself. Competitive advantage is created or lost in a connected supply chain network, often referred to as an "extended enterprise" *(Christopher 2016)*. This is also described by Walters and Rainbird (2004) as working in the macro, or strategic environment where the focus is what position a company has in its market of operation.

The work of the value chain is then to analyse key industry drivers that are present in the chain outside of the firm's boundaries (Walters and Rainbird 2004). According to Porter (1985), there is two main types of describing competitive advantage over the firm's rivals. The advantage of cost, where the company can provide the same value but at a lower price, and the advantage of differentiation, where value of the product exceeds that of its competitors (Porter 1985).
The Scholar of (Jay barney, 1991) also studied competitive advantages, but with a resource-based view, starting that the resources and capabilities of a firm combined, from basic for competitive advantage. To provide competitive advantages that are sustainable over time, the resources must be valuable, rare, imperfectly imitable and organized (RBV Jay Barney, 1991). However, to gain and higher-level value creation, the resources and capabilities must be superior to their competitors.

The value chain is an important concept when discussing changes in the products value adding processes in a firm. It extends on the knowledge of SCM and provides a deeper understanding of competitive advantages. This is supporting the work of the thesis in explaining the differentiation effect the new technology might have on the client companies.

3.1.3. Supply Chain Management in the textile-based industry

As this research focuses on the specific industry of textiles, a look at its SCM composition and involved actors is in order. According to Kumar, Hallqvist, and Ekwall (2017), the textile SC is extensive and complex with multiple actors involved. Kumar, Hallqvist, and Ekwall (2017) therefore argues that the textile-based SCs are made of exclusively B2B with the exception of the retailer that is B2C. A simple illustration of the textile-based SC network is shown in figure 6. Figure 6 is also included in large format in appendix D.

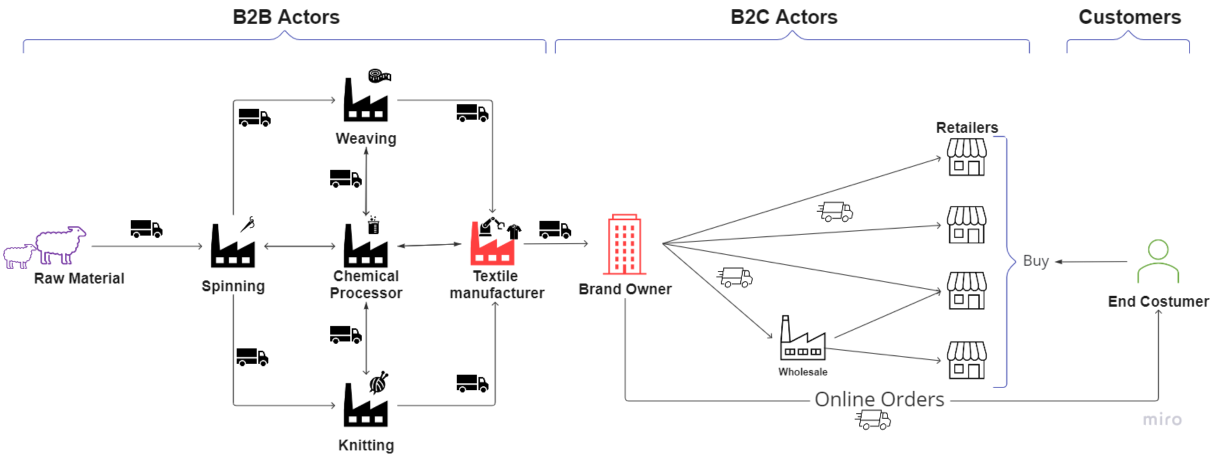


Figure 6 Illustration of the textile supply chain network, adapted from Kumar, Hallqvist, and Ekwall (2017).

Lam and Postle (2006) states that the retailers are the ones making upstream orders by forecasting market demand, making them the governing actor in the textile SC, without owning any production capacity of their own. This is a "pull" (where, demand is created by end consumer, and supply is created in response.) SC strategy, as demand flows upstream, and fulfilment of demand flows downstream. In a macro view, the B2B actors of the supply chain receive raw materials from their suppliers, alter the material and send it to the next link in the SC, repeating until the retailer (Kumar, Hallqvist, and Ekwall 2017). In the textile SC, information is critical, as each actor produces vast amounts of information and protects it as confidential information (Zhang and Li 2006; Kumar, Hallqvist, and Ekwall 2017).

There is also the need to make a distinction of garments (apparel/fashion) and furniture textiles in the textile industry SCs. Where the garment industry produces standalone products, textiles are only part of a larger SC in the furniture industry. The furniture SC also includes processing of more than just the textile, such as wood materials, metal components and various chemicals such as adhesives etc (Michelsen and Fet 2010). The actors of the furniture SC are mostly the same as of the garment industry, where there are independent suppliers within sourcing, production, distribution and retailers (De Marchi, Di Maria, and Ponte 2013). The Furniture SC is unique compared to the garment SC, in that some parts of the products (such as the textile part) are made to personal customization, governing the demand of the SC (Ranwat 2022). The furniture industry also produces to stock according to demand forecasting. Challenges of the furniture industry is that of timely deliveries, reducing inventories and reduction of cost of logistics and raw materials (Ranwat 2022).

One of the issues in the textile-based industry is that many of the textiles or garments that are leftovers from production are thrown away and not considered as resources (Koprulu and Albayrakoglu 2007). As mentioned, time also has a significant impact on the SCs, hence outsourcing is considered a strategy to reduce time and cost in large parts of the industry. There are also other strategies to gain more sustainable and effective SCs such as utilizing just-in-time production, involving stakeholders in the projects to get sustainable thinking. And involving customers in the design process and managerial decision-making (Koprulu and Albayrakoglu 2007). In other words, a well thought out supply chain would give the textile industry businesses advantages regarding sustainability and profitability business, helping them to eliminate waste at an early stage (Sukati et al. 2011).

With this literature collection, insight is made of how the textile-based industry SCs is today. Looking into the supply chain of the textile-based industry is important to describe the major processes, actors and their relationships and the specific challenges in the industry's SC. The value chains are market driven, where fast changing trends and high uncertainty in demand drivers these challenges.

3.1.4. Stakeholder theory

The different actors of the SC mentioned above is part of a larger scope of stakeholders. Where a stakeholder is an entity that can affect or be affected by a firm's activities directly or indirectly expanding the effects of the SCM outside of the SC (Donaldson and Preston 1995). A Stakeholder could be an individual person, group of individuals, other organizations or the environment (Donaldson and Preston 1995). The Stakeholder theory was first introduced in 1984 by R. Edward Freeman. He wrote that the firm is comprised of multiple stakeholders with different cooperative and competitive interest. The stakeholders can contribute to, or affect the SC, product, or service that the focal firm provides. The stakeholders might have conflicting interests among each other as well, for example owners wish to reduce costs and the world society frowning upon the use of child labour. The owners might want to employ underage workers as they know little about regulations and get paid less, but since the practice is damaging to a company's reputation: it might result in a loss of sales (Donaldson and Preston 1995).

As there are different kinds of Stakeholders, they can be split into internal and external stakeholders, illustrated in figure 7. The Internal stakeholders are circled in black, while the external stakeholders are circled in blue. All of the stakeholders affect the focal firm in the middle, but any action the focal firm takes, also affects the stakeholders. The theory states that properly addressing stakeholders allows the firm to achieve desired outcome of its operations (Donaldson and Preston 1995; Freeman 1984).

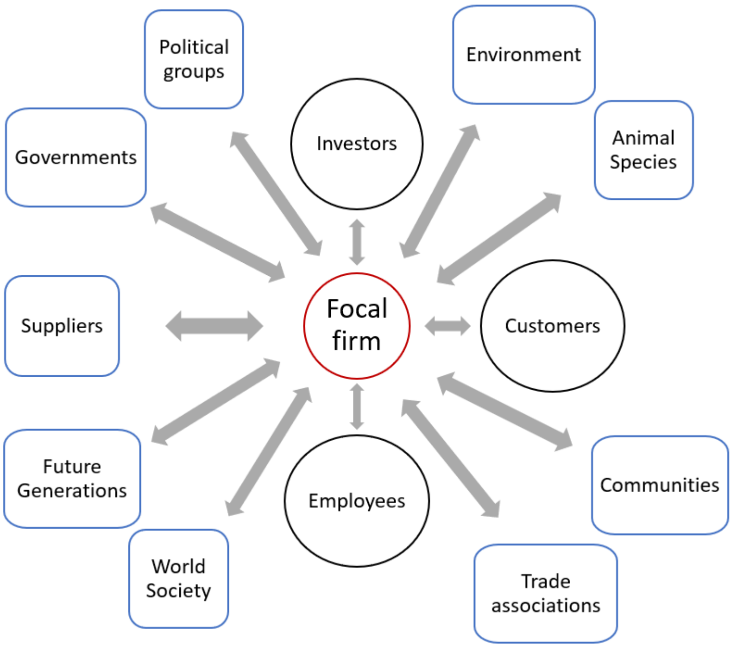


Figure 7 Stakeholder theory, adapted the figure of Donaldson and Preston (1995)

Elaborating about stakeholders of the firm is important in this thesis. As it brings awareness to the fact that conducting a business is not a free for all. There are considerations to be made in every move towards finally earning a profit. A change in the way a company performs its/their business(es), might satisfy the existing stakeholder, but might upset other stakeholders. However, stakeholder theory would also help explore how the client companies' stakeholders can be affected by the implementation of the 3D knitting technology.

3.1.5. Natural-Resource-based view of the firm

A complementary theory of stakeholder theory is the Natural resource-based view (NRBV) of the firm. The NRBV builds on the foundation made in the RBV of Barney (1991) The Scholar of Hart made a prediction in their study of NRBV that: *"It is likely that strategy and competitive advantage in the coming years will be rooted in capabilities that facilitate environmentally sustainable economic activity"(Hart 1995, 991)* Hart noticed that RBV ignored the interaction between an organization and the environment it operated in. The NRBV theory includes key strategic capabilities that firms must develop to address the natural environment and to create sustainable competitive advantages. Hart and Dowell (2011) made a revision in 2010 on the original work of Hart and came up with four strategic capabilities: Pollution prevention, product stewardship, clean technology and Base of the pyramid listed in table 2.A complementary theory of stakeholder theory is the Natural resource-based view (NRBV) of the firm. The NRBV builds on the foundation made in the RBV of Barney (1991) The Scholar of Hart made a prediction in their study of NRBV that: *"It is likely that strategy and competitive advantage in the coming years will be rooted in capabilities that facilitate environmentally sustainable economic activity"(Hart 1995, 991)* Hart noticed that RBV ignored the interaction between an organization and the environment it operated in. The NRBV theory includes key strategic capabilities that firms must develop to address the natural environment and to create sustainable competitive advantages. Hart and Dowell (2011) made a revision in 2010 on the original work of Hart and came up with four strategic capabilities: Pollution prevention, product stewardship, clean technology and Base of the pyramid listed in table 2.

Table 2 adapted from the table: "NRBV: fifteen years later" of Hart and Dowell (2011)

Strategic capability	**Societal Driving Force**	**Key resource**	**Competitive advantage**	**State of Research Development**
Pollution Prevention	Minimize emissions, effluents & waste	Continuous improvement	Lower cost	Strong empirical evidence in Favour of NRBV
Product Stewardship	Minimize life cycle cost of products	Stakeholder integration	Reputation/ legitimacy	Growing area of research, but much to be accomplished

Clean technology	Make quantum-leap improvement	Disruptive change	Future position	Little research to date
Base of the Pyramid	Meet unmet needs of the poor	Embedded innovation	Long term growth	Growing body of practitioner-oriented research, but academic attention needed

NRBV theory is applicable for answering the research question (RQ1) in terms of ensure a long-term growth of the firm (Hart and Dowell 2011). In addition, the theory provides key variables that the research consider in the investigation. It is assumed that the companies somehow follow the NRBV, but by fully moving towards NRBV would help the companies not only to reduce cost but also broadens their view to social and environmental sustainability to achieve desired profits. The NRBV can also be viewed as a continuation of the stakeholder theory as the NRBV also broadens the view of entities that can affect the performance of the firm and brings up capabilities that needs to be developed to achieve competitive advantage.

3.1.6. Triple bottom line

The NRBV brings up the planet and people on one hand. While Stakeholder theory focuses on taking care of stakeholders to archive profits. Another perspective is that of the TBL where it focused on “people, planet, profit”. The perspective was formulated in 1994 by academic John Elkington, stating that firms wanting to succeed in the marketplace, needs to focus on all three aspects (Elkington 2013). The three terms harmonize with each other as shown in the Venn diagram in figure 8.

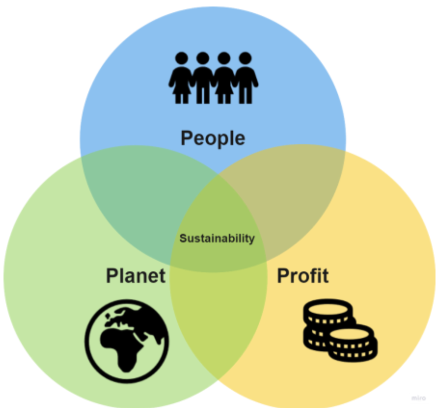


Figure 8 The triple bottom line perspective. Adopted from Dalibozhko and Krakovetskaya (2018).

To sum up the last two sections, the combination of Stakeholder theory and the NRBV justify the focus on Triple bottom line, which in turn lead to sustainable competitive advantage, illustrated in Figure 9.

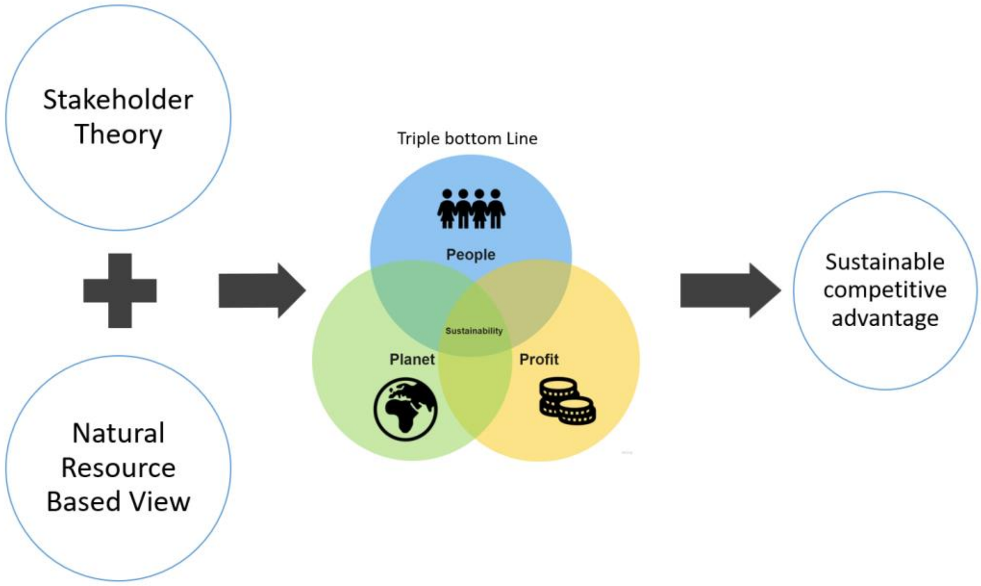


Figure 9 The triple bottom line put into perspective

The triple bottom line makes the firms focus on corporate sustainability, not only economically, but also socially and environmentally. This would contribute to a broader understanding of what changes are needed in the SC to increase the value of people, planet, and profit. It would also benefit/aid in observing whether the 3D-knitting technology gives any sustainable competitive advantage for the firm. However, these theories broaden the view of the companies, and a focus on sustainability in the textile SC can be applied.

3.1.7. Sustainable supply chain management in textile-based industry

According to Diabat, Kannan, and Mathiyazhagan (2014), the industries are currently facing pressure from the environmental initiatives such as global competition, government regulations as well as customer pressure. Further the article of Diabat, Kannan, and Mathiyazhagan (2014) states that "*The Sustainable Supply Chain Management (SSCM) system is a concept which ensures environmentally friendly practices in traditional supply chains*." The textile industry is considered a trillion-dollar industry, with sales in 2002 of $1 trillion, to $1.8 trillion in 2015 and an expected increase to $2.1 trillion in 2025 (Greenpeace International, Cobbing, and Vicaire 2017).

Hence, to deliver changes within a season to meet customer preferences is something that is acknowledged in the textile-based industry, but this varies from fashion, sporting goods, outdoor apparel, and furniture (Vaagen 2009). The fashion industries have the tendency to produce a large quantity of materials to meet customer needs, especially in areas with increased number of populations such as India (Diabat, Kannan, and Mathiyazhagan 2014). Additionally, the supply chain in this business category has a rapid change according to the demand, and this causes a huge amount of waste. The act of burning deadstock, inventory that is no longer in fashion, thereby considered as obsolete is a wide practice within the textile industry (Napier and Sanguineti 2020). Among the reasons to perform this type of pollution is overproduction as a result of poor forecasting, habits of excessive consumption by consumers, strategically maintained scarcity of luxury garments, as well as a protection of intellectual property (Napier and Sanguineti 2020) The overproduction is mostly common in cheap brands such as H&M and Zara with fashion trends being dynamic and the overproduction is a response to this. However, H&M states that burning is only done to overproduced stock, moulded garments or textiles not complying with chemical regulations (Napier and Sanguineti 2020).

On the other hand, the textile-based industry within furniture and sport fashion do not have the rapid change in their demand compared to the fashion trends. This gives the impression that the amount of waste is decreasing since the production is not changing accordingly to the trends (Vaagen 2009). Petersen (2017) wrote that the businesses found it as a good alternative with the arguments of "*particularly, cheap products produced in low-wage countries under poor working conditions, which are then shipped to western countries with a continually decreasing lifespan use while often releasing harmful substance and are finally exported back to developing countries for disposal*."

It is important to understand the process of how the textile is made before arriving at manufacturing. The furniture industry has a significantly smaller amount of textile in their production. This will also give an understanding of the outsourced production of garment compared with outsourced yarn production. Generally, the textiles consist of several fibres, creating the desired strength, durability, appearance and texture. There are also several types of fibres such as plant-, animals-, man-made-, and synthetic fibres according to Chemsec (2022). Further, the chosen fibres will be spun into yarn. The process stops here, the yarn is transported to the manufacturing to be knitted into the desired product. However, in the garment production, the process goes further to the core of textile manufacture whereby fabric production and further to pre-treatment. Further the process is during and printing, where they use chemicals and dyestuffs. Step 6 and 7 is finishing treatments and transporting the garment form manufacturing to sales and retailers. During all 7 steps (shown in figure 10), the garment manufacturing is adding chemicals to get the garment according to their desired strength, durability, appearance and texture (Chemsec 2022).

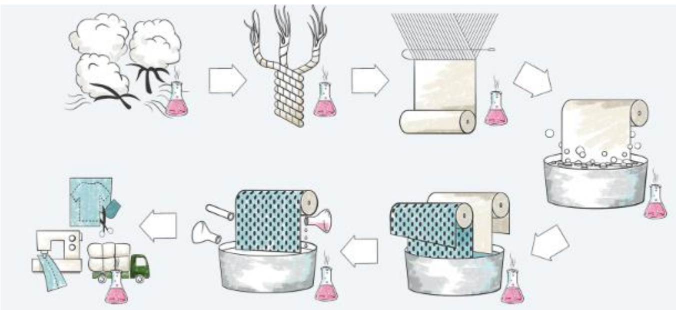


Figure 10 The whole garment process Source: Chemsec 2022

The manufacturing processes used in the textile manufacturing is divided into dry and wet processing. The dry processing embraces yarn manufacturing, fabric weaving and knitting, and the wet processing contains preparation at the fabric, colouring, and finishing. Of these two processes the most water and energy heavy consuming is the wet processing by far, because the colouring process unchaperoned consumes approximately 100 L of water/kg. This is a huge part of the textile industry that potentially contributes to damaging the environment (Franco 2017). The dry processing also impacts the environment as the use of cotton in the process require use of water, and as stated by Franco (2017) "*heavy use of pesticides, herbicides and fertilizers during their cultivation stage*". According to the world resources institute, producing a single common cotton shirt requires 2700 liters of water. To put this in perspective, the textile dying process alone uses 5 trillion liters each year. (Drew and Yehounme, WRI, 2017)

UN sustainability development goals

The UN sustainability development goals play a huge role to achieve sustainable advantage in general industries. The 2030 Agenda for Sustainable Development was created in 2015, which all the United Nations Member States adopted. These goals require a shared plan from peace and prosperity for people and the planet, that are considered today and into the future. Sustainable Development Goals (SDGs) is consist of 17 goals, and these are guidelines that are enabled by all countries and are developed/developing in a global partnership (United Nations 2015). The goals that are the most applicable for this thesis are number 8, "Good jobs and economic growth", 9, "Innovation and infrastructure" and 12 "Responsible consumption"

(United Nations 2015). The reason for the chosen goals is that there are numerous ethical and environmental negative conditions associated with textile-based industries globally. Especially when it comes to employees' rights to produce such waste amount of clothing, the use of manual labour is commonly practiced in factories and cotton fields. With this as an argument, the mentioned goals 8, 9 and 12 is considered (Fischer and Johannesen 2021) .

The discussion above is included to give an understanding of the current situation regarding sustainability in the textile-based industry. The information provided in this chapter will contribute to help us to answer the research questions (RQ3).

3.1.8. Circular Economy

The report from the Nordic Council of Ministers discuss two economical concepts, namely linear and circular economy (Palm et al. 2014; Le 2017). According to Palm et al. (2014) the textile-based industries are known for conducting a linear approach where individuals are demanding a huge quantity of clothes, using them and disposing them (Le 2017). Since the focus area of the thesis is within the textile-based industry, Kuzmina et al. (2019) states that *"The "linear" economic model of extracting raw materials and manufacturing goods to be sold, used and disposed of has been the dominant production system for the last 150 years."* This model has given the companies a huge profit generation along with decreased level of natural resources and increased level of waste quantities. CE is known as a closed loop system in terms of designing the materials and products to flow through a series of predefined closed loop life cycle. However, the concept is to repair, reuse and recycling after the product loses the value for the customer (Kuzmina et al. 2019). Where linear economy contributes the concept of take-make-dispose (Koszewska 2018).

Diabat, Kannan, and Mathiyazhagan (2014) illustrated the forward- and reverse supply chain that is a step towards circular economy. From the literature review within SCM the operational activities begin form the procurement of raw materials to be able to produce and deliver the finish products (forward supply chain). The second part that the CE consider, compared with linear economy is reverse SCM where the idea is to collect used products from customers to make a new or existing product (Diabat, Kannan, and Mathiyazhagan 2014). The article of Stewart and Niero (2018) states that to transition towards CE requires the textile-based industry to develop a new production and consumption models. Additionally, involve the stakeholders at all levels to get the best outcome.

Vaagen (2016) stated that by reusing raw materials it is possible to move from linear economy and towards CE. Today the population are approximately 7,9 billion (Kirchherr, Reike, and Hekkert 2017), and the number will most likely increase to 9.9 billion by 2050 as stated in the work of Vaagen (2017). However, as the population is increasing, the demand will also increase rapidly for materials. This indicates that the resources could become limited and as Vaagen mentioned it is important to implement the growth for the future textile-based industry. Vaagen (2016) Kirchherr, Reike, and Hekkert (2017) and Vaagen (2017) suggest that the CE concept is assembled on four R-principles (replace, reduce, redirect and rethink) to create sustainability in dynamically changing uncertain textile-based industry with 3D-knitting technology. The following description in table 3 is based on and Vaagen (2017) inputs.

Table 3 The four R-principles. Adapted from Klepp (2015) and Vaagen (2017)

Reduce fast fashion	• Reduce production by producing to real orders (reduced/eliminated overproduction) • Reduce materials consumption
Reduce resource input	• Global vs local whereby local production, with emphasis on ingredients, traditions, uniqueness, and innovation
Redirect global vs local	• Collaborative consumer-driven business models • Involve users in the design process to personalize the product thus increasing perceived value • Increased customer value can increase the product's service life and service life • Local production has the potential to create green growth and jobs in the region
Rethink for whom	• New business models • Sustainable design for reuse and recycling • It's important to not only think about how the end products are produced, but also who they are produced for and how textile affects the ability of self-expression and participation in an open society • Understand the operational activities (Forward logistics) to see where the product yar comes from compared with the textiles

Business model

A Business model addresses the logical understanding of how an organization is build, provides and portrays value (Strategyzer 2019). Hedman and Kalling (2003) states that "*Business model is a term often used to describe the key components of a given business.*" However, the term business model was introduced in 1957 (Bellman et al. 1957; DaSilva and Trkman 2014) Chesbrough and Rosenbloom (2002) defines the business model as a *"coherent framework that* *takes technological characteristics and potentials as inputs and converts them though customers and markets into economic outputs. The business model is thus conceived as focusing device that meditates between technology development and economic value creation."* Further they also state(s) that the model *"spells out how a company makes money by specifying where it is positioned in the value chain."* According to DaSilva and Trkman (2014) and Zott, Amit, and Massa (2011) a business model can be used as a template to get the understanding of how they can deliver value to the stakeholders such as focal firms, customers, partners etc. Different researchers elaborate on several business model frameworks and elements (Fielt 2013) such as Business model Schematics (Weill and Vitale 2001), Business Model Canvas (McNally 2013), Technology-market mediation (Chesbrough and Rosenbloom 2002) and Four-Box Business Model (Johnson, Christensen, and Kagermann 2008; Johnson and Lafley 2010). Of the mentioned frameworks, the most used model is Business Model Canvas, and according to Fielt (2013) *"The business model Canvas is presented as a shared language for describing, visualizing assessing and changing business models. It focussed on design and innovation, in particular by using visual thinking which stimulates a holistic approach and storytelling."*

However, together with the four R-principles the textile-based industry can stimulate innovation in business models. However, a new business model can somehow move the industry towards circular economy with the implementation of 3D-knit technology. The literature review within CE is an enabler of the ability to answer the research questions.

3.1.9. Circular Economy Business Models

As mentioned in the previous subsection, there are several CEBMs and frameworks that can help the companies move towards circular economy. Such models enable keeping product and materials in use for a long as possible time by designing the product and materials with maximum value it can give. Hence, according to Zero waste Scotland (2022) CEBMs can *"offer new commercial opportunities, contribute to business growth and sustainability, generate new revenue, transform a business 'relationship with its customers and protect our economy against resource shortages and the rising cost of materials."* According to Pieroni, McAloone, and Pigosso (2021), the CEBM is *"Building on the value logic concept disseminated in the traditional BM literature, the aforementioned definition indicates when a BM qualifies as CE-oriented by focusing on how resource productivity (i.e. the goal of CE) can be materialised through different strategies (i.e. slowing, closing or narrowing resource flow)."* Mwesiumo, Kvadsheim, and Nujen (2020) and Vaagen (2009) mentioned five common circular economy business models (mentioned below), where these can be used individually or together to accomplish the CE.

1. **Sharing platform:** Share assets, for example the 3D-knit machines. Whereby they locate the technology where it is accessible for the companies. However, the model focuses on is that instead of owning the product or the service, the company can give the customers the access instead. An example is renting apartment when you're traveling then actually buying it. Services that provide such solutions is Airbnb (Mwesiumo, Kvadsheim, and Nujen 2020; Kvadsheim 2020).

2. **Product as a service**: This model considers leasing, renting or pay-for use agreements. Hence, it allows customers to buy a service or desired result (Veolia 2022). With such model, the textile-based industry can leas the 3D-knit machine for other companies or customers. This concept is an advantage for the customers in the sense that the costumers only pay for use of the product throughout the product life cycle. On the other hand, the manufacturing, the model contributes to give the company's revenue stream that conduct them a sustainable busines model as result (Mwesiumo, Kvadsheim, and Nujen 2020; Kvadsheim 2020).

3. **Product life extension:** G. Lee (2019) states that the product life extension is a *"term that describes how long a product or item can be used for, with ultimate goal of maximizing any given product`s "utilization" rate and duration."* An important element that was mentioned by G. Lee (2019) is that in clothing and consumer products has a high amount of waste, and every time they throw a product, additionally the company is losing an energy and resource that can be reused to another product (Kvadsheim 2020).

4. **Circular supply chain:** Where enabling technologies for a circular supply chain (Vaagen 2016). As mentioned by Kvadsheim (2020), Circular supply chain is *"use of renewable energy, bio-based or potentially completely recyclable materials."* Hence, the circular supply chain engages in a supply chain within the manufacturing, logistics and sourcing. An example could be to reuse materials from a product. For instance, H&M came with a new solution where the costumers can give the sweaters that are on

their end of lifecycle. These sweaters go through a process where the machine retracts the yarn from the sweaters as skein to produce new sweaters. Such solution where launched in Sweden, where the machine is placed in a container. This process is also called reverse logistics (Einarsdòttir 2020).

5. **Recovery and Recycling:** In this model, it's important to enable constructive recycling and composting. Buy materials that are environmentally friendly whereby secondary materials as the input for production (Le 2017). For example Bergans has a collection called Stranda that are made of one yarn, spun as of post-consumer waste (Kvadsheim 2020). Whereby the water and chemicals are significantly decreased. This indicated less energy consumption and decreased level of carbon footprint (Mwesiumo, Kvadsheim, and Nujen 2020; Kvadsheim 2020).

The CEBMs provides insight to which business model is applicable our study. However, the model would contribute to find solution on how the companies can move from a linear economy to a CE. With the literature review, sharing platform, product life extension, and recovery and recycling are seen as applicable ones. These models can be used alone or combined with each other to find suitable model for the companies.

3.1.10. Closed-, open- and narrow-loop supply chain

According to Mwesiumo, Kvadsheim, and Nujen (2020), how the resource flow through a system divided into three types, whereby slowing loops *"is about designing long-life products and extending the life of products to slow down the flow of resources."*, secondly closing loops *"is about recycling to close the loop between post-use and production"*, lastly narrow loop *"aims at using fewer resources per product (e.g., through efficient manufacturing processes and lightweight product design)."(Mwesiumo, Kvadsheim, and Nujen 2020)* The textile-based industry falls into the narrow loop with today's linear economy, and slow and close resource loops characterize CE. Above we mentioned that the three CEBMs that are applicable for our research is sharing platform, product life extension, and recovery and recycling. Corresponding to Mwesiumo, Kvadsheim, and Nujen (2020), product life extension falls into the category of slowing loops, where Tudelft (2022) strengthen the argument by saying that Slowing loop is involved to extending a products useful life. However, this contributed to slow down the general flow of resources (Tudelft 2022). Recovery and Recycling is denoted as closing loop regarding to Mwesiumo, Kvadsheim, and Nujen (2020), and they create a circular flow and yet the recycling of assets. Moreover, (Tudelft) explains narrow loop such as a model to use fewer raw materials per product. However, they also state that "*Efficient use of resources (often referred to as reduce) is already applied in linear business models and, by itself, does not affect the speed at which products are cycled in the economy or whether their resources are retrieved through recycling."(Tudelft 2022)*

This review shows that closed and open loop is applicable for this research according to the chosen CEBMs, sharing platform, product life extension and recovery and recycling. The Closing and narrowing of the loop also connect to the natural resource-based view of Hart and Dowell (2011) and their strategic capability of product stewardship.

3.1.11. Industry 4.0 technologies

According to Kvadsheim (2020) there are three drivers pushing the shift towards circular economy. A customer centric trend, sustainable use of resources and new enabling technologies. With the background knowledge accumulated on SCM, Value chain (VC), NRBV, Sustainability and textile industry as broad topics, the focus of the literature starts narrowing towards the technology part. This section focuses on technology development, and how it has affected industry practices.

Within the area of technology, new terminologies are rapidly emerging to describe advances and development. Germany was the first mover regarding a digital shift in the industry as whole with industry 4.0 technologies. An article was published by DFKI et al. (2011) with the name "Industry 4.0: The 4th industrial revolution and the internet of things". The technological advances of industry 4.0 help to improve operational manufacturing efficiency regarding a reduction of time and cost but also in an increase of productivity (Erboz 2017).

The industry sector is considered to have evolved throughout history in 4 stages or industrial revolutions. These stages are illustrated in figure 11 by(DFKI et al. 2011).

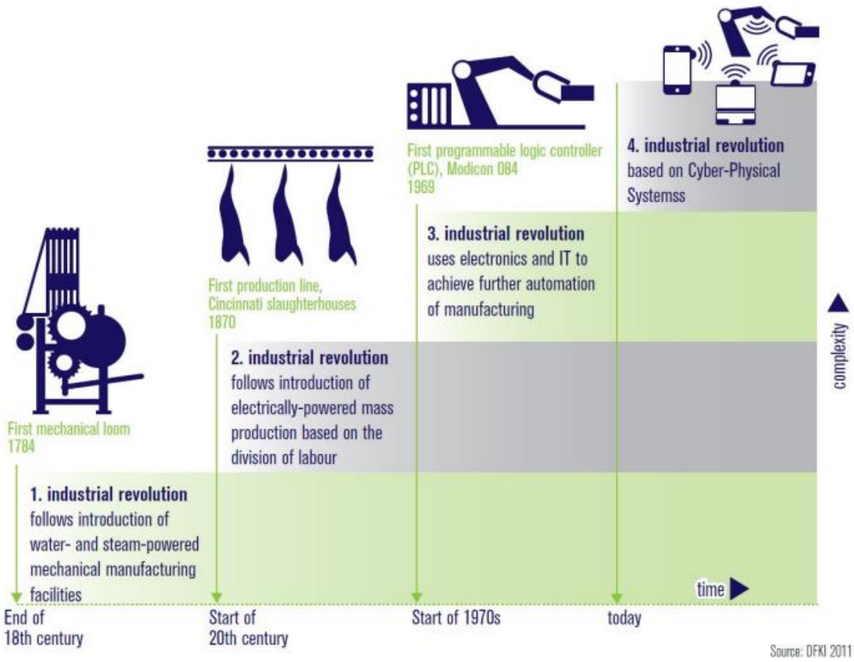


Figure 11 - The four stages of industrial revolution. Source: DFKI (2011)

The 4th revolution is a result of manufacturing making a shift towards a basis on cyber physical systems (CPS) and Internet of Things (IoT) and is thought to be the stage of adaptation of a "smart" industry. In its most basic form, this means adapting the use of various sensors and actuators throughout the entire supply chain, by reading values remotely through the internet with each machine and being able to communicate in a network environment (NFV, Ravnå, and Schjølberg 2016). Although there are a lot of similarities with the third revolution, the connectivity of industry 4.0 is what differentiates it from the digital revolution in the 1970s. The definition of industry 4.0 is consistent throughout the literature, just with some different takes on formulation. One description that is well-articulated is from the company of McKinsey defining the term industry 4.0 as *"digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber physical systems, and analysis of all relevant data."* (McKinsey&Company 2015) Another good formulation is that of Erboz (2017), where he describes it as *"The current vision shaping the future of many industries by creating new business models though CPS."* Cyber physical systems interact with machines and the physical space and processes through different types of sensors, actuators, communication and computation (Tan et al. 2013). Although the common industry practice is to apply it to manufacturing, CPS can be used in any other industry that use this type of monitoring and control. Some examples are aviation, traffic control and smart structures(J. Lee, Bagheri, and Kao 2014). A common use of CPS machine is illustrated in figure 12.

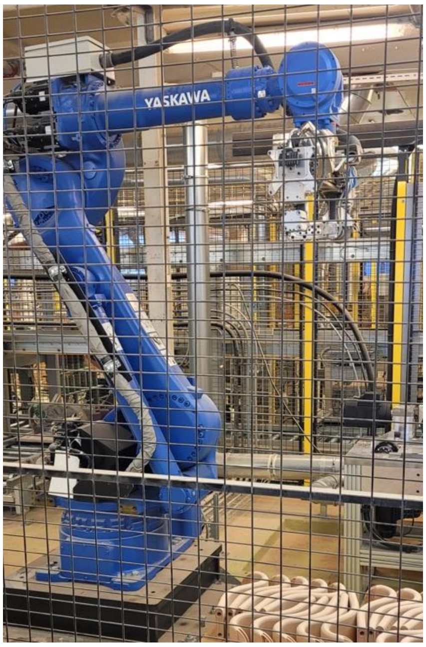


Figure 12 A CPS Machine at work in Ekornes. Source: (Norem and Pushparajah 2022a).

According to Erboz (2017) Industry 4.0 can be divided into 9 technologies that are considered the main drivers. According to Immerman (2020) at machine metrics there are 10 technologies that have emerged with significant importance. Collected, an overview of the technologies is provided in table 4.

Table 4 - The main technologies of Industry 4.0 Source: (SAS 2022; Immerman 2020; Erboz 2017)

Technology	**Description of the technology**	**Real life examples of the technology**
Big data and analytics	A term describing data in a certain volume, velocity and variety that are difficult to process by traditional means of data processing. Can be used for decision making.	Shop floor sensor collecting data on manufacturing, big data analytics software and algorithms. Predictive maintenance of assets is an example of decision making.
Autonomous Robots	Robots that can perform in environments, precision or repetition that humans can't.	Robots in the assembly lines of automobiles
Simulation/digital twin	Mathematical modelling that simulates with real world by creating a virtual twin. Often in the form of a 3D representation.	A 3D rendering of a physical asset or space, like a manufacturing plant, as a 3D rendering in virtual software.
Integration of horizontal and vertical systems	The connection and sharing of data both within a company or with outside partners. The way of	Sharing data within departments or across facilities. Smart factories and "lights out factories" (factories that operate fully

	connecting big data and cloud computing.	automatically with robotics without human interaction) Wallach (2022)
Internet of Things (IoT)/ Industrial internet of things (IIoT)	As maybe the main technology of Industry 4.0 it consists of connection of every asset in a network, large and small.	Connection of physical assets to cloud systems, by collecting data or by access to remote actuators. Sensors or machinery in a manufacturing plants are good examples of this. "Smart" products are examples of consumer products.
Cloud computing	A virtual system is used in order to provide resources and services as a client and server-based system. The cloud provides the storage needed from the other technologies such as big data.	There are mainly three different kinds of cloud computing: Software as a service (SaaS) Example: Customers paying for an ERP solution that is run remotely. Platform as a service (PaaS) Example: Customers provided access to the applications in the cloud Infrastructure as a Service (IaaS) Example: Basic access such as storage.
Cybersecurity technology	Software that prevents and protects against unwanted attack or access.	Security breach plans and protection of intellectual property, data and equipment.
Augmented Reality (AR)	Overlay technology that either improves or assists human interaction with the world.	Smart glasses that assist in training personnel or enhances other work tasks.
Artificial intelligence (AI)	Machine learning using algorithms and big data analysis to make software make decisions without human interaction.	Accurate predictions in forecasting demand and enables predictive maintenance.
Blockchain technology	A technology of distributed ledger allowing storage and sharing of data in a decentralize and immutable manner in a peer-to-peer network (Jaber et al. 2021).	Can be applied to cyber security, Supply Chains, smart factory and Internet of things amongst other Industry 4.0 technologies where trust is a concern.
Additive manufacturing (AM) technology	Additive manufacturing consists of technology fabricating items by adding layers of materials through different methods of fusing the materials into one product.	3D printers of different types, where layers are added instead of subtracted, common in traditional industry practices.

The literature review within Industry 4.0 lays a foundation of what technologies that are available, and companies are conducting in their supply chains. According to this clinical study this chapter would help us to understand the technology development, and how it has affected the industry practice. The technology is an enabler of integrating various stakeholder and supply chain functions as it is an enabler of real-time transfer of data creating new opportunities for decision making and makes the supply chain more integrated, as the next section will explore.

3D Knit as an enabler for integrated supply chain

An integrated supply chain contributes to reduce costs, build value regarding the partners in the supply chain and its stakeholders (Bagchi et al. 2005). According to National Research Council (2000) every supply chain is integrated to a degree. They wrote: *"An integrated supply chain can be defined as an association of customers and suppliers who, using management techniques, work together to optimize their collective performance in the creation, distribution, and support of an end product. It may be helpful to think of the participants as the divisions of a large, vertically integrated corporation, although the independent companies in the chain are bound together only by trust, shared objectives, and contracts entered into on a voluntary basis." (National Research Council 2000, 27)* Table 5 illustrates the strengths, weaknesses the integration enables.

Table 5 Strengths and weaknesses of supply chain integration. Adopted from National Research Council (2000, 33)

Strengths	Weaknesses
Increase collaborations and minimize disconnect.	Exaggerated Regulation
Increase connectivity in the supply chain (Procuremnt–production planning – logistics	Can lead to complicated scenario (shared resources and avoideable wasted)
Increased information flow throughout the supply chain	Suppliers can terminate or not willing to renew contracts (if the integration do not suit their business)
Combined flexibility	
Reduced Waste	
Centralization of data	
Reduce warehouse space (decreased inventory level)	
Developed Margins	
Escalate profitability and competitiveness	
Fast response to changes in the market demands	

The focus of this thesis is on 3D Knit technology as one of the AM technologies of industry 4.0. The 3D Knitting technology is not only limited to the actual printing but is a digital technology with integrated functions across consumer driven design, planning, production and reproduction, or an enabler of integrating the supply chain as explained in the previous section. According to Naghshineh and Carvalho (2022) AM is considered a disruptive technology. Meaning that the adoption of AM applications is most likely to influence the structure and capability of Supply chains (Ivanov and Dolgui 2020).

The recent example of the global pandemic proves that changes in the availability in the current global SCs are genuinely important (Ivanov 2020). Where Covid-19 drove the Supply chain to be more resilient (Ivanov and Dolgui 2020; Pettit, Croxton, and Fiksel 2019). The research of Naghshineh and Carvalho (2022) concluded that AM technologies could improve Supply chain resilience as well as brings up new challenges. Keeping this in mind, the industry 4.0 technologies presented in table 4 cover a lot of different applications.

As mentioned, a focus is on just one sub-category and application of Additive manufacturing, the 3D Knitting. Meaning that the 3D knitting technology is just a small part of adopting industry 4.0 in general. And even though it could be described as disruptive, it needs to be supported throughout the rest of the SC as well in order to function optimally. Especially in the current SC environment. The 3D Knit technology and its relation and effect on the Supply Chain is explained in more detail in the next chapter.

3.2. Systematic literature review of 3D Knit technology

This section of the thesis conducts a systematic literature review to get sufficient information on 3D Knit technology with the underlaying understanding of the sustainable potential that the technology has in the SCM. This examination will give a broader understanding about how 3D Knit technology have affected the supply chain and provides knowledge on existing research to get a foundation for further discussion. To identify patterns in methods, findings and gaps within various peer-review publications the systematic literature review approach is deemed appropriate (Orheim and Utvær 2021).

The common narrative literature review can contribute to lack of information that are required. A systematic literature review approach can help to avoid this issue, where *"Systematic reviews differ from traditional narrative reviews by adopting a replicable, scientific and transparent process, in other words a detailed technology, that aims to minimize bias through exhaustive literature searches of published and unpublished studies and by providing an audit trail of the reviewers decisions, procedures and conclusions."(Tranfield, Denyer, and Smart 2003)* Systematic literature review was originally introduced in the medicine academic fields in 1972. Today such research has increasing attention in numerous fields (Durach, Kembro, and Wieland 2017). Further, Charles Sturt University (2022) states that a systematic literature review should start with a clear stated criterion, because such research is comprehensive. A transparent search is conducted among numerous databases and grey literature. Paez (2017) says that "*Grey literature may thusly reduce publication bias, increase reviews' comprehensiveness and timeliness and foster a balanced picture of available evidence. Grey literature's diverse formats and audiences can present a significant challenge in a systematic search for evidence. However, the benefits of including grey literature may far outweigh the cost in time and resource needed to search for it, and it is important for it to be included in a systematic review or review of evidence.*" Also, Paez (2017) mentioned that grey literature includes not published work in commercial publications, that can contribute for a significant value in the systematic literature review. The grey literature can also be divided into tiers according to Garousi, Felderer, and Mäntylä (2019). Where the extreme of "White literature" is referring to peer reviewed articles, while 3rd tier on the other side of the scale is literature sources that should be validated if used such as blogposts or other sources that should be fact checked. The different tiers are shown in figure 13 (Garousi, Felderer, and Mäntylä 2019). In this SLR, peer reviewed articles (white litterature) is used to support and validate the use of grey literature.

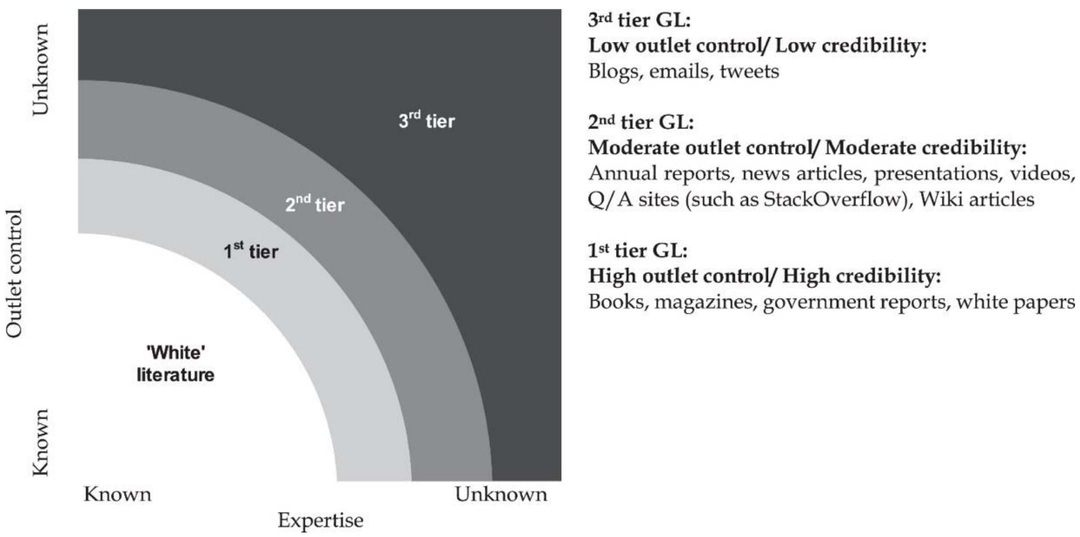


Figure 13 Describing tiers of grey literature. Source: (R.J. Adams, Smart, and Huff 2017)

3.2.1. Review process

This paper made use of academic search engines such as google scholar and Oria. Both engines have access to what is considered major academic publishers, such as ScienceDirect, Emerald, Wiley and Springer as this paper does not limit to one publisher or journal. Google scholar is an open search engine, while Oria is connected to the library at Molde University College.

Listing books, articles, journals and other electronic resources. Google scholar has been used as the main tool for finding academic literature, while Oria has been used as a supplement and a way of validation to confirm the results found by google scholar. As a means of sustaining value of the articles studied, Pawson (2002) encourages researcher to consider a large number of articles.

An examination of scientific papers and grey literature relevant to the selected search terms provides a deeper knowledge of the concept. The existing research of academic literature gives a basis of knowledge, but the grey literature provides additions in areas that are not fully covered by research limitations. The hands-on approach of grey literature provides updated information of the current situation. When delving into the topic, there was some uncertainty on narrowing down the scope of the review and search terms as there are several describing terms, but with different meaning shown in table 7. In the end, the most covering and relevant search terms were “3D Knit” and “Supply Chain Management”. They were chosen to get results that were relevant and covering for this study. ***“Sustainability”*** was considered as a main search term as well, but as a lot of the literature of the two major search terms covered “sustainability” and it was not selected. However, the term is explored in the context of the chapter “Sustainability by using 3D Knit technology”.

The two terms were used by themselves and in a combination, yielding results ranging in size from over 3000 hits down to only a handful of hits with some of the term combinations. Different combinations were explored, where “3D knit” yielded 154 results, while the combination of “3D Knit” and “Supply Chain Management” yielded 42 results. The term “seamless knitting” was considered as the substitute in the beginning for 3D Knit, but 3D knit provided more consistent and relevant results. The ones that were relevant with “seamless knitting” included “3D knit” in some way or another anyways.

However, as discussed by Godin et al. (2015), by using a generic google search for grey literature, there is a need to rely on Google’s own ranking algorithms to yield the most relevant findings on the first pages presented. A concrete number of 5 of google search results pages to be screened was set in advance to maintain consistency and time management across searches. This represents about 50 results for each search term. When conducting the review on grey literature, relevant results are considered from the generic google search and articles that are not peer reviewed from the scholar search but still meet the inclusion criteria of grey literature.

The scholars of Kmet, Cook, and Lee (2004) proposed inclusion criteria based on a standard quality assessment, which are comprised of pertinent title, abstract and study design. The objective should be sufficient, the results should support the conclusion and the papers must be peer-reviewed. Evaluating the grey literature should follow the same set of criteria, with an adoption to the philosophy of grey literature as mentioned.

As an effort to increase students' knowledge of discriminating between sources that are credible and noncredible, the scholars of Calkins and Kelley (2007) proposed a checklist for evaluating sources of research and their quality for use in academic writing. The checklist name is an acronym for credibility, accuracy, reasonableness and support.

TABLE 2. The CARS Checklist for Evaluating Research Sources

1. Credibility
   - Author's credentials, evidence of quality control, evidence of peer review
2. Accuracy
   - Timeliness, comprehensiveness, audience, and purpose
3. Reasonableness
   - Fairness, objectivity, moderateness, and consistency
4. Support
   - Source documentation or bibliography and corroboration

Note. Adapted from Harris (2002).

Figure 14 The CARS Checklist. Source: Calkins and Kelley (2007)

Most of the articles used are written in English language as suggested by Harris et al. (2014), but with the use of grey literature in this study, Norwegian has also been utilized to get a better coverage of the current situation in Norway.

As a means of having a step-by-step process to the inclusion and exclusion of articles, the use of the PRISMA flowchart as suggested by Harris et al. (2014) was applicable to this thesis. The flowchart suggested four different levels of application of the criteria of studies to find the final number of eligible articles. The PRISMA flowchart also separates database searches from other searches shown in figure 15, which is applicable to the use of grey literature in this research.

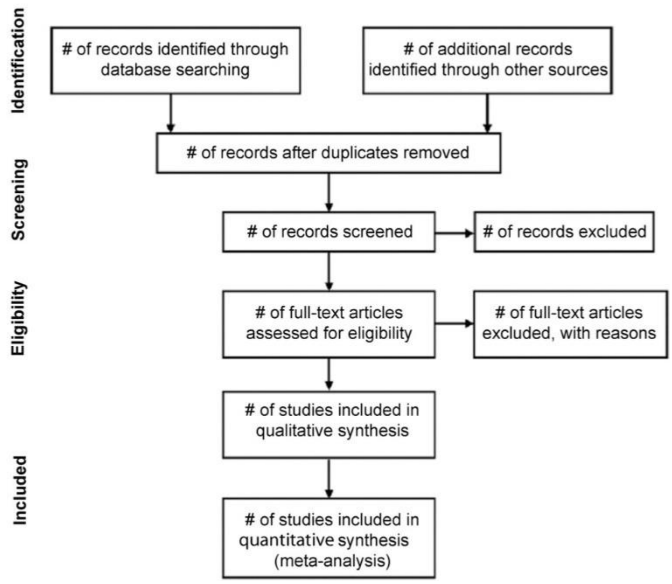


Figure 15 The PRISMA flowchart of (Harris et al. 2014)

The articles used in this research spans from 2001 up to the current year of 2022, with the most recent article being from March 2022. The gathering of articles was ceased by the start of March 2022. In summary, the review resulted in 60 articles that satisfy the inclusion criteria and is presented in the SLR. The included articles are listed in appendix A. Table 6 below summarizes this review process.

Table 6 Protocol of the review process

Research	**Description academic literature**	**Description grey literature**
Search engine	Google scholar and Oria providing academic literature from numerous databases.	Generic google search on published documents.
Search fields	Titles and keywords	N/A.
Number of search result pages to be screened	N/A.	10
Search terms	“3D Knit” and “Supply chain management”	“3D Knit” and “Supply chain management”
Publication	Peer-reviewed journal articles, no restriction to specific journal	1st and 2nd tier grey literature.
Language	Publications in English	Works in both English and Norwegian were considered.
Date range	From 2001 to 2022.	From 2001 to 2022.
Criteria for inclusion	Pertinent title, abstract, study design, proper objective, conclusion reinforced by	Pertinent title, 1st and 2nd tier grey literature or known author with

	results and should be peer-reviewed.	credentials if 3rd tier, objective approach, referencing to external sources
Criteria for exclusion	Fails to meet inclusion criteria and does not fulfil the CARS checklist.	Fails to meet inclusion criteria and a lack of referencing to factual statements.

3.2.2. Findings of SLR

This section is divided into five parts: About 3D Knit technology, 3D Knit technology and the impact on the supply chain, Sustainability by using 3D Knit technology, Areas for future research, Gaps and Practical examples of applying 3D Knit technology.

About 3D-knit technology

Knitting, weft and warp, and textile weaving counterpart

Historically, knitting was a home industry, originating from hand knitting. Evolving into personal devices, and mass production as a result of the first industrial revolution. With the latest addition being exploration into smart factory automation (Chung, Kim, and Jang 2020). Frunze (2019) defines knitting as: "*The process of using two or more needles to loop yarn into a series of interconnected loops in order to create a finished garment or some other type of fabric*"(Frunze 2019, 467)

According to K.-M. Choi, Kim, and Song (2012), knitting is the second most popular process of turning yarns into fabrics just beat by the process of weaving. Generally, knitted fabrics have a higher porosity compared to their woven counterparts, resulting in differences in properties and appearances both physically and mechanically. Underwood (2009) describes the difference between the two most basic knitting types, weft, and warp knitting. Weft knitting uses horizontal rows of loops (also called stiches) across the fabric horizontally with one or few yarns. In warp knitting on the other hand, the loops consist of threads running vertically, made from many yarns, up to 12 000 individual yarns (Charles 2022). The researchers state that weft knitting is most beneficial for 3D shapes as it provides the most potential and versatility (Underwood 2009).

3D knit terms

The literature describes the phenomenon of 3D-knit in different ways. Different descriptions, combination of names and manufacturer specific references have been used. The different descriptions are collected in table 7 below. The terms were noted down during the research as the different descriptions may bring confusion to the reader. For simplicity, this thesis will use the phrase 3D knit to describe 3D knitting technology. Table 7 is not an exhaustive list of number of times mentioned but provides an overview of different terms used across the literature.

Table 7 Summary of the various 3D Knit terms. Developed by the authors.

Term	Origin	Referred in
"3D knit (3D knitting/ 3D-Knit)"	An umbrella concept of the machinery, design (virtual sampling) and structure of fabric or garment.	(J. Taylor and Townsend 2014; Huffa 2017; Mahbub, Wang, and Arnold 2014)
"Wholegarment"	Trademark name of Shima Seiki knitting technology.	(J. Taylor and Townsend 2014; Huffa 2017; Lawson 2021; Smith 2013; Giglio, Paoletti, and Conti 2022; Mahbub, Wang, and Arnold 2014)
"Knit and wear"	Trademark name of Stoll knitting machinery.	(Huffa 2017; Lawson 2021)
"Seamless"	Refers to a general term of fabrics or garments without seams present.	(K. Foster and Istook 2017; Lawson 2021; Mahbub, Wang, and Arnold 2014)
"True seamless"	Term used to separate 3D knit garments from the plain "Seamless" term	(Power 2012)
"Seamless Knitting/ knitwear"	Description of knitting a garment of fabric in on sitting without the need for postprocessing.	(Huffa 2017; Smith 2013; Mahbub, Wang, and Arnold 2014)
"Complete garment"	Description of garments knitted in 3D knitting machinery, mainly flatbed knitting machinery.	(K. Foster and Istook 2017; Lawson 2021; Power 2012)
"3D printed knitwear"	A similar term to "3D knit" but in addition to referring to 3D knitting machinery, also includes fabrics produced with 3D printers.	(Mikahila 2021)
"3D knitted preforms"	An academically pleasing way of describing 3D knit shapes.	(Liu, Li, and Yuan 2019; Peiner et al. 2022)

"3D-Knitwear"	A term used to make consumers/readers more aware of the technology potential	(J. Taylor and Townsend 2014; Bendt 2016)
"3D Textiles/ 3D fabrics/ 3D garments"	General terms, much like that of 3D knit	(Giglio, Paoletti, and Conti 2022; Mahbub, Wang, and Arnold 2014)

3D Knit definition; 3D knit vs 3D print

Raycheva and Angelova (2019) used a definition made by Badawi (2008) describing 3D Knit as: "*A basic common definition of 3D fabric is that these types of fabrics have a third dimension: in the thickness layer. In 3D-fabric structures, the thickness or Z-direction dimensions. Fibers or yarns are intertwined, interlaced or intermeshed in the X (longitudinal), Y (cross), And Z (vertical) directions*". Huffa (2017) describes 3D knitting as a part of additive manufacturing, but as a separate entity of 3D printing. Mikahila (2021) also sheds light on the differentiation between 3D printing and 3D knitting, concluding that the production process of 3D knitted product are seemingly similar. Starting out on a CAD software, for design and programming purposes. The difference between the two starts at the physical production and the machines conducting the manufacturing. The process and principle are the same in the way of layering, but instead of extruding filament or power, it is addition of layers of garment in 3D knitting. The separation of the technologies is in other words connected to the materials and machinery used.

Raw materials in 3D knitting

W.-S. Choi and Lee (2010) states that wool or wool blends (ex. wool crepe consisting of 80% wool and 20% Rayon) are suitable to make effective 3D knit fabrics. This is due to the wool`s elasticity, resiliency, cohesiveness, heat retention, and softness to mention some factors. Whereas Raycheva and Angelova (2019) depicts that yarns used for knitted furniture are both natural and artificial such as synthetic fibres, conductive yarn, and unspun wool strips. They also argued that knitted upholstery come in two types, soft covers or as a structural knit.

Ciobanu (2011) discusses the term of 3D knitted fabrics and the complex composition of materials but has a focus on technical textiles and the functional structures created with the knitted fabric. The use of these types of materials, is mainly explored as structural rigidity for aero, automobile and construction purposes. This claim is supported by Mikahila (2021) and

Underwood (2009). But Underwood (2009) also states that research on this is performed in the medical sector.

With materials in mind, Ciobanu (2011) also discusses the use of textile reinforced composites (TRCs). TRCs consist of a "matrix" material that is the constant, while the "reinforcement" modifies or improves the matrix. The TRCs are just one of many types, as illustrated in figure XZ made by Ciobanu (2011). Figure 16 can also be found in appendix

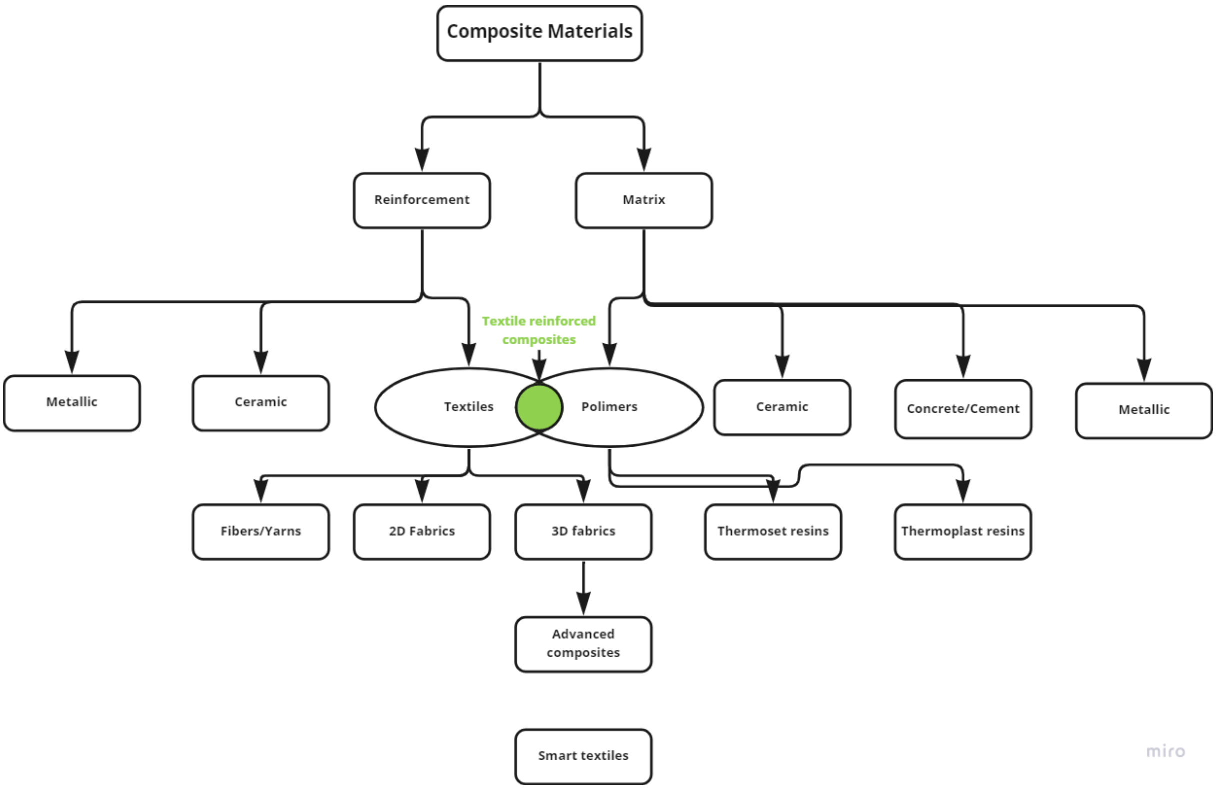


Figure 16 The structure of composite materials: Source Ciobanu (2011, 1)

Some of the benefits of using TRCS are better weight/ strength ratio, ability to maintain integrity under extreme conditions and have and improved fatigue life. However, according to Ciobanu (2011), knitted textiles on their own have a reduced strength and stiffness compared to that of woven, braided, and non-crimp fabrics.

Smart textiles

Scott, Kaiser, and Nerlich (2021) defines smart textiles as technical textiles that can interact with their environment. Sensing, react to, store, or send data about the conditions it is in or other externalities such as mechanical, thermal, or chemical, to mention a few.

The case of Scott, Kaiser, and Nerlich (2021) also looked at the application of electronics imbedded into 3D knitted textiles, where the information is used for medical health monitoring. The yarn needed can be used on its own, as raw yarn or as a supplement to be in contact with the body. The study of Bulathsinghala (2022) also researched embedded electronics, but in the form of fabric antennas to support communication for smart fabrics, where knitted antennas were deemed a possible for stretch and bending applications such as sportswear.

A challenge proposed with the development of smart textiles is the fact that garments can be subjected to machine washing during its lifetime. One way of mitigating this issue is plastic encasement, laminate tape, or conductive fibres that can withstand the washing process. According to Frunze (2019), future 3D knit fabrics will include other kinds of sensors, actuators and antennas creating the possibility for computer interaction through garments. The current use case of Sensoria has the conductive sensors laminated to their garments, rather than included into the manufacturing process (Frunze 2019).

Flatbed knitting machines vs large circular knitting machines

The technology's machinery is also separated into flat bed and circular knitting machines (Simonis, Gloy, and Gries 2017; Peiner et al. 2022; Underwood 2009). K.E. Lee (2017) states that there is a differentiation to be made between 3D seamless knitting and traditional seamless knitting, using flatbed knitting machines instead of circular knitting machines. The speed difference of production of the two can be 10 to 50 times faster on the circular knitting machine according to Peiner et al. (2022). This creates an improved cost reduction, compared to flatbed machines. Flatbed knitting is limited to discontinuous movement of carriage and the amount of possible feeding systems. The flatbed knitting has 4-6 feeding system compared to the up to 144 in circular knitting machine. The continuous movement of the needles in circular knitting makes it more suited for mass production. Products in circular knitting machines are produced as a roll of fabric, that needs to be cut and sown downstream in the value chain (Simonis, Gloy, and Gries 2017). However. Simonis, Gloy, and Gries (2017) also states that the knit-to-wear and 3D structures are currently not possible with circular knitting machines.

Simonis, Gloy, and Gries (2017) describes 3D Knitted fabrics made with flatbed knitting machines to be using a technique of needle parking to shape the garment. Either by extension or constriction, increasing or reducing number of active working needles.

Flatbed knitting machines has the possibility of individual needle selection, according to W.-S. Choi and Lee (2010). This type of machine is also greatly suited to make complex 3D knit structure due to its possibility to utilize different knitting techniques such as knitting, tuck, loop transferring, racking, float (or miss), and rib and purl (links-links) among other techniques (W.-S. Choi and Lee 2010). Another technique for creating 3D structures is partial knitting suggested by Liu, Li, and Yuan (2019). This method yields a Knittable 3D mesh with faces and a 2D knitting map that is pixel based, where the faces and pixels represent each stitch. This research also applied composite structures as textile reinforcement. The study of K.-M. Choi, Kim, and Song (2012) explored the use of jersey, rib and cable stitching, with two yarn types, fluffy thick and thin yarn type.

Drivers and Barriers for 3D knitting

Mechan et al. (2016) found several factors that influence successful integration of 3D, amongst others, were barriers of terminology, technology skills, machine capability and awareness of the process.

K. Foster and Istook (2017) proposes different drivers or barriers for the technology adoption. With advantages of reduced waste, increase of quality, versatility of patterns and reduction of human interaction with the final product, resulting in lower cost and reduction in human error. Mentioned disadvantages are costumer unfamiliarity of the technology and the advantages it brings, potential alteration of the current supply chain and adoption cost. K. Foster and Istook (2017) states that 3D knitting is at a "pre-diffusion" phase, meaning that it is not yet significantly spread into the industry. An article referenced in K. Foster and Istook (2017) by Ortt (2010) proposed at there are three systems of factors contributing to this phase, namely main organization, the technological system and the market environment. Mikahila (2021) also lists some challenges as programming the code for production, complete turnover of the current fashion market, high cost compared to conventional textile industry and slow technology adoption in the industry.

The dissertation of K.R. Foster (2017) studied factors that influenced U.S based companies' adoption of 3D knit technology. Foster wrote that a general industry practice in the standard textile manufacturing was slow rate of adopting new technology. During analysis of Foster's case studies, there was developed a theoretical framework for innovation decision making as a result of identified drivers and barriers. These are listed in table 8. Where the researcher stated that the most noticeable drivers were cultural and operational. The major barriers were found to be knowledge and operational.

Table 8 The Drivers and barriers for 3D Knit adoption, found by K.R. Foster (2017)

Drivers for 3D Knit adoption	**Barriers for 3D Knit adoption**
Culture	Knowledge
Operational	Operational
Consumer	Management
Demand	Capital
	Consumer

Foster also discovered 18 areas of influence, as illustrated in figure 9 describing the potential of adoption of 3D knitting technology.

Table 9 K. Foster and Istook (2017, 6) Areas of influence model, figure 1.

Area of influence:	
Managerial	Market/demand for product
Personnel/training	Perceived benefits
Investing/ Cash flow	Perceived limitations
Plan considerations	Supply chain flexibility
Size of firm	Logistics considerations
Inception of firm	Positioning of product
Sustainability	Quality considerations
Production processes	System openness
Reshoring	

Furthermore, K.R. Foster (2017) combined the drivers and barriers with the areas of influence, yielding a synthesis of the three, illustrated in figure 17.

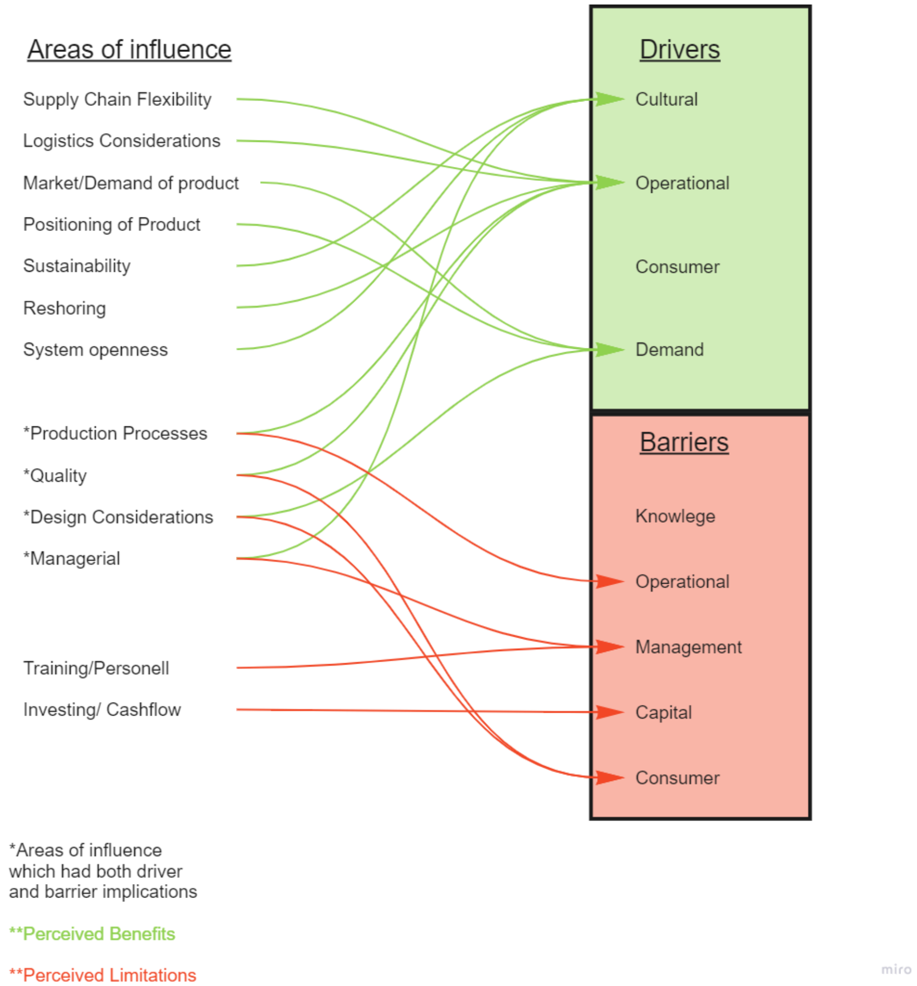


Figure 17 Synthesis of "Areas of influence, drivers and barriers", figure 20 of K.R. Foster (2017)

K.R. Foster (2017) concluded that education plays a major role for the successful adoption of new technology in the industry, where the downside of the technology is unfamiliarity with the benefits and supply chain potential in addition to cost of production adoption (K. Foster and Istook 2017).

Benefits of 3D Knit

W.-S. Choi and Lee (2010) discussed possible benefits and applications of 3D knit fabrics brought up by Mouritz et al. (1999) as following: 1. 3D knit fabrics are more "drapable" resulting in better formability. 2. It is possible to create more complex "near-net-shape" fabrics. (Shapes that are fully fashioned) 3. Certain 3D knit fabrics have properties of energy absorption and high impact damage tolerance. 4. A reduction in cost of production is possible, due to reduced production time. The 3D structures are achieved by knitting the rib and purls fabrics together using latch needles that are connected to a transfer spring, making the desired 3D shape shown in figure 18.

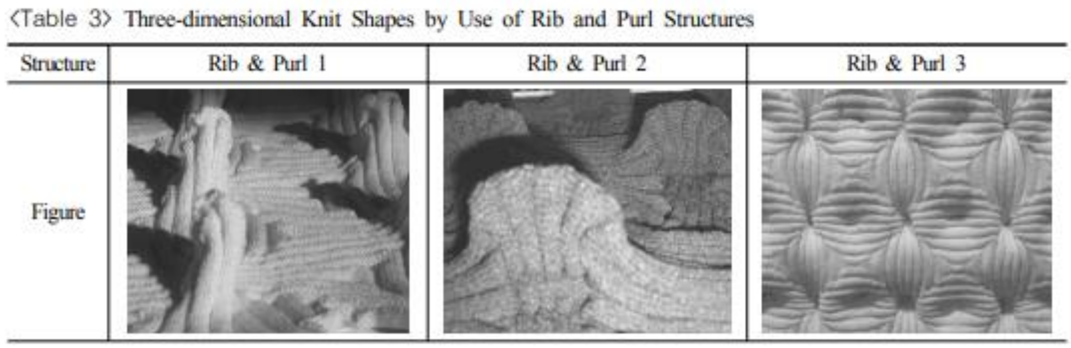


Figure 18 Illustration of different 3D shapes made by rib and purl fabrics. Source: (W.-S. Choi and Lee 2010, 114)

Additional benefits of 3d knitting are cost and delivery time reduction and products free of defects, increasing product performance (Maiti et al. 2022).

In addition, K.-M. Choi, Kim, and Song (2012) states that the current development of textile engineering, computer hardware and software has made it possible for textile industry personnel to make use of virtual 3D clothing design software.

Integrated 3D knit technology

Mechan et al. (2016) stated that there is a connection to the processes of 3D modelling, visualization and manufacturing, but that there is a lack of literature on the fashion products development within 3D knitting. The study uses the term 3D printing and is more focused on this instead of 3D knitting but draws parallels with the two in terms of the manufacturing process. "*3D-Integrated design technology*" is also brought up as a major component of 3D knitting, making modelling, visualization and 3D scanning a part of the designer's toolbox for virtual sampling (K.E. Lee 2017). The area of 3D Scanning of fabrics was explored by K.-M. Choi, Kim, and Song (2012), using a structured light 3D Scanner to acquire three-dimensional data from real life.

Designer and technician skill gap in 3D Knit – Challenges and solutions

J. Taylor and Townsend (2014) elaborates on a known skill gap of knitwear designers not familiarized with the current flatbed knitting technology. This problem is not something new, as it has also been explored by (Eckert 2001) back in 2001. The study of Eckert (2001) focused on British, German and Italian knitwear businesses depicting a communication breakdown between designer and technician. Eckert (2001) also states that *"Knitwear is inherently difficult* *to describe, as no simple and complete notation exists; and the relationship between visual appearance and structure and technical properties of knitted fabric is subtle and complex."*

The study of J. Taylor (2015) further discusses the fact that design and technology must be reunited to create innovation of products with 3D knit. It also acknowledges a skill gap of the technology and technicians. The major barriers found were the discussed communication bottleneck and skills gap in the technology. One Solution to this is presented by the paper as a creation of a new role, "the technical designer" or design teams consisting of both designers and technicians. This role is also described by J. Taylor and Townsend (2014), but with the name "Design Interpreter". In the work of Yang (2010), conducting research with Shima Seiki technology, they concluded that the "high fashion knitwear designer" is able to handle all aspects of design and production with flat v-bed knitwear machinery using computer produced knit data.

The culture of the industry needs to change as well, with focus on training of existing personnel the technology, and facilitation of teamwork. During interviews, the research of J. Taylor (2015) found that the industry focused only on the change of production of fully fashioned knitwear instead of the full impact it has, or put in other words, a lack of understanding. J. Taylor (2015) noted that the cultural organization in the company has been a significant factor for designer and technician mindset of working together. The need for manufacture specific training is requested by designers to build up "know how" together with the technicians.

The study of Liu, Li, and Yuan (2019) also states a lack of connection between the designer and the knitting machine, where they suggested that the process of transforming 3D models and patterns into knitting information is time consuming and that experienced technicians are needed. The study resulted in generating 2D knitting map from the designers' models. Where the final product can be knitted continuously, the 3D knit mesh show each of the stitch placement, using partial knitting as the significant technique and where the 2D knitting map is able to produce knitting information directly.

In J. Taylor and Townsend (2014) work, Shima Seiki is utilized as it is one of the providers of 3D knit design systems and flatbed production systems. The working approach of a knitting technician (Shima Seiki) and a designer is different, where the research suggests a more proactive approach to learning programming techniques. The designers are lacking the understanding of the complexity of the technology. The technology of 3D knitting is a combination of flatbed knitting machines, digital 3D designing tools and computing power. (Reflecting back on the section of 3D knit as an integrated technology) The change in the way of working shifts with the use of the new technology, where the designer is no longer hands on but is separated from the actual process of knitting and only left with the design process. J. Taylor and Townsend (2014) concludes with the whole garment machinery being developed to handle existing patterns produced at a more efficient rate, not yielding possibility for experimentation and innovation. When designers are collaborating with skilled knitting technicians, the technology is used to its full potential according to J. Taylor and Townsend (2014). In other words, the role of the designer needs to be redefined. Experimentation by engagement with the technology and collaboration is needed. Smith (2013) proposed a method for designers to re-engage with the technology to bring designers into the loop with a designer technology interface instead of just technical development.

Bendt (2016) explores the design aspect of 3D knitting, where it suggests that the designers creative process emerges already at the pick of yarn, rather than from the selection of textile fabric. They argue that most designers are familiar with graphic design software, but only a few have knowledge of knitting techniques, required for development of new ideas of shapes, surfaces and fabric designs in knitwear. Bringing up the conflict of interest of the designers and technicians. Where the gap in communication of idea and final outcome results in frustration for both the designer and technician.

3D knit in furniture industry

The paper of Raycheva and Angelova (2019) states the point of a tendency shift of applying 3D knitting in furniture design, and that the focus of designers has generally shifted over to textiles and knitting. The researchers discussed that designers could make use of ideas and techniques from other industries, for example the textile industry. The benefits of the 3D knitted furniture includes the accessories possibilities with it being easily transformed according to the need of the customer. The products are considered individualistic, making the products memorable and captivating, with the use of variation in colour, shape, detail, texture, and motives (Raycheva and Angelova 2019).

3D-knit technology and the impact on supply chain

In general, a shift in Europe has been towards the customized market, focusing on design competitiveness and innovative products (Chung, Kim, and Jang 2020). Bendt (2016) also discussed the fact that the industry has faced globalization and standardization of production, development, and cost savings, where designers generating new ideas lose a lot of the creative process the technicians get, programming the machines. Meaning that the technology can also have an impact on the supply chain, that is explained in this section.

In traditional textile manufacturing, Mikahila (2021) mentions the challenge of transparency of value chains and production methods. This is supported by the paper published by Power (2012) suggesting that (UK based) clothing SCs are not transparent. Meaning consumers know the materials used and where the materials originate from, but most often not the manufacturing technologies and its connected sustainability. Chung, Kim, and Jang (2020) concluded that current industry practices are overflowing the current demand in the market. The fabrics produced are not diverse enough due to the uniform nature of mass production. However, 3D Knitted fabrics make it possible for consumers to produce diverse and small quantity products to meet the needs of the individual. This will lead to reduced logistics costs, as there is no more need for import and export (Of clothing) as shops can produce customized clothing. Chung, Kim, and Jang (2020) also suggested that the fourth industrial revolution is supporting this new type of customization type of market and exact demand and supply.

3D Knit Supply Chain benefits and challenges

The explored literature mentions several benefits when adopting 3D Knitting technology in the Supply Chain. According to Maiti et al. (2022), possible SC benefits are a reduction of labour, time, cost and environmental impact as a result of reduced waste and requirement of raw materials. Bendt (2016) mention advantages of minimized yarn waste and post operations needed, with the option of local production and lean logistics as a result of closer supply chains. As mentioned in the “Integrated 3D Knit technology” section, the exploration of 3D Knit connected to body scanning is also reducing energy consumption even further. Lead time and waste is further reduced with this technology adoption as virtual sampling is reducing time to market and removing time consuming processes like creation of physical samples. (Huffa 2017) proposed that the technology’s machinery permit the elimination of human error if maintenance is sustained, while (Viramgama 2019) proposed that personalized goods provide new revenue streams and gives consumers and manufactures the possibility to turn digital designs into finished goods.

The need for training is mentioned as a challenge by Knitting Industry (2021), as the education is no longer as present locally, it is also proposed as a challenge for general education in a country. A case company study explored by Oxborrow and Brindley (2014), wanted to implement 3D knitting as a technology for production. The challenge of this adoption was that of what strategic direction the company was going to adopt, with either high volume at low cost, or lower volume with differentiation possibilities at a higher cost.

3D Knit as an Industry 4.0 driver in the Supply Chain

Colli (2020) states that 3D knitting is one out of many other enabling technologies within industry 4.0. While Y.-A. Lee (2022) argues that the fashion garment industry is late to make use of industry 4.0 technologies compared to other industries. Jin and Shin (2021) argues that the fourth industrial revolution technologies in general are addressing three major goals, namely hyper personalization, sustainability and productivity. With the major challenges of the fashion industry being unmatched demand and oversupply due to adoption of "push" (Production of forecasted demand, where the consumer is not stimulating the demand.) supply chains and eventually leading to end consumer and industry unease of sustainability, 3D knitting is just one of many technologies of industry 4.0 looking to solve these goals. A very important point made by the researchers Jin and Shin (2021), is that these goals are reachable both with and without industry 4.0 technologies. The moment to change the fashion industry is now, due to the current focus of sustainability an exposed practice throughout it according to (Nachtigall 2021), where resources used in the manufacturing process has a major impact on the sustainability.

Sustainability by using 3D-knitting technology

Sustainable manufacturing and production with 3D Knit technology

The textile manufacturing process is identified as an environmental hotspot, and the stage of garment production has the highest socio-economic costs (van der Velden 2016). Smart textile production is also seen as an unnecessary environmental impact if sustainable design is not applied.

The results of van der Velden (2016), discovered that 3D printed textiles (a form of 3D Knitting) digital design and local production is not more environmentally friendly that their conventional counterparts. However, the output, its use, and the impacts of the social aspects were positive. A real-life example of this is that of Knitting Industry (2021) where they state that the technology makes sense on a social and environmental level. They report that their production with 3D knitting also save 20-30% of raw materials compared to traditional manufacturing as there is no material waste with the finished goods.

Maiti et al. (2022) states that knitting machines are more environmentally friendly than their weaving counterpart. This is due to higher energy consumption and carbon dioxide emission in weaving manufacturing mainly as a result of a need for more than just one machine. 3D knitting is also contributing to lower waste and transport emissions, and the removal of post finishing operations (Maiti et al. 2022; Power 2012).

Sustainable sourcing and production

In general, a transition to less impactful fibres has started in the textile industry, but more than half of all clothing is produces with fibres that are man-made (Mikahila 2021). The yarns used with 3D Knit should be carefully selected to meet sustainability demands, either through organic yarns, made through a sustainable process, or recycled materials. Bendt (2016) explored the use of sustainable polyester yarn, commonly used in the automotive industry for safety features (seat belts and airbags) rather than for clothing. Testing out the mechanical properties of the yarn, resulting in new types of applications for fashion.

3D knitting technology by itself, also provides less environmental impact and energy consumption compared to its conventional knitting counterpart (Maiti et al. 2022). Huffa (2017) supports this claim where they state that the way of producing with 3D knitting yields a reduction of waste as the products are made in one finished piece with only need for finishing. Rosanne van der Meer in the work of Mikahila (2021) also brings up the possibility of taking a product apart and reusing the thread again is also a possibility with 3D knitted products. And the production of 3D knitted products by itself has 30% less material waste. Overproduction and large inventories are not considered a problem with 3D knitting, as it is produced on-demand and requires shorter supply chains. 3D knitting results in both reduced transport costs, emissions and waste.

Leading knitting manufacturers recognizing the potential of sustainability, have adopted solar panels to harvest renewable energy and made use of heat from production. Initiatives such as greeneries are examples of reducing carbon footprint (Maiti et al. 2022).

Areas of sustainable influence

K.E. Lee (2017) shed light on five phases of environmental sustainability of the textile industry. These are separated into sourcing of materials, the manufacturing process, at retail, during consumption and when the product is disposed after its intended use. K.E. Lee (2017) research also found three key concepts that lead to sustainable business practices, namely the corporate social responsibility, green SCM and ecological designs. The study found that stakeholder involvement is critical to encourage environmentally friendly production and consumption in the textile industry. J. Taylor (2015) looked at certain sustainability potentials of 3D knitting, were the potential of reduced workforce as a result of minimized finishing process, and engagement with the consumer through co-design and mass-customization and zero waste is the key for making the fashion industry more sustainable. Regarding the products life cycle, knitted products are generally kept for a long time, even down to generations. In addition, when wool garment is used, the raw material used is natural and decomposable, leading to no environmentally harmful microplastics (Dyrnes 2021).

Circular Economy perspective on 3D Knit

Sandvik and Stubbs (2019) looked into drivers, enablers and inhibitors for the creation of a textile-to-textile recycling system in the fashion industry of Scandinavia. One approach suggested to solve the industry's growing waste problem is that of circular economy. During the research, they found that inhibitors of adoption for such a system were limited technology, making it hard to separate materials, high costs of R&D and making supporting logistics. The supply chain complexity of stakeholders in product development was also one of the factors. Enablers were identified as new designs and material use, in addition to garment collaboration. The researchers suggested that such a recycling system could be made possible with adapting new technologies, creating: "Transparency, traceability and automatization" (Sandvik and Stubbs 2019). This new way of recycling also disrupts the entire value chain, where changes such as new practices in designing, collection of materials that are no longer in use, reverse logistics and legal frameworks (Realff 2006; Mathews 2015; Sandvik and Stubbs 2019).

The study of Salmi (2021) looked at implementation of CBM in 11 Finnish clothing brands and finding solutions to the linear way of take-make-dispose. It was shown that a transition to CBM is done over three sequential phases. Firstly, the lucrativeness of CBM transition should be evaluated through customer behaviour, value chain, ecosystem for recycling, stakeholder pressure and availability of recycled materials. Secondly the company at hand should develop circular capabilities and multi disciplinarity cooperation. And lastly it should start with design and customer behaviour influence through marketing and incentives (Salmi 2021). Concludes that a "learning by doing" approach is usually the key to a successful CBM adoption, even though it can take years or decades. The way of remanufacturing makes it possible to extend the lifetime of a good and maintaining its value (Bakker et al. 2014; Krystofik et al. 2018). An example mentioned is that of upcycling with the use of nylon fishing nets as raw material in 3Dknitting footwear (Krystofik et al. 2018; Zalando 2022).

Corporate social responsibility opportunities with 3D Knit

The study of Parschau and Hauge (2020) investigated if automation in production was stealing jobs, with a focus on South African apparel industry. It concluded that jobs are not disappearing due to automation in general, but that 3D knitting might bring this disruption, but on a local production level. For certain product types, they suggested that the west might reshore production due to the nature of the new technology (Parschau and Hauge 2020). Though two of the study's interviewees viewed this technology as a serious threat to sewing jobs in developing countries, mid to long term. However, also noted that SC investment and readjustments need to be made first before actively becoming a serious threat (Parschau and Hauge 2020).

Practical applications of 3D knit technology

3D knitting flatbed machine supplier: Shima Seiki

Several authors of the reviewed sources mentioned Shima Seiki Wholegarment as a major supplier of 3D flatbed knitting machines, i.e.: (J. Taylor and Townsend 2014; Smith 2013; Giglio, Paoletti, and Conti 2022; Power 2012) to name a few. Shima Seiki was one of the textile companies who pioneered 3D knitting machines, with their WHOLEGARMENT® in 1995 at International Textile Machinery (ITMA) exposition, helping them to revolutionize the knitwear industry. The knitting technology has experienced substantial progress since the technology was introduced all those years ago, in areas such as efficiency, flexibility, reliability, and capability for expanding patterns and product variety (J. Taylor and Townsend 2014).

Shima Seiki's Wholegarment is not only machinery, but also software, with their ApexFiz design system, connecting the 3D knitting physical machinery with the digital design process and making it more than just a flatbed knitting machine (Lawson 2021).

Shima Seiki's SDS-ONE CAD system can handle all stages of the knitting production. From planning, design, evaluation, and production itself are all included in the system (W.-S. Choi and Lee 2010). This is exemplified by Giglio, Paoletti, and Conti (2022), explaining that with the use of Shima Seiki's realistic fabric simulator it is possible to come up with new sample outcomes. Making it possible to control the process all the way from design to manufacturing with the system.

Shima Seiki's yarnbank is also mentioned as a significant new addition to their technology. Where yarn manufacturers can upload information about their product to an online platform. Included on this service platform is also 3rd party certification search of yarns (Yarnbank 2022).

Sayer, Wilson, and Challis (2006, 39) mentioned that: "*This flatbed 3D seamless knitting machinery allows creation virtually finished garments that require little make-up*." It's also mentioned by Sayer, Wilson, and Challis (2006) that such technology is helping the industry to "*reduce labor time by creating garments that are virtually complete, drastically reducing labor-intensive making-up*." Additionally, the technology contributes to explore more in terms of multiplying variety, minimizing the lot production, quick machine response adapting to changes, opportunity to meet customer needs, supporting wider range of materials and sustainable production while using minimum materials (Shima Seiki 2022b). WHOLEGARNMENT® eliminates the sewing process leading to a more efficient process, resulting in a demand driven production. Overall, the machine is more environmentally friendly and a sustainable solution (Shima Seiki 2022a). These machines perform in different industries such as home furnishings, fashion, automotive, healthcare, shoes and accessories, industrial materials (Shima Seiki 2022c).

With Shima Seiki's 3D-knit technology the knitwear is produced in one entire piece without having human resources to put together the end products. All this can be made directly on the knitting machine and consumes only the required amount of yarn for the specific item. Shima

Seiki has many positive advantages compared to traditional knitting machinery, specified in table 10 (Shima Seiki 2022c).

Table 10 Summary of Shima Seikis technology advantages (Shima Seiki 2022c).

Increased cost performance	• Increased knitting efficiency • Steadiness in mass production • Decreased level of defect rate • Decreased level of running cost • Rapid creation of knitting program • Saves power
Sustainability	• Eliminate unnecessary labor and material • Minimizes fabric loss in terms to stable production • Integrated design system and software called SDS-ONE APEX
Numerous-range, small – lot production	• Support of on-demand production • Mass customization possibility for end customers
Instantly response	• Just in time (JIT) production • Short delivery time

As the machinery and technology of Shima Seiki is going to be the main focus of this thesis, it is worth mentioning that they are not operating in a monopolistic market. One of their main competitors for flatbed 3D knitting machinery are Stoll Knitting (Chung, Kim, and Jang 2020; Underwood 2009; Power 2012) as well as Santoni Knitting machinery (Underwood 2009; Knitting Industry 2021; WKS™) amongst other competitors of varying size.

Norwegian knitting production at Rauma Ullvarefabrikk

The Norwegian factory of wool clothing, “Rauma Ullvarefabrikk” is one of the few factories in Norway that has utilized the technology of 3D-Knitting. According to the CEO of Rauma Ullvarefabrikk, the assembly of product before 3D-Knit technology took around an hour. With the knitting of a backside and frontside in addition of arms. But today it takes only around 10-15 minutes to assemble (Dyrnes 2021). At Rauma Ullvarefabrikk they have are using the machines for sweaters, socks, hats and mittens (Rauma Collection 2022).

This factory is also using domestically sourced wool from either Norwegian white sheep (crossbred wool) or Norwegian short tail landrace (Rauma Collection 2022). The specific supplier they use is Norilia which sorts and classifies the raw wool at local stations in the country. The wool form Norilia is quality marked with “svanemerket” representing a minimal usage of chemicals, water and energy, maintained animal welfare and good working conditions for workers (Norilia 2022). The leader of Norilia wool department, Marion Tviland states:

"Wool is a nature fibre- 100 % natural and renewable. It is also biodegradable and does not contain any microplastics" (Tviland 2021) (Own translation)

Gaps

The literature screened consist of 59 included relevant scientific articles and grey literature. Overall, the review shows a focus on possibilities of the technology and the technologies connection to supply chain integration. The technology is also an enabler of new and different business models and design approaches. This brings further research to be affirmation and validation of results through the recommendation of applying the same strategies in other locations, industries, or practices. Throughout this systematic literature review, there are certain reoccurring areas within the research agenda. The designer's role in technology adoption, Lack of designer education in the technology and unwillingness to adopt.

This research aims to fil the gap of a practical approach to the technologies impact on the integrated supply chain. There is also a reduced amount of research on the furniture industry. However, this work will build information towards the sustainable growth of the industry. It will also answer what kinds of business model will be suitable for the client companies, and possible other Norwegian companies wanting to explore the technology potential. The thesis also contributes to exploring the differences between a luxury fashion garment application and a furniture application, to explore the differences between the industries, and how the technology can be an enabler for an integrated supply chain.

Areas for future research

During this systematic literature review, some of the academic articles listed some areas for future research within 3D Knitting. These are summarized in table 11.

Table 11 A summary of suggestions for future research found during the systematic literature review.

Suggested Future research	Authors
Exploration on possibilities for diversification and development of 3D design.	Ciobanu (2011)
As their research of Sustainability risks in the SC focused on Bangladesh textile industry, an expansion to other industries and	Raian et al. (2022)

locations was suggested. Larger sample sizes and investigation between risk factors and groups was also suggested.	
Even though the research is more mature, their suggestion for future research is still relevant. They suggested research into the development of design functionality with 3D Knit technology.	Smith (2013)
Four different future research areas were found by Yang. Development of new models for knitwear garment construction, geometrical Knitwear that can be worn in several ways, Exploration of combining the technology with new yarn types and research into deliberate failure of knitted garments, post finishing.	Yang (2010)
Research into a mold system to support the application of knitted textiles for architectural and structural application to textile reinforced composites.	Liu, Li, and Yuan (2019)
Same area as Liu, Li, and Yuan (2019), Peiner et al. states that specific research into molds or retaining shape for the 3D garments within large circular knitting machines. Another research area is also that of making lining materials with large circular knitting machines to explore a new market potential. Research into pattern digitalization is needed to fulfil 3d Knit fabric potential, and to reduce development costs.	Peiner et al. (2022)
Development of designer education, focusing on the technical and practical aspects of knitting. This includes training in standardized design programs, with libraries of patterns and a focus on awareness of sustainability aspects of 3D Knit production for the students. This is estimated to result in designs and fabrics that are more innovative.	Bendt (2016)
Research into low end 3D Knit machines at its possibilities of personalized garments to be adopted by small business owners or retailers.	Chung, Kim, and Jang (2020)
The study for adoption 3D Knit technology was limited by geography, time and founding. The same research should be conducted in other locations to validate the results and see if the	K.R. Foster (2017)

same conclusions can be met. Barriers for adoption of the technology can be explored by interviewing or surveying companies that currently have no relation to 3D Knit technology. Research could also focus on key components necessary for technology adoption after looking at the current SC.	
Surveys or interviews with 3D Knit programmers of education needs for future employees. Examination of the cultural match of technology manufacturer and customer (production company) and an assessment of demand and supply of knitting programmers.	K.R. Foster (2017)

The future research suggestion that is most applicable to this thesis is that of K.R. Foster (2017) as the suggestion is to explore barriers and drivers for 3D Knit technology adoption at other locations to validate the results. The aim of this thesis is to investigate the key components for technology adoption will also be explored during the work of this thesis.

3.3. Chapter summary

SCM is a relevant topic to be able to understand the basic principles. However, in this thesis, this theory helps map out the current SC of Ekornes and Devold and thereby see the changes by implementing 3D knitting technology in the SC. Additionally, the value chain perspective is important for this thesis as it helps to illustrate where changes in value adding activates in the client companies when adopting the technology. Mapping the value chain helps to identify the effect the changes have on the strategic advantage the companies have over their competitors. Along with the SC and VC, relevant literature within textile-based industry were discovered to map the current problem the industry is facing.

When implementing a new technology in a SC, it is of importance to consider the stakeholders. Stakeholder theory is a relevant theory for this study to see which changes the stakeholders would meet by adapting the new technology. Furthermore, triple bottom line contributed to see how sustainable such technology can be for the company regarding the profit, people, and the planet. Ekornes and Devold take use of a linear approach where the concept is “take-make-dispose.” To find applicable solution and suggestion for the companies to move towards CE is by including approaches and theories as CEBMs (sharing platform, product life extension, and recovery and recycling), UN sustainability goals (number 8, 9 and 12), the 4 Rs (Reuse, Rethink, Redirect and Reduce) and close-open or narrow loop.

With the systematic literature review regarding 3D knitting technology, an understanding that the technology is established in the market but is not mainstream by manufacturers. The review also provided broad knowledge about the technology on how it provides sustainable growth and how it affects the supply chain. Additionally, there is relatively few publications about the technology, especially in Norway. Ekornes (early stage) and Rauma are two of few companies who make use of the technology. The review also provided knowledge on how the technology can work for companies who want to make use of it (Devold of Norway and Nansen by Devold). The 3D Knitting technology is not only limited to the actual printing but is a digital technology with integrated functions across consumer driven design, planning, production and reproduction, or an enabler of integrating the supply chain as explained in the previous section. During the SLR, sustainability comes up as a natural topic, and relevant findings for this thesis is included. As the SLR includes a future research section for academic sources, this can help this thesis to uncover new areas for future research and answer some of the suggested future research.

4. Research methodology

The previous chapter gave an overview of what approaches has been done to implement 3D-knit technology in the supply chain, and how it has been affecting different companies. This chapter presents the methodological choice that have been made to this research. To include the practical and philosophical issues regarding the topic of this study, of relevance to differentiate between methods and methodology (Kirsch and Sullivan 1992). The method addresses techniques, strategies, and tools for gathering evidence regarding the research. The methodology, on the other hand, is the choice of strategy, process and action plan that is to determine the specific method needed. The difference between method and methodology can easily be compared to food preparation. Where method is the ingredients needed to complete the recipe and methodology is the recipe (Mathison 2016). Mohajan (2018) stated that *"Every research must involve an explicit, disciplined, systematic (planned, ordered, and public) approach to find out most appropriate results."*

With the aim of getting the best results in this research, the "research onion" model introduced by M. Saunders et al. (2019) is applied. This model, illustrated in figure 19, describes the stages through which a researcher must pass when developing an effective methodology (15writers.com 2022).This model, illustrated in figure 19 describes the stages through which a researcher must pass when developing an effective methodology (15writers.com 2022; M. Saunders et al. 2019).

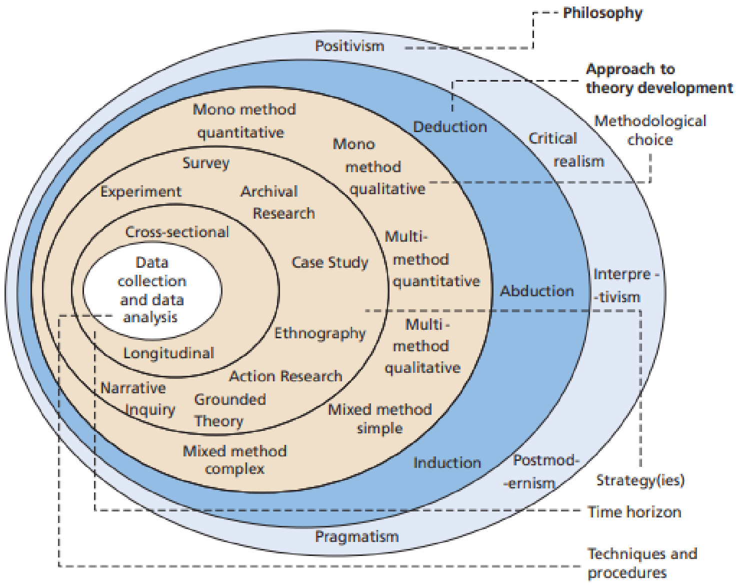


Figure 19 The "research onion" by M. Saunders et al. (2019)

The following sections are divided according to the "research onion", each starting with a brief introduction to its elements. Section 4.1 explores the research philosophy, and what approach is considered in this research. Section 4.2 build-up on the approach chosen in 4.1, and this section involves the approach to theory development. Sections 4.3 consider the research design, and section 4.4 addresses the unit of analysis. Section 4.5 presents the research strategy. Further, section 4.6 considers the data collection in this study. Lastly, the section ends with an explanation according to research quality.

4.1.Research Philosophy

The first layer of the "research onion" is the research philosophy, where it refers to the set of theories concerning the nature of the existence being explored. Further it addresses with assumptions, knowledge, and nature of the study. Whereby it consists specific way of developing knowledge in a particular field. (Dudovskiy 2022b) The knowledge development one is embarking upon does not need to be a dramatic new theory, it could be a problem that an organization is fazing. M. Saunders et al. (2019) stated that "*Whether you are consciously aware of them or not, at every stage in your research you will make a number of types of* *assumptions. These include (but are not limited to) assumptions about the realities you encounter in your research (ontological assumption), about human knowledge (epistemological assumptions), and about the extent and ways your own values influence your research process (axiological assumptions)."* Overall, these assumptions together shape the understanding of the research questions, the methods used, and the understanding of the findings.

This research layer is assembled by 5 elements, namely Positivism, Critical realism, Interpretivism, Postmodernism and Pragmatism. Positivism characteristics an idea that states scientific knowledge is acceptable knowledge of this world. Unlike Positivism, the Critical realism and Interpretivism does not support scientific knowledge fully, because Critical realism and Interpretivism consider the reliability together with the knowledge and they consider qualitative research with analysis to get their outcome rather than quantitative – or statistical analysis (AllassignmenthelpUK 2019). According to Mora (2012), Postmodernism is *"real life phenomena are replaced by representations."*. Further Patton (2015) mentioned that it somehow overlaps with other concepts like pragmatism, and he stated it as "It also seeks to account for the possibility of criticism and to maintain commitments to freedom and progress, however redefined." Lastly, the Pragmatism focus on considering the practice and the theories. However, such research philosophy acknowledges ideas that are relevant with the condition of if the ideas supports the actions (Dudovskiy 2022a).

The clinical companies have contacted us to "seek help" in finding out if 3D-knit technology can be a sustainable alternative in their supply chain. Furthermore, also about how efficient such a process can be compared to their traditional production. In this study, the most suitable research philosophy would be Pragmatism. This is because, it depends on what information is provided from the company (companies) to decide whether the method is qualitative, quantitative, or mix of the two (Dudovskiy 2022a). An important part of such an approach is that the method can be chosen according to the information provided from the companies. M. Saunders et al. (2019) elaborated that "[pragmatists] *recognize that there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture and that there may be multiple realities*" With this, it is notable that the most fitting solution for these two companies in Norway might change if they were located in another country, because there are numerous factors that can affect the solution and one example would be laws and regulations. However, the result also can change according the researcher. M. Saunders et al. (2019) emphasizes the belief within that pragmatism is the best choice of research philosophy for this research, because it *"aims to contribute practical solutions that inform future practice. Researcher values drives the reflexive process of inquiry, which is initiated by doubt and sense that something is wrong or out of place, and which recreates belief when the problem has been resolved."* Further M. Saunders et al. (2019) states that *"As pragmatists are more interested in practical outcomes than abstract distinctions, their research may have considerable variation in terms of how "objectivist" or "subjectivist" it turns out to be."*

Key point for the pragmatism is problem solving (Morgan 2014). The research philosophy pragmatism is examined regarding ontology and epistemology. First thing first, ontology is the study of existing. It explores the nature of existence; What it is and how these things are classified. Secondly, the epistemology can be described as knowledge that is familiar and how one can gain that knowledge. It basically focuses on the nature of the knowledge and its scope. In terms of this study the ontology is a foundation, providing an understanding to what the reality is and how it can be properly understood. Furthermore, how one can classify if 3D-knit can give a significant impact on sustainability in the company. Overall, Ekornes AS has started to use the 3D-knit technology in their production, and this can help constitute the reality and understand the existence to develop such technology in Devold of Norway.

4.2. Approach to theory development

The second layer of the research onion is approach to theory development. In a research it is important to review the existing theory to accomplish the theory development. However, such research methods help to differentiate the relationship between theory and research (Spens and Kovács 2006). According to M. Saunders et al. (2019) the approach can be eighter deduction, induction, or abduction. This part would be chosen regarding earlier research aims, limitations etc. Inductive researches start by collection data that are relevant to the research. After the data is collected, it is analysed to find a pattern to develop a theory that can explain the patterns (DeCarlo 2018). DeCarlo (2018) states that "*they move from data to theory, or from the specific to the general."* In deductive approaches, the process is handled in reverse compared with induction approach. Where deductive approaches start with social theory and then test it with collected data that are relevant (DeCarlo 2018). However, such approach focuses on what others have done theoretical and further test hypotheses that can develop the theories that have been examined (DeCarlo 2018). Abductive approach is described by M. Saunders et al. (2019) as

"Instead of moving from theory to data (as in deduction) or data to theory (as in induction), an abductive approach moves back and forth, in effect combining deduction and induction." Such approach matches more towards business and management research, because *"Abduction begins with the observation of a `surprising fact`; it then works out a plausible theory of how this could have occurred."(M. Saunders et al. 2019)*

The abductive approach is what suits this research the most because it explores two companies who want to implement 3D-knitting technology in their supply chain. As previously mentioned, such an approach suits more towards business and management research, because the initial step is observing the companies within what their thought is and how their traditional supply chain is etc. As mentioned by Gordon (2022) "*The abductive reasoning method is the logical process of making observations and seeking the hypothesis that would best fit or explain those observations*." This research is abductive because it starts with observations and then develops the theory that would be the best match.

4.3. Research design

According to Akhtar (2016), the research design provides an applicable framework for a research. Further Akhtar (2016) states that *"A very significant decision in research design process is the choice to be made regarding research approach since it determines how relevant information for a study will be obtained."* However, research design includes research methods and techniques that have been developed by researchers. It explains the research topic and what research that are applicable. There are five type of research designs and they are as follows: Descriptive-, Correlational-, Experimental-, Diagnostic-, and Explanatory Research Design (Team Leverage Edu 2021). According to M.N.K. Saunders, Lewis, and Thornhill (2016) the descriptive research gives an exact description of a person or persons, events, or circumstances (Akhtar 2016). Further Akhtar (2016) adds in that such design *"offers to the research portrays an accurate profile of described relevant aspects of the phenomena of interest from an individual, organizational, and industry-oriented perspective."* Whereby, the explanatory research addresses a situation or a problem to be capable to explain the relationship between variables in a study (M.N.K. Saunders, Lewis, and Thornhill 2016). Regarding Seeram (2019) the *"Correlational research is a type of nonexperimental research that facilitated prediction and explanation of the relationship among variables."* Compared with correlational research, the experimental research contains a hypothesis whereby the researcher has the opportunity to manipulate a variable. Also, the variables can be measured, calculated, and compared, as the researcher collect the data that are necessary and the result with either support or reject the hypothesis. Voxco (2022) describes it as: *"In a diagnostic research design, the researcher is trying to evaluate the cause [and effect] of a specific problem or phenomenon."* Additionally, Vach et al. (2021) states that by using diagnostical research, the research have the ability to improve the distinction between two well-established states. Further, the research also compares the situation to the existing current possibilities.

However, with the discussion above with the different research design, it is decided that the applicable research design for our study would be Diagnostic Research Design. Such methods helps with learning more about the factors within implementing such technology by finding the foundation of the issue, diagnosis of the issue and lastly finding a solution for the issue (QuestionPro 2022).

4.4. Unit of Analysis

Gorichanaz, Latham, and Wood (2018) positions it as "In social science research, the unit of analysis is the main entity under study." Whereby, organizations are one of the potential units of analysis in social science research (DeCarlo 2018). He also wrote that the unit of data significantly differ according to if the study is based in quantitative or qualitative research designs. And defines unit of analysis as *"the entity that you wish to say something about at the end of your study, and it is considered the focus of your study. A unit of observation is the item (or items) that you observe, measure, or collect while trying to learn something about your unit of analysis" (DeCarlo 2018).* The unit of analysis and unit of observation may in some cases be the same, for instance if the researcher want to explore social media addiction, the unit of observation would be students. As the researcher has the purpose of saying something about the addiction among the student regarding usage of the social media (DeCarlo 2018).

Regarding our study the unit of analysis differs for each research question mentioned in this thesis. In RQ1 the unit of analysis is the companies SC and the unit of observation that will give us the understanding of the SC is the employees in the organization. The observation and the unit of analysis for RQ2 is the organization, to find out which barriers that the companies can face by the technology. The same is applicable for RQ3. This is illustrated in table 12.

Table 12 Unit of analyses and unit of observation. Inspired by DeCarlo (2018)

Research question	Unit of analysis	Data collection	Unit of observation
RQ1: How would the traditional supply chain be affected by the implementation of 3D knitting technology?	Supply chain	Interviews, observation, email inquiries, document collection, web pages.	Organizations (the client companies)
RQ2: What barriers do the companies face when implementing 3D knitting technology compared with the traditional supply chain?	Organizations (the client companies)	Systematic literature review, observation at the 3D-knit lab, interviews	Organizations (the client companies)
RQ3: How can 3D knitting technology help Ekornes and Devold move from a linear economy towards circular economy?	Organization (the client companies)	Literature review, interviews, email inquiries, document collection, web pages	Organizations (the client companies)

4.5.Research strategy

As mentioned by Mackenziecorp (2014) *"A Research Strategy is a step-by-step plan of action that gives direction to your thoughts and efforts, enabling you to conduct research systematically and on schedule to produce quality results and detailed reporting"*. However, research strategy is an important part because it describes the rationale for this research, and the experiments done to move towards the desired goals (Mackenziecorp 2014). There are numerous of possible strategies, it is chosen depending on if the research is qualitative, quantitative, or mixed methods. In this research the most suitable research strategy is clinical management research method.

Since this research addresses a problem that was presented by client companies, the application of a CMR is a viable option. As described in the book Research methods for operations management by Karlsson (2016): *"The key characteristics of the clinical approach are that the researcher is asked to intervene in a diagnostic relationship and its concurrent development of the researched object, that is a company or other organization and the research field."* Such a study aims to solve a "problem" much like one would get if visiting a university hospital as a patient to get a cure or remedy. It is done by a combination of observation and intervention as an expert consultant (like a doctor/researcher) as described by Schein (1987) "*The Clinical perspective in Fieldwork*". From the definition of Karlsson (2016, 269), we see that CMR fits well with the design of this research, the diagnostic design. *"In the clinical model an important distinction is between process consultation that highlights helping the client to solve his or her own problems and expert consulting that puts the clinician into a doctor or expert role from which he or she prescribes solutions."*

In this research, Ekornes and Devold of Norway are the “organizational patients/clients” with the problem/challenge of needing to gain knowledge of the implications of implementing 3D-knit technology in their supply chain to gain sustainable production. This study and it is “clinical researchers” aim to fix this specific problem by uncovering the actual implications of an implementation of such a technology as the “prescribed solution”.

Some of the factors playing a role in choosing this type of method are, among others, the company having a problem, compared to say case research, where there is a wish to explore an issue. The purpose of the research is to solve the “problem” (implications of 3D-knit) and exploring possible tools. Compared to action research, where the purpose is to address a practical problem. Another important denominator for choosing this type of method is the level of analysis. The companies “get help” from the researchers or “clinicians” to explain the symptoms, reasons, cures, and effects for their problem. This method provides the companies with the opportunity to gain a deeper understanding and a rich insight than one might find with other types of methods. In the end of the thesis, this way of approaching the issue, can provide information about the causes and relations with choices of strategic nature like the change from a linear economy to CE, and the issue of 3D knit implementation and what effects it might have when intervening with the supply chain. According to Karlsson, gathering of data in clinical research is done by inquiry and is focused on the client and the problem at hand. In this project, this is done through Ekornes and Devold to get information as close to the problem as possible. As of the already acquired knowledge of the project, the use of a mixture of different qualitative and quantitative methods might be applicable. Quantitative methods of cost benefit analysis could be appropriate to uncover the possible monetary implications of 3D-knit investment, however qualitative interviews with design experts, end users and executives can be used to gain insight on possible social impacts, such as change in stakeholder structure.

It is also necessary to use literature review to collect data on a given topic, and as mentioned by Robert K. Yin (2014), it is easier to find the right research question by investigating relevant literature for the chosen topic. The literature is collected, and systematic literature review is done within 3D-knit technology and how it can affect the supply chain and how 3D-knit technology can give sustainable advantage. By doing so, the research gap in the selected area of the sub-research question was uncovered, regarding answering the main research questions.

As mentioned in Karlsson (2016) *"The researcher collects in-depth data through interviews, documents and often trough participative observation",* shows that these ways of getting information would be viable for this research and it helps the research questions. Since 3D-knit technology is not utilized that much in the market, there is a lack of information about implementing 3D-knit technology in a company. The data collection methods help gaining information and provides the ability to test against the theory that have been done regarding 3D-knit technology.

4.6. Data Collections

The last layer in the research onion is data collection and data analysis. Baker (2020) states that "*Data is knowledge, and knowledge is power*". However, by collecting data and analysing them appropriately, one can find where the problem relates and how a researcher can build strategies and come up with suggestion according to the research. Further Baker (2020), explain that *"Data is a collection of measurements or observations that represent the real world."* Adams, Khan, and Raeside (2014) says that data are facts and numbers that are collected to be used in records and statistical investigation. This information is used to find out if the research is qualitative, quantitative, or mixed methods (Adams, Khan, and Raeside 2014). Qualitative methods consider descriptive data of which is written or communicated words and observations behaviour (S. Taylor, J., Bogdan, and DeVault 2015). Quantitative methods collects numerical data (Sukamolson 2007). These methods together are considered as mixed methods.

In our research, the chosen method might change according to information collected from the companies. If enough variation in the data gathered from the company a use of the mixed methods is applicable. If not, the qualitative method is considered. As observed from the collected data, the thesis is mainly a qualitative study (Jacobsen 2015).

The book by Adams, Khan, and Raeside (2014) shows that there are two sources of data in research, primary and secondary data. However, primary data are the original data that are collected for a specific research problem. This could be collected by using procedures that suited the research problem the best. The data collected is part of the increase of the existing store of social knowledge. These materials are available so other researchers in the general research community, can reuse and this is then called secondary data (Hox and Boeije 2005). Hox and Boeije (2005) states that "*Most of the secondary data sets contain quantitative data;*

that is, the information consists of studied objects whose characteristics are coded in variables that have a range of possible values. A qualitative database consists of documents, audiocassette or videocassette tapes, or the transcripts of these tapes." The chosen research strategy states that in clinical research every intervention count, meaning the very first contract from the company to recommendations suggested by researchers, and the application. All the data collected in this study is important in terms of answering the research question. Further, the primary data is conducted by transcripted interviews, meeting notes, observations, documents, email correspondences, and client companies' websites. The following section presents our primary and secondary data collections.

In addition to the primary data collection from the companies, literature sources support the findings. The literature has added knowledge of what information is available today, and what information needs to be covered through primary data collection.

4.6.1. Primary data: Interviews

The case of this study, the main strategy for data collection was interviews, observations and email inquiries. As a researcher, according to Gill et al. (2008), by using interviews one can "explore the view, experiences, beliefs and/or motivations of individuals on specific matters". For example, how 3D-knit technology could affect their production today. However, Gill et al. (2008) and Fox (2009) states that interviews provide deeper understanding and knowledge of social phenomena. Firstly, the interview process is described before other strategies conducted to collect information for this research.

First, an introductory meeting was held with the two companies, Ekornes AS and Devold of Norway. This provided the opportunity to talk to the product developer from Devold of Norway and the product compliance and sustainability developer from Ekornes.

In the second step, a prearranged interview guide was provided for the companies. The interview guide was helpful tool to cover the main topics of the study. It is important to not follow it strictly, and instead use it as a guide to collect similar type of information from the companies (Kallio et al. 2016). A semi – structured interview was conducted, where three interviews with the client companies and their SC were accomplished. The questions were made in a supply chain structure where the initial questions were about the production, the suppliers and lastly the customers and stakeholders. For the first interview with Ekornes, an interview guide consisting of 47 questions were prepared. For the second interview, 26 question were prepared. With Devold of Norway an interview guide consisting of 45 questions was used. The interview guides that applied for the companies are displayed in Appendix B. The interview guide was sent/provided beforehand to the contact person from each company. And it made the company representatives able to prepare in advance. When executing the interviews, follow-up questions were asked regarding their answers, so that a clear understanding of their issue and current situation was gained.

However, the interviews were executed online, because of today`s situation with Covid-19. The data tool used to conduct the interviews were zoom, because this tool supports audio and video communication. It also provided the opportunity to ask the interview objects if they wanted an audio or video conversation. Everyone accepted the camera to be on, and it made it a little less demanding to have a digital meeting since included body language observed during physical meetings. As the situation is today, the virtual solution was not an issue. The interviewees have been anonymised by a mutual agreement, as the interviews was conducted in confidentiality (The Chicago manual of Style Online 2022). The interviews were organized with the companies between February 11^{th} and 25^{th}. Where the interviews lasted for approximately 1,5 hours and some 2 hours. After each interview, the answers was discussed by the researchers. The interview was also transcribed and sent to the interview objects, following the current GDPR rules (NSD 2022). This gave the interview objects the opportunity to remove or add in information, so they could be satisfied with the interview result. The interviews and the transcripts were completed in Norwegian. In total of all interviews, it amounted to 32 of pages and 16 879 words across the transcripts.

After the transcription, some follow-up questions were sent to the company’s email. This resulted in 7 number of emails from Ekornes and roughly 4 pages, 13 from Devold and roughly 4 pages, 2 from 3D-knit lab and roughly 2 pages, and 1 from Nansen by Devold.

The first interview was executed with two employees from Ekornes. The contact person working with the Product Compliance and sustainability in Ekornes, where they secure all the products they have in accordance with laws and regulations in the countries where they produce their products. The second interview object was the product developer for Ekornes. This person has a long work experience as a product developer for Ekornes and for the last four years worked with 3D-knit technology. The product developer also works with prototyping different solution with 3D knit technology where they collaborate with 3D knit technology lab.

The second interview was executed with three employees from Devold of Norway. Interview object one was the contact person from the company based in Langevåg, who is a Product Developer working towards the production they have in Lithuania. The second interview object has the responsibility for their production in Lithuania. The third interview object is based in Oslo and have the responsibility for product and business development for the company.

The third interview was accomplished after the observation at Ekornes with the contact person from the company. Which provided the opportunity to ask follow-up questions regarding the observation.

4.6.2. Primary data: Observation

Observation is a form of data collection method, where Gill et al. (2008) stated *"some of the most important findings in research have been accidental and captured from observations of the failures of other data collection methods".* The first observation was executed at the 3D knitting & Technology lab (3D knit lab) in Sykkylven. This observation was organized to increase the understanding of how 3D knit machine works in practice, where follow up question were asked along the way. A summary notes where executed to make sure that every necessary detail was collected from the observation (Gill et al. 2008). Additionally, as clinical researchers, discussion was elaborated to cover every space that one may have experience and to make sure that no important information gained were excluded.

The second observation was completed at Ekornes to see how their production work. Before the visit, questions regarding their supply chain were prepared. Such observation made it easier to understand the collected data from the interviews, and increased knowledge about their production. Along the observation, notes were taken to discuss after. Additionally, summary of the visit was made to make sure that all collected information were gather one place.

In total of all notes that was made after every observation, it amounted to 12 of pages and 4 596 words.

4.6.3. Primary data: Documents and webpages

According to Bowen (2009) "*document analysis is a systematic procedure for reviewing or evaluating documents – both printed and electronic (computer-based and Internet-transmitted) material.*" We have also used primary data sources within reviewing documents that are online and sent by the client companies, their web pages, catalogues for Ekornes Stressless dining chairs and relevant news articles. This information helped us to gather information about Ekornes and Devold of Norway. The collected data regarding documents and webpages were investigated and interpreted it to provoke meaning, increase understanding, and develop experimental knowledge (Bowen 2009). Additionally, the chosen research strategy provides the opportunity to cross-check the information that is explained by the corresponds from the documents that have been sent and what is on the websites.

The data collection is summarized in the following figure 20, a large format of the figure can be found in appendix D.

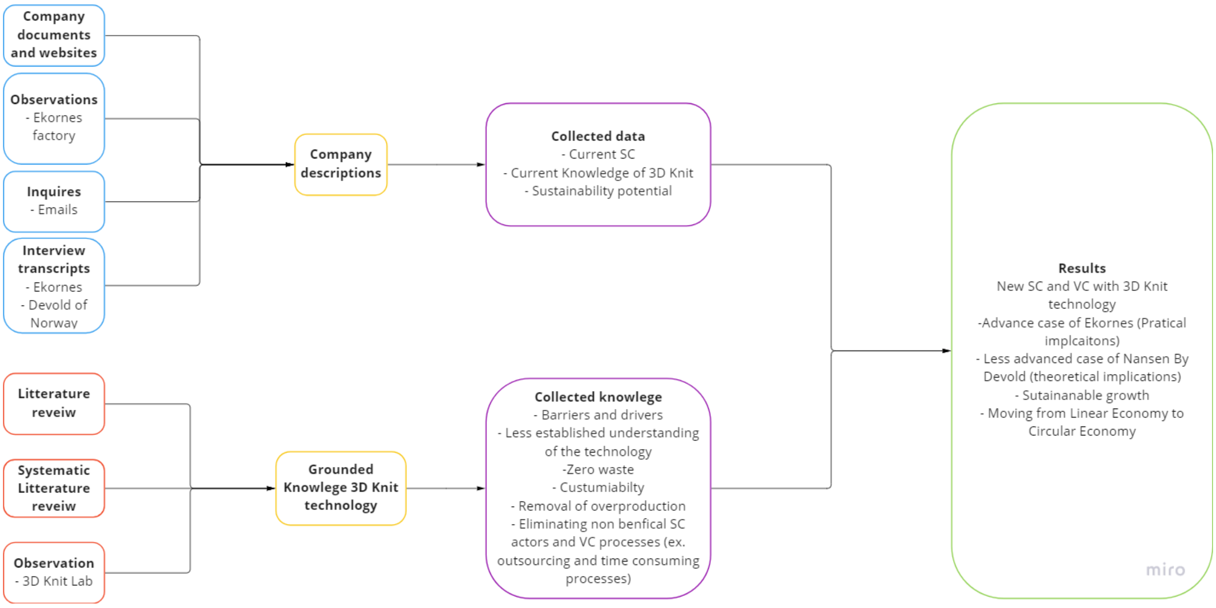


Figure 20 Summary of the data collection, created by the authors.

4.7. Research quality

Moss (1994) states that "without reliability, there is no validity", because according to M.N.K. Saunders, Lewis, and Thornhill (2016), reliability and validity plays a central role to judgment the quality regarding the research. Middleton (2019) states that *"they indicate how well a method, technique or test measure something."* Reliability contains the consistency of a measure, and the validity contains the accuracy of a measure. This section explains how the research meets the reliability, construct validity, and that the study can be checked by exiting literature that exists (R.K. Yin 2009; Hansen and Wingaard 2021).

M.N.K. Saunders, Lewis, and Thornhill (2016) defines the construct validity as *"extent to which your measurement questions actually measure the presence of those constructs you intended them to measure."*, and R.K. Yin (2009) defines the construct validity as *"identifying correct operational measures for the concepts being studied".* According to Ellram (1996) "*Three elements are associated with the establishment of construct validity: using multiple sources of evidence, establishing a chain of events, and having key informants review the case study research*."

Multiple data Sources

One of the primary elements in research for construct validity is triangulation and it also collect numerous data source to validate evidence (Ellram 1996). Triangulation contributed to eliminate bias regarding interviewing human subjects by combining multiple information. In this clinical study, the obtained information is combined with web pages, documents, use of direct observation, inquires on emails, and with this argue that this study fulfil the triangulation in multiple data sources (Ellram 1996).

Maintain a Chain of Evidence and draft Review by key Informants

Ellram (1996) states that "*This second element of construct validity relates to the ability of the reader of the case study to follow the case study data and analysis from the initial formulation of the research questions to its final conclusions*." However, this paper was continually provided to the supervisors, by sending drafts. These drafts where carefully and critically reviews from start to finish. Additionally, feedback from external review was also considered.

This research ensures reliability by gathering information in a systematic and verifiable manner. As an example, interview guides made it possible to ask the same questions to both companies. Having premade questions to the observations, made it possible to ensure that what the literature explains about how 3D Knitting work, also applies in practice. The systematic literature covers a significant amount of basis, while the key interviewees provide information about how the technology works in practice.

5. Findings

In our clinical study of the textile-based industry in Norway, we look at the implementation of 3D-knit technology in the existing supply chain of Ekornes and Devold of Norway. Further, what advantages and disadvantages such technology can give as an outcome towards sustainability compared with the traditional production. This chapter presents the findings from our primary data collections regarding interviews and inquire on emails, observations, documents, and webpages. Informal conversations before, during and after the observations (visits) enrich what has been said in the interviews and what us, the clinical researcher saw during the observations. This also helps to verify what has been said in the interviews, as the interviewees are in a more relaxed setting. From the interviews the possibility presented itself to map their current supply chain and find what they expected from this master thesis. The collection of information by the interviews showed that Ekornes has come further than Devold with the 3D-knit technology and that it has a transfer value for both Ekornes and Devold. As the literature is mostly focused on using the technology in fashion, rather than furniture industry. Therefore, it will be useful for this thesis to include Devold in the process that falls under the category of fashion.

5.1. Traditional supply chain

5.1.1. Ekornes today

The product of Ekornes can seem different according to the product they offer, but most of the production is based on standardized components, assembled in different configurations, where the product is industrialized. The main basic components are wood, metal, foam, and leather or textiles. However, the products differ from each other by customers wishes regarding textile, leather or size. Chairs are produced in small, medium, and large, and these are the sizes the customers have regarding choice of sizes for example for the stressless dining chairs. Hence, the production is also consisted of 90% costumer orders, regardless several of the components are industrialized and manufactured under standardized production.

Overall, their production is based on linear production and follows a linear business model. Whereby, the product has a long lifespan and after the product is used by the customer for roughly 20 years, it is usually considered waste. But in some cases, quality of the products makes it possible to resell second hand long after 20 years. Since their production is so industrialized, they find it challenging to separate the steel and foam from the chairs, because the parts are cast together. To change such part of the production, a consequence is a redo the entire production they have today. In relation to our interview object one, this is not an issue for stressless dining chairs, as this is a simple product, and it is not as industrialized as the other products they produce. The production also utilizes lean manufacturing and have eliminated waste to the best of their abilities. Repetitive, demanding, and certain general logistics operations are robotized and/or automated. One example is the use of driverless trucks transporting finished components in between production at one location and storage to the next location in the production. Just the one truck can save one-to-two-man labour years that can be utilized in more effective areas.

One of the product groups they use textiles on is the stressless dining chairs, and this is the product group that is a focus in the analysis. According to product groups, data collection was then narrowed down to get further information about the current production for the stressless dining chairs.

5.1.2. Stressless dining chairs

The Stressless production is based in Norway, Sykkylven. The stressless chairs came out in the Norwegian marked in 1971 and has been in and out of stock-exchange listing, where the company is currently owned by the Chinese company called Qumei (Christensen 2018). In between the 3 factories in Sykkylven, there are around 1100 employees, where 900 of them work at Ikrones. Where the factory consists of 74 square meters of building mass. Ekornes production is also ISO9001 and 14001 certified (Ekornes Interview 1 2022).

5.1.3. Production value chain

This subsection will show the process of their production for stressless dining chairs regarding the interviews and observations in detail. First part of the sub section will consider the standard process for every stressless production, and thereby give a clear understanding of how their textile production sewing. During the observations, pictures where taken, can be found in appendix C to help illustrate the observations.

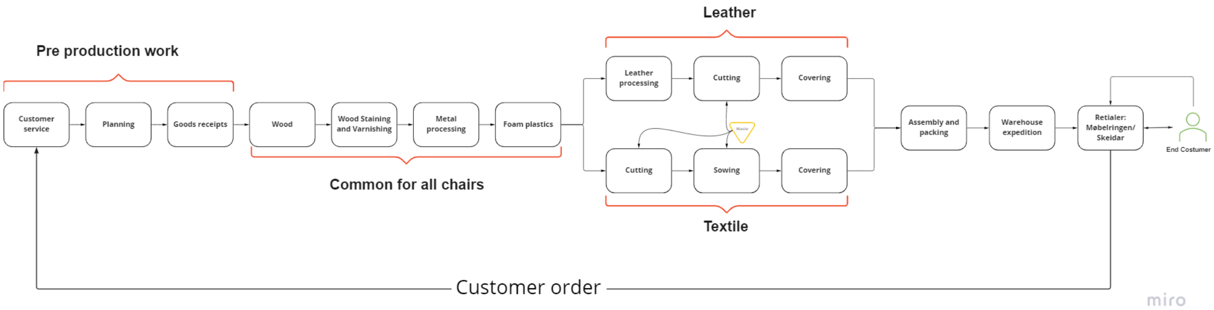


Figure 21 Process map of Ekornes production of Stressless dining chairs.

In figure 21 above, (Figure 21 can also be found in large format in appendix D) one can see the whole process map of how their production look alike, this process was discussed during the interview when the interview objects explained about their production process. The process starts by receiving orders from the customer, and some of their customers are Møbelringen and Skeidar. Interview objects one and two mentioned that, regardless of the industrialized and standardized production, customers can order the chairs they want. Where they can choose the colour of the fabric or leather. This gives the customer an ownership of the product that they have customized. A more detailed explanation of this comes under the textile section for Ekornes. When the customer places their order, it take approximately 72 hours before it goes into the planning phase. There are often many products that have similar assets that coming from the same platform structure because it goes through the same production. With the stressless chairs, it is different since they had to map the market first and work with product development before they could produce the product. However, in the planning phase the employees plan the process relative to their capacity and if any of the orders can be made together to make the process more efficient to create flow in the production.

Standardized production for Stressless:

1. **Wood**

There are 8 colours of wood used in Ekornes. It starts out with veneer sheets from Europe that are dried to 4% humidity. They are laminated and glued together consisting of 32 layers. These are cut into half-moons and are made into circles by finger joints and the use of high frequency presses. The wood is then refurbished by robots and manually controlled by humans. After this it is scanned by computerized robots for unevenness and is sent to wood staining or rejected products.

2. Wood staining and varnishing

In this process the assembled wood composites are put into a one-kilometre-long racking system consisting of over 500 hooks. In this system, they pass through robots treating them with staining and varnish. Once done with this process, the use of manual labour is used instead of robots in quality control as the human eye is currently superior to technology checking for errors in varnishing.

3. Metal processing

The processing of metal starts with steel tubes arriving at the factory in bulk. These are welded and bend with the use of automated welding cells and robots. The metal is then degreased, epoxy is applied and sent to an oven to harden. The water used in the degreasing process is reused to maintain sustainability.

4. Foam plastic

At this step, chemical plastics is sprayed into the chairs metal components. This is the step that is still viewed as a challenge from a sustainable point of view. This is left to hardened for two hours, and block casted foam is glued on for additional comfort. The foam is coloured differently to differentiate firmness. The block casted foam is casted in sheets of 2x1x12 meter and is cut to different models. The cut offs are blended with chemicals and casted into new blocks, used in less quality demanding parts of the final product, like feet and armrests.

5.1.4. Textile part of the production

The customers get the opportunity to choose the cover regarding whether the cover should be in leather or textile. They sell a large proportion more of leather products compared to textiles. About 10% of what they produce in total is textile produced cover. The textile part will be the important part for our study, to be able to map how the traditional production is with textiles. The information collected through the interviews gave us an in depth understanding on how 3D-knit technology can be compared to the traditional textile. Before writing about the collected data for the textile part, a short summary is provided about the leather production. The factory hosts a significant storage of leather from mainly Brazil but also some from Italy. There are 4 types of quality, and the combination of colours makes a total of 60 possible types. The leather is stored flat long-term but is hanged on tables that imitates the natural shape of the animal. This to minimize creasing. The leather is scanned by computers and given 4 different colours to mark difference in quality. Yellow for excellent quality, blue for exposed areas and red for insignificant areas. The last colour is reserved for leather that does not meet quality standard. The leather is then cut by the machines in the optimal manner where wasted is collected and sold to manufacturers who make leather bags and wallets.

1. Textile production

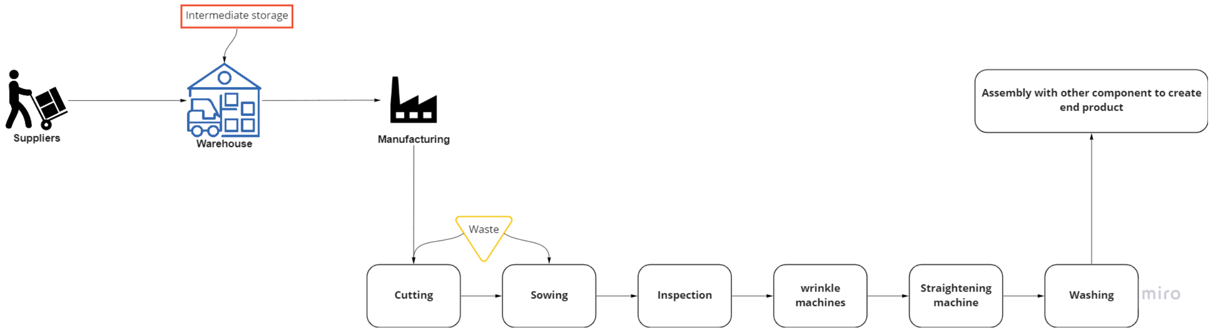


Figure 22 Textile production in Ekornes.

Figure 22 illustrates the current textile production isolated in Ekornes. Figure 22 can also be found in appendix D in large format. Interview object two, the Product developer mentioned that, to make a Stressless dining chair, you need a lectra and a sewing machine. In addition, it must go through a wrinkle machine, regular straightening machine, etc. The process of making a cover to the chair approximately 3-4 sewing operations before the cover is ready to put on the chair.

Ekornes orders textile rolls, of which they are equipped to have approx. 100 colour choices. This means that customers have a wide choice over the chair they order. As of today, they have a warehouse they store these textile rolls, so they are not ordered based on demand. The process begins by ordering textile rolls from the supplier they have. The supplier buys the yarn from another supplier and transport it to the textile supplier. The textile supplier then sends the yarn to a spinning facility who spin the textile into a textile roll. This is then transported to Ekornes, where they cut out the correct shape and pieces that are necessary to produce the cover for the Stressless chairs. Here they often have approx. 20% wastage, and in the long run this accumulate. Further in the process, the textile parts are transported to the sewing room where these parts are sewn together. From our observation at Ekornes, sewing machines was where the work was done with human resources. The textiles that were cut out in sizes S, M and L on the Stressless dining chairs, are sewn together at this station. Where they end up getting two covers (back support and the seat) that will cover the foam. The interviewees also mentioned that it is easier to separate the foam from the Stressless dining chairs compared other products they produce.

The second to last step in the traditional production is covering of the foam. Leather and textile are then stretched with the help of vacuum and plastic sheets to present the final finished product. The product is handled by robots in packing as a health and safety measure and then manually by pallet trucks onto trucks or ships.

2. **Suppliers**

When it comes to suppliers for textiles, the supplier market is large, because they buy ordinary textiles in production. Interview object one mentioned that, the suppliers who supply textiles or leather must meet certain requirements, for example in furniture, there are some requirements such as rubbing, dyeing authenticity, etc. The interviewee confirms that it is not just a matter of using any textile and get the product done, but they need to make sure that it is done with the correct requirements which transforms furniture industry. For example, with washability, fire requirements, etc. In addition, it is also important that the products comply with the requirements of other countries for which they wish to launch their product.
In the Norwegian market, there are several textile suppliers, and this makes it easy for Ekornes to shop textiles from. There are also no customized textiles specifically made for them and their production, regardless of the requirements the suppliers must meet. It is important to understand that every supplier does not deliver the same textile as another supplier. Object one mentioned that for a finished textile, they have one supplier they buy from. If any challenges occur with the supplier, they have the option to either replace the textile with another textile (from another supplier) that is in the portfolio. However, by changing supplier, you will not get identical textiles. If there is something wrong with the supplier that you must terminate the contract, then the entire textile collection must be removed. This textile collection has either been returned to the supplier or considered as waste.

3. **Stakeholders**

Figure 23 Overview of Ekornes stakeholders. Source: (Ekornes informant 1 2022)

Ekornes mentioned in the interview that to have an overview of the Stakeholders was a part of the ISO certification, and the overview were sent through email inquiry. This overview is shown in figure 23.

To summarize the information that was gather for Ekornes, the thesis has illustrated Ekornes current supply chain in figure 24. A large version of figure 24 can also be found in appendix D.

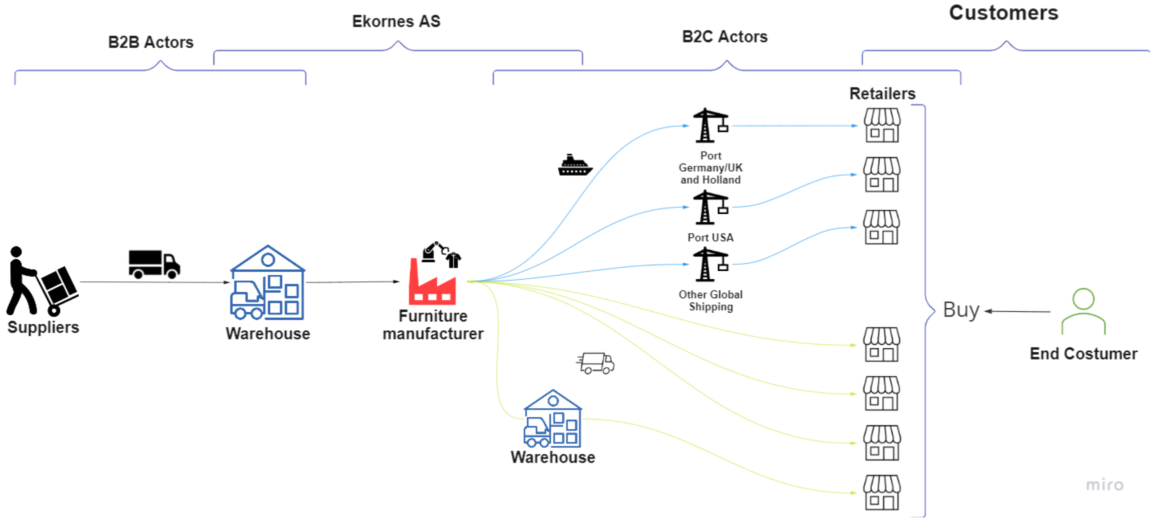


Figure 24 Ekornes current supply chain.

5.2 Devold of Norway today

The current state of Devold of Norway value chain consists of several different products and product groups. This study will focus the value adding process of a knitted sweater and its current supply chain. The knitted sweaters that Devold has are made up of 3 different product groups divided into fineness of the knit. These are of 3-part sweaters, 5-part sweaters and 7-part sweaters. Fineness of the garment is defined by how many needles is used for knitting. More needles result in finer fabrics, and less needles result in thicker the fabric. The classic Devold sweater is a 3-part sweater. Current manufacturing processes makes Devold able to produce 60 000 sweaters in 2021. With the ambition for future production of around 70-80 000 sweaters. The production is mainly order based, pre ordered 6 months in advance and accounting for 80% of the volume. The residing 20% are supplement orders, coming in during the production. The sweaters produced at Devold are fashion products that last over several years, making it easy to have control over production. Regarding the production, Devold employs their own mechanics, resulting in reduced downtime (Devold of Norway Interview 1 2022).

Value Chain

The raw materials sourced for the sweaters is Norwegian wool, sourced from either Norilla or Fatland wool supply. The wool is then shipped to England for washing, to remove any impurities from the wool and to make it production ready. Where all the raw wool is bought in full trailer loads. It is then shipped to Lithuania where the raw wool is refined into garments in spinning facilities. After the finished spinning process, the garment is shipped a short distance to Devolds factory in Panevezyz for further processing. The manufacturing process stats with knitting of backside, frontside, arms and neck in all separate processes on flat bed knitting machines. The garments are then sent to washing and colouring at a separate location, a couple of hours away. Coming back, the garments are pre-steamed and cut to adjustments if needed. Now the separate garments are ready to be assembled into one whole sweater, using “Kettle” and sowing machines. The final stages of the production process are comprised of quality control of the garment and steaming of the finished goods on steaming tables. The finished goods are packed, and either put in warehouse within the factory or shipped out to customers. For products destined to Norway, fully loaded semi-trucks are sent to a central warehouse of the logistics provider, then distributed to retail stores or central warehouse of the retail chains.

Devold's current value chain for sweaters is illustrated in figure 25.(Figure 25 can also be found in appendix D) This figure depicts the main activities that make creation of a 3-part sweater possible. Support activates like material sourcing, design and transportation comes as an addition to the main activities. Within the manufacturing process, spinning, washing, and colouring are outsourced processes. Devold does not look at this as an issue since the facilities are just a couple of hours away.

Figure 25 The current value chain of sweaters in Devold of Norway.

Devolds sustainability today

The manufacturing that Devold employs as of today, are based on traditional or linear production. Structured in a way of allowing lean production with no waste and caching of semi-finished goods. At Devold, raw materials are put into a production process, turning it into a new garment. The garment has a relatively long lifespan, as the quality of the garment allows for passing it down to younger generations. Ultimately, the garment is considered as waste of the end of its lifetime. In the eyes of production, 20 years of constant improvements of the production process, and a focus on reducing their carbon footprint has resulted in Oeko-tex® certified products. In addition to this, Devold is also part of Scandinavian outdoor group (SOG), stating that their products are of premium quality and made with Scandinavian traditions and heritage, in an innovative way (SOG 2022).

Production of sweaters yields only a few percentages of waste, with the little waste produced is collected to be used for other purposes. The leftover yarns get sold for a pretty penny to other producers or repurposed at Devold to make limited edition designs. One of the main reasons for not producing more waste, is that the sweaters are knitted to shape, and requires less cutting and postprocessing as garments cut from fabrics. Overproduction is not an issue at Devold either, due to their order-based production.

Other sustainability measures that are put in at Devolds factory facilities are solar panels and import of only green energy where solar does not suffice. Sustainability is also discussed with suppliers, where some of Devolds suppliers are managing to give a positive carbon footprint.

Devolds Stakeholders
According to the interview with Devold informants, they have made an overview of current stakeholders. Analysing what was told in the interview, it is shown that there are stakeholders present, but awareness of stakeholders is lacking. Looking inward, workers are subjected to different workload, depending on the order sizes, and have interests in their health and safety concerns. Outwardly suppliers are concern about sizes and frequency of delivery. Whereas Devold being a part of SOG, makes a statement of Devolds image to the final costumer.

To summarize the information that was gather for Devold, the thesis has illustrated Ekornes current supply chain in figure DEV. A large version of figure 26 can be found in appendix D.

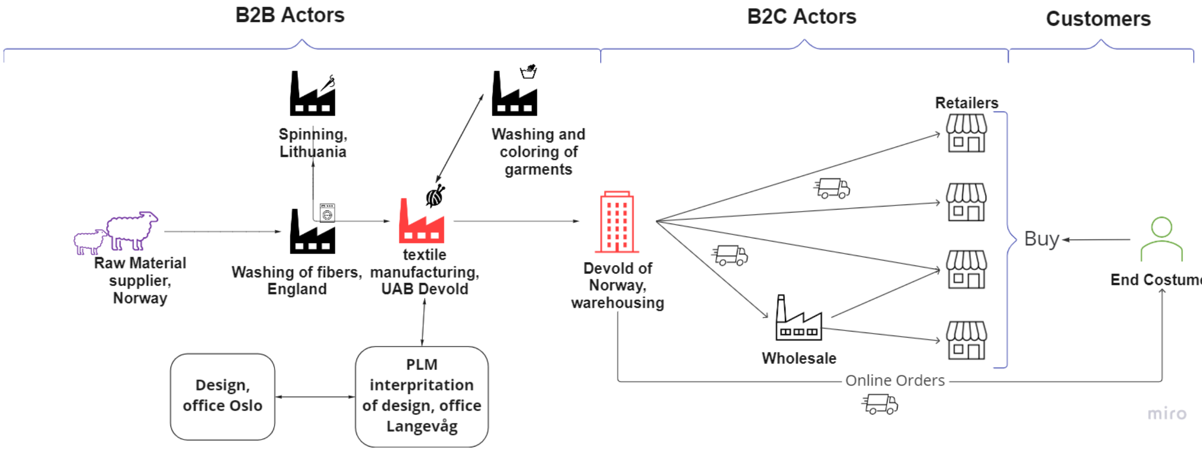


Figure 26 Current supply chain for Devold of Norway.

5.3 Supply chain with 3D-knit technology

5.3.1 Observation at the 3D-Knit LAB

During this research, a visit was made to a 3D Knit Lab in Sykkelven, in which experimentations and production of working prototypes with the industry is performed. Pictures from this visit can be found in appendix C, to get a more in-depth understanding of how the lab functions. The lab included 3 Shima Seiki Wholegarment knitting machines. Utilizing the models Mach 2XS 153, Mach 2VS 183 and SVR 13SP. For the companies that already have implemented the technology in their production, (Such as Ekornes) the lab provides technical support and cooperation with the supplier of Amatec AS to supply the machinery. Amatec is a company focused on robotics and has 3D knitting machines from Shima Seiki as one product segment in their portfolio. Amatec has been working with Shima Seiki for 25 years to introduce

Wholegarment technology to production in Norway. Representing the technical expertise of Shima Seiki's Wholegarment machinery, the "technician" has 14 years of experience at different departments within Shima Seiki. With an educational background of material engineering degree. This granted us a unique opportunity of an introduction to 3D knit technology. Representing Amatec, the "supplier" has been working in the textile industry since 1978, having excellent knowledge on the topic.

Why 3D knit lab?

To justify the existence of the 3D Knit lab, the Case of Varner group (Dressmann) was made by the supplier. Production is done 6 months in advance of sale, needing decisions on product, colour, fabrics, production numbers and other factors. Making production based on historical forecasting or computerized best guess estimates. He explained that they order x number quantity of products that they need to produce. For example, they order 1600 sweaters, and they only sell around 600, and the products that are left would either be sold to burned (Napier and Sanguineti 2020). Sometimes as bad as 90% of the production can be leftover stock, to battle stockouts. With this, it is understood that one should forecast the demand, to forecast and then order more. For example, to order first a smaller quantity, and then order more after knowing if the demand is high on that product. It was mentioned that if the traditional production (when cutting out the materials that are required) makes less than 30% waste, then it's a good production. If it is between 30% - 50% is waste, this is something that the industry should have as a focus area. These materials are not reused as well, resulting in an environmentally hostile production. Introducing 3d Knit to reduce waste, since the machine produces exactly what is required and it is a circular production. The only thing is that the machine must start with demo knitting two - three rounds at the beginning before it knits the product to find the pattern. As an industry example, Ekornes was mentioned as relevant for our case. With their exploration of 3D knitting machines in production. Stating that they were eager to develop it more, but that the missing piece was expertise in 3D knitting. The technician also pointed out that one of the signs of lack of expertise, was a neglect of proper machine maintenance, highly likely from a lack of knowledge and competence.

SC issue, and 3D Knit SC benefits

When discussing the topic of supply chain in the textile industry with the technician and supplier, there was a few main points that were brought up. One challenge was the importance of local suppliers of yarn. The yarn produced in Norway is not applicable to be used for all

products as the different designs need different types of yarn. The raw materials production was eyed as a point of shortage. Too few producers and washing machines are in Norway, making it an oligopolistic market of raw materials and the washing to be outsourced to England.
3D Knit SC however, the most important benefits where that of reduced labour cost and lead-time. Since industries have outsourced production abroad, this is also one of the major environmental problems of the industry. Additionally, there are also extra costs such as tax, shipping, etc., constituting an increased level of lead-time. With 3D knit, one can produce on demand and the company does not have to wait for the product to be shipped, but that it can be sent immediately to the customer when the product is produced.

The outsourcing of the industry also reduces designers' creativity and feedback that they get from being at or near the production, resulting in reduction of designer knowledge and competence. The workers in the outsourced location are also able to affect the production in their own unique way, and a shift in education on a society level in both the original country and the outsourced country for future generations. During the visit at 3D Knit Lab, the supplier and technician started a discussion on Wholegarment knitting being able to start a trend of reshoring production back to Norway. They believe that this trend will be made possible by 3D Knits reduced process of design to finished product and by on demand production responding instantly to potential stockouts (Norem and Pushparajah 2022b). They believe that the current view of SC is linear and traditional. Making an example of containers shipped over months yielding massive lead times that are too long meet flexible market demand. In the traditional SC, designers make designs up to 2 years in advance, that is no longer in line with the todays fast moving and demanding world.

A common theme when discussing 3D knit was that of reduction of waste. The technician mentioned one enabler of this benefits, where the product is knitted in the same way as you knit by hand, yielding the opportunity to pull out the yarn from the manufactured machine. This is made possible with an attachment fit to the machines to rewind waste garment. Resulting in less waste in a machine crash or similar event. The quality of the material may become reduced depending on the material, but one can mix it with other yarns and produce for example sample products, filling material or setup of the machines. The quality reduction is especially noticeable with wool yarn, as the quality drops more on wool products than on other yarn types (Norem and Pushparajah 2022b).

The Supplier also mentioned a possible solution for the industry to make a shift to 3D Knit production from outsourced production. By using Amatec as a “hub”, Different companies can focus on only making their design, while Amatec takes care of their production. The finished goods can then be directly transported to the end costumer. The benefit of this solution is obviously the environmental one, but also that of economies of scale and availability of expert knowledge in production. With the few companies currently producing in Norway, this in the eyes of the supplier can be a feasible solution to mass implementation of 3D knit technology in Norway (Norem and Pushparajah 2022a).

Design

The technician also made an introduction to the latest design software by the name of “Apexfiz” of Shima Seiki. Run on Shima Seikis own hardware system “SDS-ONE Apex 4”, made entirely by themselves. Here the designer can design the product they want to print in the 3D knitting machine. Making it possible to have customized production. The advantage of such software is that you do not have to print physical samples, with adjustments, shape simulation, loop simulation and change of material and yarn on the product in the software itself digitally. Making it possible to simulate the product. This in turn reduces waste, compared to the traditional production where you must produce a new collection every time a small part is changed. The Shima Seikis own yarnbank is also used at the 3D lab, providing access to digitally registered yarn suppliers, to be downloaded directly for the designer. The software also uses patterns such as 150 loop X150 loop to define tightness for the tension in the garment. Traditionally, a calculations sheet based on physical measurements is used in order to achieve optimal loop count. See figure 27 below to understand the process better.

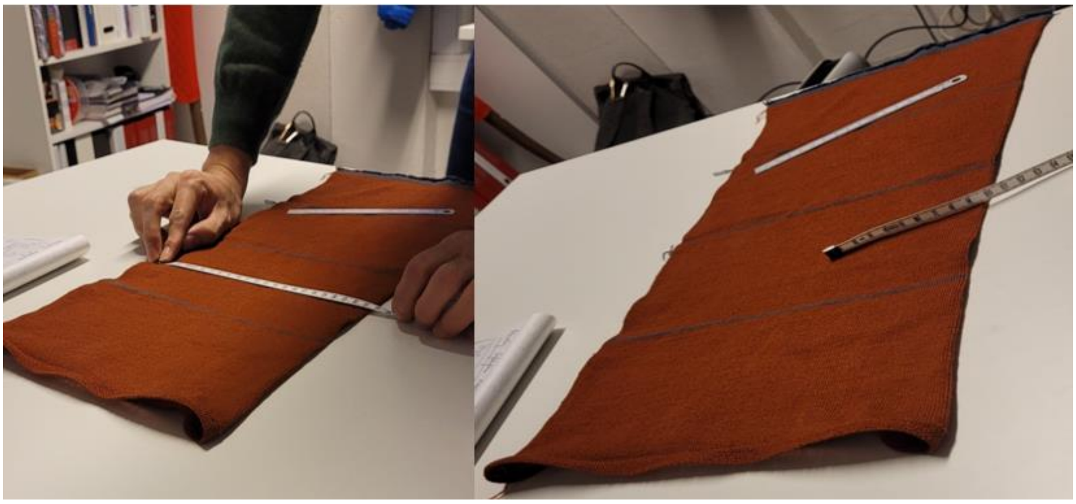


Figure 27 The technician measuring loop count in a test garment. The garment is seperated into different tightness in the different areas.

After years of development, the software now has the possibility of parametric design and automatic programming. Meaning that if there is one change made to the garment, other parameters of the garments is changed at the same time to maintain the integrity of the garment. In early development, the technology has been known for its tedious programming. For example, a common sweater needing 1-2 weeks of programming. With today's technology and a senior programmer or operator, the same process takes only a day or two. When coming up with newly composed design, one runs the risk of failures in the knitting process. One of the measures in place for reducing such failures is the simulation in the software, showing possible snags and knitting time and the operator can choose to ignore warnings if there is a certain desired outcome. The simulation is run a few times, until desired outcome is produced.

To work with this software, supporting skills are highlighted as important. But, even if the person is highly competent, the software's safety measure will tell all the error messages that can damage the machine, for example if the recipe has two threads in a needle and the needle does not handle it then the software will notify before exporting. This gives you the opportunity to correct the errors in advance. Once the product is designed, the template is transferred to a USB and connect this to the 3D knitting machine. A unique thing here is that the USB model can be placed on any 3D-knit machine anywhere in the world, but it's important to remember that the thickness of the yarn is what determines which machine to use. Thicker thread needs needles that are thicker etc. The set-up time before printing the product takes between 30 min - 1 hour.

Different products take different amounts of time to make. A simple sweater without complicated patterns can be produced in approx. 45 minutes. Another important element that one must keep in mind is that when washing wool, the product shrinks and therefore it is important to design regarding this on the software. As a rule, the designer makes it a few centimetres larger. The product is also washed immediately after production so that it shrinks one notch and not two notches when customers wash it in the machine.

Products can be made to order as well, as 3D knit technology allows for 3D presentation to the consumers to provide feedback. Or in other words, selling the goods before production. For example, the consumer can get a choice of 10 garments and choose the favourite one, making the possibility to produce what the market wants. This can also lead to competitive advantages in today's digital environment. As such way of marketing can provide information on costumer attributes, behaviours and other big data that can be used to create new market opportunities. Finding niche markets and producing exact demand batches are some examples that can come out of this newfound information collection.

5.3.2 3D-technology in Ekornes

As mentioned by the interview objects and the websites, Ekornes has the mindset of future-thinking, where they try to create collaboration between robots and humans to create sustainable furniture. They are one of the first movers when it comes to automating industrial production in Norway, and today they have 197 robots in operation at factory in Sykkylven, where the numbers of robots are set to increase. Nothing stops them for thinking innovatively and be solution oriented regardless of finding solutions that gives them sustainable advantage or not. However, with their knowledge and as first movers in the industry within technology, they started with 3D knit technology to see if such alternative can be more sustainable then the traditional production with textiles they have as of today. They started with the technology 4 years ago, where they begin with the introduction of the technology with research, development, training where they collaborate with Shima Seki who are Ekornes supplier for 3D-knit machines. They have learned programming of knitting machines, how to operate, as well as increase the knowledge of yarn. Interview object two mentioned that they have always been working with textile rolls so it will be a new chapter for them to learn about yarn. With textiles, everything was spun in advance, and they only got the textile rolls, but now they get yarn skeins, where they need to knit the covers for Stressless dining chairs fully. However, they wanted to find out if this was a technology that they could use in their production and if there were benefits, they could bring out with the technology in Ekornes. Overall, with the learning curve, the interview object one mentioned that the more they learn, the more opportunity they see by using the technology. Additionally, they buy external programming help from 3D knit lab and Shima Seiki in England who can help them to create programs on prototype.

The SHIMA SEIKI technician stated that:*" …Replacing existing established mass production line" is not an easy task. Wholegarment technology can reduce post-process(cost) and give the possibility to make products in consumer are OnDemand, but we need to find suitable product and something new for Wholegarment which can coexist with existing production…" SHIMA SEIKI technician, E-mail inquiry (Technican 3D Knit lab/ Shima Seiki 2022)*

The technician is under the impression that that Ekornes has great amount of knowledge and experience in making high quality product, to a luxury price. And that leather and woven fabric can be hard to replace with 3D Knit. The introduction of 3D knitting machine will only replace the traditional knitting machines and is seemed as less flexible during production but has a reduced need for post processing.

"Wholegarment technology has possibility, but still traditional knitting machines are more flexible for making many structures and color design although they need post process. Wholegarment machine also can do same things, but programmer need higher skill and knowledge." SHIMA SEIKI technician, E-mail inquiry (Technican 3D Knit lab/ Shima Seiki 2022)

The challenge of knowledge is important and is shown in Ekornes' need for skilled workers. And is explained by the SHIMA SEIKI technician:

"… designers need to understand limitation, difference, and character of the Wholegarment. … but we must educate not only programmer but also designers if we want to grow up the market of Wholegarment product in Norway. However, this problem is not only in Norway." SHIMA SEIKI technician, E-mail inquiry (Technican 3D Knit lab/ Shima Seiki 2022)

Today they own 3 knitting machines that are programmed by interview object two. Currently there is full-fledged production on 2 of the 3 3D knitting machines. The first machine is used in production when demand calls for it, otherwise it is used for prototyping. The interview object two have already tried many designs and solutions that they might use in the future. Ekornes launched its first 3D-knitted Stressless Dining Chair in October 2021, and now it is sold at Møbelringen. The production of a cover for back and seat cover takes around 70 minutes. The current production uses recycled polyester yarns (50-75%, post-consumer), but the use of wool is currently being prototyped. However, wool has a good quality and very comfortable material to work with compared to the previous yarn types they had used on the prototype, stated interview object two. Furthermore, interview object two mentioned that the next step for them is to get the stressless dining chairs with wool covers that are washable. So that they can launch it in Germany and sell it in Europe from Germany. As the covers are knitted in one, zippers, Velcro and other functional inclusions is sown in afterwards. At Ekornes they make use of 8 colours yielding 30 possible combinations. As mentioned in the traditional supply chain the chairs are produced in small, medium and large, but the 3D knitting is mainly produced in size medium (Ekornes Interview 1 2022).

Each set of covers uses around 300 grams of yarn, yielding 3 chains per 1kg with current setup. The yarn used is also certified regarding durability and the covers have gone through extensive testing regarding wash shrinkage, shape consistency and friction testing. In the end, the final products of Ekornes are supported by a 10-year minimum guarantee. Moreover, the advantage that they see of 3D-knit machine is that covers get quite elastic, so it gets easier for a customer change their own seats. The covers are made washable, and this is not a solution many companies give with good quality. The customer can also buy a one size fit cover, that they can pull over their stressless dining chairs, if they are unlucky and ruin the upholstery. So, the customer doesn’t need to buy a new chair for the damage.

The interviewees also mentioned many advantages and disadvantages by using 3D-knit technology compared to their traditional one. One of the advantages they see by contributing such technology compared to the traditional one is that they do not have to go through several operations. Here they can just program the seat cover with the design they want, and it is ready after 70 minutes. While the traditional textile piece must go through 3-4 sewing operations before it is ready to be pulled on the chair.

Some of the advantages of the technology are that you can create unique designs, you can knit different zones into with an elastic zone, you can knit support and conform in other ways. The machine can knit several layers while you can knit upholstery for example, and you avoid sewing together the parts. For instance, you can knit a cover where the back has a fixed cover that you can sit on, you can also have soft paddings on and put a cover on the top with a pattern. However, one gets the opportunity to knit all the mentioned elements in one piece, and thread it onto the frame. They also can remove feather and foam that they usually use on the traditional production. Another advantage of 3D knitting is that you have zero wastage. Several other advantages that were mentioned both in the interviews and observation was that they had the ability to make unique designs, eliminate the process of sewing each part together compared with the traditional one, and it requires a small stock space. Additionally, the technology provides the opportunity to have the production closer to the customer.

The disadvantages they experience with the technology is that the programming part is quite time consuming, and increased need knowledge within the technology is an missing and required. Interview object two stated that to make a stressless dining chair cover is not just a quick fix, because one must build it on a computer program before starting the production. Compared to the generic textile, where they have forms, they cut the pieces out of. In 3D-knit there are many numbers and colour codes to build in a system to make it easier for the machine to read. However, it’s not just the shape but it's how big the stitch should be, which thread to use, how fast the machine should go. In their case, they mentioned that the dining chairs were easier to implement such a technology on compared to Stressless, because there is a lot of duvets, and several elements overlap. They also mentioned that, when they first had everything programmed, it is easier to make changes on the template. However, preparation is what is considered as a time-consuming element (Ekornes Interview 1 2022; Norem and Pushparajah 2022a).

Table 13 below shows a summary of the advantages and disadvantages mentioned by Ekornes of using 3D-knit technology.

Table 13 Ekornes advantages and Disadvantages of 3D Knit technology.

Advantages	Disadvantages
Rich by opportunities within developing new products	Need much knowledge to program and it is a huge job
Zero waste	It’s not a quick fix
Unique design	
No need to sew the parts together	
Requires a small stock space	
Very short process in terms of production	
Less to carry regardless of yarn	
Provides the opportunity to have the production closer to the customer	

5.3.3 Devold of Norway

Based on the information given during the interviews with Devold, their production as of today is based on traditional manufacturing processes that has been optimized over the last 20 years. The current SC they employ is a result of owning critical processes themselves and outsourcing where others have a higher competence than themselves. The implementation of lean manufacturing processes investment in infrastructure to achieve sustainability are key attributes of their SC. Resulting in a SC that is deemed as sustainable and well organized. Transportation between locations is kept to a minimum, as their supply chain for sweaters only require Intereuropean transportation. A constant dialogue with the logistics supplier, makes them able to ship full containerloads of both raw materials, and finished goods. Even though they have outsourced some of the supporting manufacturing processes, the outsourced locations are within hours of the factory, limiting the environmental impact of the decision (Devold of Norway Interview 1 2022).

When interviewing Devold, the interviewees claimed that their current production and supply chain is deemed sustainable in today's standards. Since they are placed in the luxury garment production, this is especially noticeable towards the fast fashion industry. The exploration into 3D knit technology is not a hunt for Devold to achieve higher productivity or sustainability, but rather to explore new technology and a new possible market share for even more premium sweaters. The interviewees stated that it can be a new potential revenue stream due to higher finish and potential to make use of even higher quality yarns. As 3D Knit is an innovative technology Devold has established a subsidiary company, Nansen by Devold, to investigate the potential of 3D knitted sweaters in their assortment (Devold of Norway Interview 1 2022).

During this research, an inquiry attempt was made to establish contact with Nansen by Devold directly, but due to company's limited knowledge and time restrictions, the information received was of general nature. It was confirmed that Nansen by Devold is made possible in collaboration with the 3D Knit lab. But is still in development and in the area of exploring the technology potential for 5-part sweaters or even coarser knitting. Currently, the Shima Seiki knitting machines are not able to handle 3-part sweaters, which is what Devold hopes to be possible to make the classic Devold sweaters on 3D Knit in the future (Devold of Norway informant 1 2022). As of writing this thesis, the production of 5-part sweaters is possible with Shima Seiki Wholegarment knitting machines. After finding out that 3-part sweaters are not possible to produce with Wholegarment machinery, future tests will be performed on Stoll's Knit &wear machinery (Devold of Norway informant 1 2022). If the proceedings of Nansen by Devold is successful, then the 3D knitted sweaters and other products will be separated from that of Devold of Norway (Devold of Norway Interview 1 2022; Nansen by Devold informant 2022).

The informants of Devold lists a reduction in labour cost as one of the main reasons to implement 3D knitting, especially if it is placed in Norway. Interview objects one and two in

Devold of Norway stated the following respectfully to a question benefits of 3D Knit sustainability compared to the current situation:

"*It is mostly on worker labour that I think we can save" Interview object one, own translation. (Devold of Norway Interview 1 2022).*
"Yes, it is mostly in labour one can save in production hours included in a garment" Interview object two, own translation. (Devold of Norway Interview 1 2022).

The most limiting factor of making 5-part sweater possible with 3D knit is also their choice of Yarn. Where Devold makes use of "woollen drafted yarns" that has varying fibres, making it more difficult to work with.

"I also think that a challenge is with the type of yarns we use today. The woollen drafted yarns can be a little problematic in a 3D Knit machine…" Interview object one, own translation. (Devold of Norway Interview 1 2022).

The issue of woollen drafted yarns is something that was discussed in a later inquiry to the knitting technician of 3D Knit lab. It was explained that it won't be an issue if a machine that fits the appropriate yarn thickness and surface hair is used. Methods like waxing the yarn can also be applied to reduce the negative impact.

"Knitting machine has various knitting gauge. (Knitting gauge is counted by number of needles in 1 inch) If yarn thickness is fit to our knitting machine, it will be stable even yarn is not smooth. Although knitting is more difficult when yarn has more hair on the surface like mohair yarn, we can reduce the defect by waxing the yarn, etc." Shima Seiki technician, E-mail inquiry (Technican 3D Knit lab/ Shima Seiki 2022)

In addition to reducing the impact of woollen drafted yarns, the SHIMA SEIKI Wholegarment knitting machines can be equipped with a feeding system that reduces possible failure or damage to the yarn used.

"…, intrigant yarn feeding system is equipped on SHIMA SEIKI Wholegarment knitting machine. It can control the tension of yarn digitally and can reduce the tension depend on the

sensitive woollen yarn. Also, it will make stable when in mass production using multiple knitting machines." SHIMA SEIKI technician, (Technican 3D Knit lab/ Shima Seiki 2022)

The high investment costs of the machinery are also viewed as a limiting factor for implementing the technology in Devold of Norway.

"As of today, with the setup we have in Lithuania, we do not consider it (3D Knit) as a wise investment. And if we are going to produce as many sweaters a year (compared to the current setup) then it will be a significant investment to buy all the machines. (To match the quantity)" Interview object two, own translation. (Devold of Norway Interview 1 2022).

Compared to the traditional way of manufacturing, the interviewees think that the manufacturing time itself will not be reduced by 3D knit but they are convinced that 3D Knit removes most of the post processing steps.

"... You can say that my assumption is that the knitting time with 3D Knit will go up a little bit compared to what we have now on a garment. And the production time or operator time for seams will be reduced with 3D (Knitting Industry). The lead time will be approximately the same in that we have dimensioned our capacity to a degree that things are left unfinished." Interview object two, own translation. (Devold of Norway Interview 1 2022).

Even though there are limiting factors, the interviewees stated that Devold has been following the 3D Knit development over 15 years, but still does not see it as time to convert to 3D Knit regarding Devold of Norway's production. (Not Nansen by Devold)

"... it is close to 15 years that we have kept an eye on what is going on, and made test etc. But we still don't see it as the time to convert. (the traditional manufacturing of Devold of Norway)" Interview object two, own translation. (Devold of Norway Interview 1 2022).

The focus of implementing 3D Knitting technology will then be a focus in Nansen by Devold, where they will establish a new production line, instead of replacing an old one.

"We have recently established a company called "Nansen by Devold", or with that as a working name. And it is they who want to start up production (with 3D Knit). That is a

subsidiary company to us. It will not be our products, but their own…" Interview object one, own translation. (Devold of Norway Interview 1 2022).

6. Discussion

In this chapter a comparison is conducted of the findings from the comprehensive interviews, observation and inquiry analysis. With a support of the literature collected throughout the literature review. By doing so, it is possible to given answers to the three sub research questions of this thesis. As presented in the following sub-chapters.

During the literature search, a focus area was on the connection of 3D knit and SC. Reviewed grey literature stated some SC implications but was lacking in-depth descriptions of why it was happening. The academic literature supported these claimed SC implications, but the academic literature was far in between, meaning that the topics of the scholars where varying and just a few investigated specific SC implications.

In the start of this research, the impression of the writers was that the production of Devold of Norway would replace or supplement production with 3D Knit. The limitation of this practice is the current extreme high production volume and choice of course yarn, making it difficult to make use of 3D Knit technology. This is reasoned by the investment cost needed to replace the current production machinery and is why implementation is investigated in Nansen by Devold instead (Devold of Norway Interview 1 2022, 12).

6.1 RQ1: How would the traditional supply chain be affected by the implementation of 3D knitting technology?

The discussion in this section connects findings from the structured literature study to findings from case studies to answer what effect the 3D Knitting technology will have in the SC for Ekornes and Devold of Norway, and how it contributes to a sustainable design-production in Ekornes and Nansen by Devold.

Ekornes

The Ekornes production process is built on lean manufacturing principles to eliminate waste (Ekornes Interview 1 2022). Repetitive, demanding (time consuming), and certain general logistic operations are robotized, and/or automated (Norem and Pushparajah 2022a). The findings show that the 3D knitting technology has been explored in the organization for over 4 years by them, including investments in the technology, training, and experimentation with potential uses cases.

By implementing 3D-knit technology, Ekornes expects that several steps in the SC and VC will be either altered or new solutions will be introduced. This correlates with literature screened in this study. The changes in the SC and VC starts with the supply of raw materials (Mikahila 2021). In the traditional textile production Ekornes uses textiles cut to fitment (Ekornes Interview 1 2022). In the 3D knit SC, textile materials are to be replaced by yarn, leading to changes in the supplier network by replacing textile material suppliers with suppliers of yarn (Norem and Pushparajah 2022b). Another supply chain change is related to inventory and warehouse operations. Textile rolls need a larger storage and warehouse operations space than yarn. Implementation of such technology will contribute to reducing post processing steps and time (Bendt 2016). Building on existing evidence that the garment is produced as one whole garment and reduces labour and time costs, lead time to end consumer and waste (Chemsec 2022; Maiti et al. 2022).

Ekornes market strategy is to move towards increased product customization to real time customer orders. The 3D Knit technology enables customers to be involved into the design of their products, by customizing certain product characteristics (like choice of material, colour, shape). This requires careful design analysis to better understand what design parameters are appropriate to be allowed customized, E.g., design attributes that have high potential on end-user value and that also contribute to sustainability (for example, by extended use-cycles). Currently Ekornes have a webpage that allows customers to partly customize their products (choice of materials and frame). In an informal conversation with the product developer from Ekornes, it was mentioned that they partly have started to prototype 3D visualization in their "own" environment (Ekornes Interview 2 2022). However, such technology provide customization connected to the 3D knitting technology and production of textiles (Chung, Kim, and Jang 2020). Adoption of 3D Knit technology can help to achieve competitiveness in this market trend for Ekornes.

The findings show that there are several steps before and after the textile arrives at manufacturing. A move towards the technology adoption can contribute to increased control over the production. A comparison of a supply chain with and without 3D knit technology by

Shima Seki is illustrated in Appendix D. Additionally, 3D knitted fabrics make it possible for consumers to produce diverse and small quantity products to meet the needs of the individual (Chung, Kim, and Jang 2020). As the observation at the 3D Knit Lab and the article concludes with the same, such a solution would lead to reduce logistics costs, as there is no more need for import and export other than raw materials. After all, the implementation can contribute to local production and lean logistics and result in shorter supply chains. For Ekornes as a furniture company, the 3D-knit can easily provide possibilities according to the need of the customer (Raycheva and Angelova 2019). Since the products are considered individualistic, making the products memorable and captivating, with the use of variation in colour, shape, detail, texture, and motives (Raycheva and Angelova 2019). The observations at Ekornes made it clear that that the textile or the yarn need to have the required specification to support the furniture's capabilities of washability, fire requirements, etc.

In Ekornes traditional production, the interviewees explained, and the observation showed that there are several processes involved in the VC. The 3D-knit process on the other hand has a shorter VC, where the materials (yarn) will then be passed through the manufacturing, and the designers design the desired product and load it into the 3D-knit machine. After 1.5 hours the cover is ready, still elastic, ready to be pulled over onto the chairs. According to our systematic literature review, there are significantly less research papers regarding implementing 3D-knit technology in the furniture industry than in garment industry. However, our research varies from other studies precisely because of the experimentation of 3D-knit technology in a furniture company, that also does not fall under the category of "fast fashion".

Figure 28 illustrates changes that occur by implementing 3D knitting technology in their current VC of Ekornes. Compared with the current VC, production processes namely cutting, sowing, and covering will be removed. A large version of figure 28 is also included in appendix D.

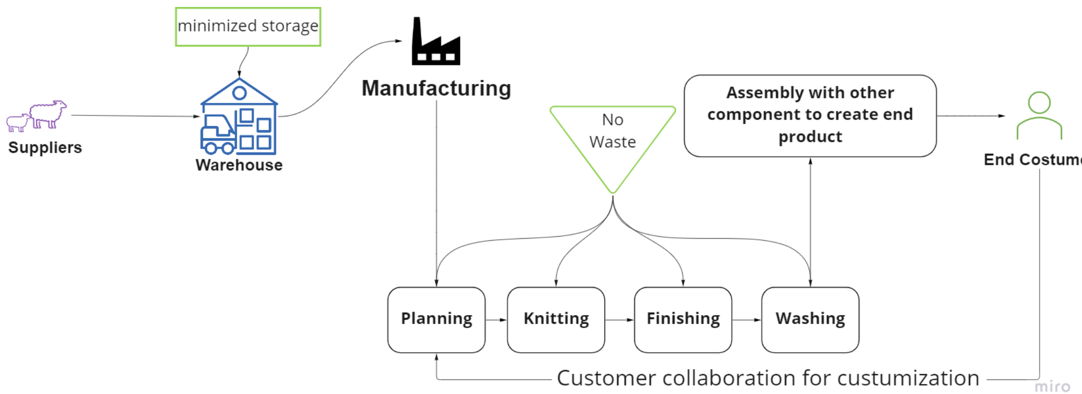


Figure 28 Ekornes 3D Knit textiles VC.

Corresponding supply chain for Ekornes with the implementation of the 3D knitting technology is shown in figure 29. Figure 29 is also included in appendix D. The SC for Ekornes will not be affected to any large extent, as the production of textiles only account for 10% of the total production. The only significant change is in the suppliers for the textiles section in Ekornes' production from textile rolls to yarns.

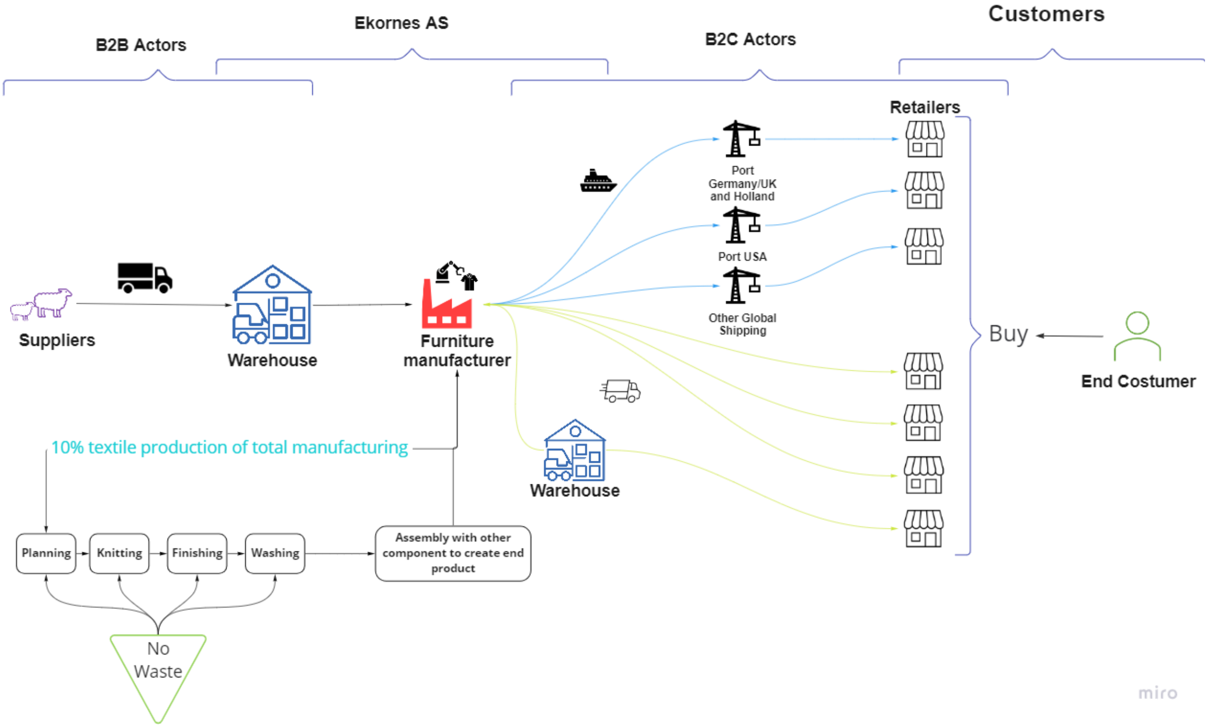


Figure 29 Ekornes 3D Knit SC.

EKORNES STAKEHOLDERS

In line with the lean production philosophy, Ekornes prioritizes tight collaboration with stakeholders across the supply chain. The 3D knitting technology affects stakeholder relations in multiple ways. The question to be answered in this section is "What impact the technology has on stakeholders and what advantages does the technology give." In figure 23, an overview of Ekornes stakeholders was shown.

Internal stakeholders

Employees

The employees are positive towards the 3D-knit technology, as it is important that the production is not outsourced. But workers activity is affected by the 3D Knit enabled change, by removed or replaced activities and by new knowledge needs (I.e. programming skills for new design solutions). By implementing 3D-knitting technology, Ekornes will still have their production locally, which previous experiments also agrees with. From our perspective, such a technology can increase an employee's competence and knowledge. However, this can contribute as a positive effect for the employees, as they get more attractive in the work market. In the company's perspective, it will reduce labour cost and time. Several processes will be eliminated as the 3D-knit lab also mentioned during the observation.

Owners/ Group management

The procurement department plays an important role in the supply chain as they are the one who buy the raw materials that are required to produce the stressless dining chairs covers. Today, if an isolation is made of the textile part of the supply chain, the outsourced element in their supply chain is the textile rolls they order from the supplier. Hence, the supplier that produce the textile rolls, buys the raw materials (yarn) and make use of a spinning facility to make the final products, or the textile rolls in Ekornes case. As Christopher (2016) stated, the outsourcing is ideal for companies when an activity is not bringing an advantage by either reduced cost or increased value. The value chain is then extended outside of the firm itself and supply chain is formed as the value chain of the firm.

The above-mentioned process would be eliminated, and the process will rather start with buying raw material (yarn) from a supplier. With 3D knitting, the company will have more control over their SC rather than outsource a part of the SC, and get significant little control over the production of the process (Christopher 2016). For instance, Ekornes would not have the same insight into the production of textiles rolls compared with their own supply chain.

External stakeholders

Suppliers

A technology shift in production can affect the suppliers in many ways. First and foremost, a transition from buying yarn instead of textile rolls. These are suppliers that Ekornes has little knowledge of, as they have worked with textiles for many years. As they are early in using the 3D knitting technology, the results indicate that they already have suppliers in Europe who delivers yarn. It was also mentioned both in the interview and during the observation that textile suppliers don't deliver the same product. However, it will be variation from supplier to supplier on how the textile rolls are produced. This is also applicable for yarn suppliers. The interview object two from Ekornes mentioned that they could not buy the samples Shima Seiki had on their supplier overview because the sample size where insignificantly small. So, they ended up buying large quantities, as they want to test whether the quality of the yarn meets the requirements of the textile industries. A suggestion could be to collaborate an agreement with the 3D-knit lab to get common vendor overview.

Implementing 3D knitting technology can bring changes in machine vendors. Since the 3D knit machine requires other suppliers who have the knowledge within the technology, as it can be quite advanced for beginners (Mechan et al. 2016). This technology offers many advantages in a supply chain perspective, it is also important to look at the consequences that come from replacing current production with 3D knit technology (K. Foster and Istook 2017). First, they must terminate the contract with existing textile suppliers. These may be suppliers they have had for many years, and it is not certain that those suppliers will take it positively. The suppliers may be dependent on Ekornes buying from them or Ekornes being one of the largest purchase agreements they have. It is possible that the suppliers want negotiation, and that Ekornes falls into the temptation to accept a lower price. Environmentally, the best option is to have 3D knitting compared to textiles. One solution may also be to ask today's textile suppliers if they supply yarn. It is also important to see how environmentally friendly those products are.

Environment (Authorities, Local community, Industry organizations, Media)

Interview object two from Ekornes expressed that the information about 3D-knitting in the industry is generally lacking, and it’s challenging for the interested actors to increase their knowledge in it, since it is a complicated process that is time-consuming to learn. However, this could be a factor that indicates why the technology is not widespread in Norway. Another reason is a general outsourcing strategy in the industry. A suggestion increase awareness is to promote the products of 3D Knit to end consumers.

The UN Sustainability goal 8 and 9 highlights the importance of eliminating child labour, illegal working hours etc. Increase the innovation and move the production closer to the consumers to decrease pollution and emission to get a better world to live for our future generation. Such negative impacts can arise by having production abroad. However, this does not affect Ekornes, but can be a current issue regarding their textile suppliers if they have their production abroad. This is something Ekornes should look closer at. With 3D-knit technology the above-mentioned issues would be resolved (K. Foster and Istook 2017; Mikahila 2021)

Interview object one mentioned that they wanted to involve their external stakeholder in their new ideas and technologies. Ekornes showed the 3Dknitting machine and design at the Cologne (Germany) event (a furniture fair where people from all over the world participate) in 2019. Here they presented the products they have made with the 3D knitting machine. Hence, they received good feedback according to pattern and colour. Currently the 3D knitted products are only available for Norwegian consumers, but an expansion to Europe could happen in the future. The chairs that they have made and launched on Møbelringen are chairs with a lot of colour and pattern. These may be more attractive in other places of Europe as they are more accustomed to colourful interiors than in Scandinavian countries.

Ekornes should have a meeting with their current authorities and local community to find out what expectation they have regarding the 3D knit technology. An idea applicable for Nansen by Devold would be to come up with benefits of moving the production to Norway. However, this can contribute to a move more production to Norway and increase the local production. Ekornes is at the forefront of the technology within furniture industry, and this can give them a competitive advantage in the market. Hence, it creates a positive mention in the media as well.

Triple bottom line for Ekornes

Elkington (2013) stated that if a firm wanted to succeed in the marketplace, it’s important to focus on the three aspect of people, planet and profit called triple bottom line. The observation from the 3D knit lab gave the impression that local production can increase the knowledge among the population of the products as well. Furthermore, customized product will reduce waste as people design the exact product they want (J. Taylor 2015). Furthermore, local production will reduce lead time, emissions, and transportation costs. What can be a counterargument with the technology is that the costs are high when you are going to establish the technology, but in the long run it can pay off. Where the customers get what they want and the quality increases.

Nansen by Devold

The results indicate that Devold SC is vertical integrated whereby they own and monitors large part of the processes (Nørstebø and Gjørtz 2014). The SC they have today is quite sustainable. For them, it was more relevant to create a new line called Nansen by Devold to try the 3D-knit technology. Here they will mainly knit 3-piece sweaters. These products will not be Devold by Norway's, because they have separate products and will not be the same products as designed in Langevåg. However, it will be appealing to build a new line or company to take advantage of the new technology. The distance from Lithuania to Norway is not that far, so the production can continue there or be placed in Norway. As a solution they can use environmentally friendly solutions for driving, and the washing could continue in England. There will be an element here that is outsourced and transport from England and Lithuania can be minimized by changing this. As mentioned, they have their own maintenance employees who carry out the service on the machine to reduce maintenance cost and downtime. The argument is that it is cheaper to have maintenance inhouse than outsourced. With the information from the interview, an impression was that they have implemented LEAN in the production. Today they have a structured production, where they do not have intermediate storage. The challenges that can arise by implementing 3D-knit technology can be for example supplier logistics. Since the supplier logistics can be complicated when implementing 3D-Knit. The positive factor that 3D-knit can emphasize for Devolds production is reduction in manual labour. If they move the production to Norway, the cost can increase significantly. Another idea that Devold should have in mind is that the war in Ukraine could affect production in Lithuania. Due to this, moving production locally may be a solution in the long run. It may be a good idea for Nansen by Devold to start with that, so that Devold gets an insight into how 3D knitting technology can help them.

However, instead of substituting a current VC and SC, a creation of a new subsidiarity Nansen by Devold is applied instead. As Devold has a high functioning, sustainable and developed value chain. A proposal of a new value chain is then based on the current SC and suggested principles from the current literature is applied.

As the raw materials are nationally sourced and is a part of the Scandinavian image, this is something that is carried onwards. As per the view of the interviewees of Devold, the washing of the raw materials is currently conducted in England because of a lack of Norwegian suppliers. The view the interviewees of 3D knit Lab had, is that if the general textile production in Norway increases with time, this process might be profitable in the future to reshore back to domestic production. Spinning is something that is planned to be kept at the current location in Lithuania, meaning that transportation is needed back to Norway again as the production location of the 3D Knit manufacturing will be in Norway. Locating the production in Norway is a smart move for Nansen by Devold. Resulting in creation of local jobs, and logistical reductions due to shorter distances and an even more integrated Value Chain (Knitting Industry 2021; Chung, Kim, and Jang 2020). The actual manufacturing is where adoption of 3D Knit will drastically change the SC. As the garments are produced in one go, the processes of sizing adjustment and assembly of parts is eliminated from production. Supported by the research of (Bendt 2016) where eliminating time spent in production and labour cost for reduced post processing. The rest of the SC will then make use of the current infrastructure to reach customers.

Keeping this in mind, a VC and supporting SC can be made for Nansen by Devold. The proposed VC for Nansen by Devold is illustrated in figure 30. Whereas the supporting SC for Nansen by Devold is represented in figure 31 below.

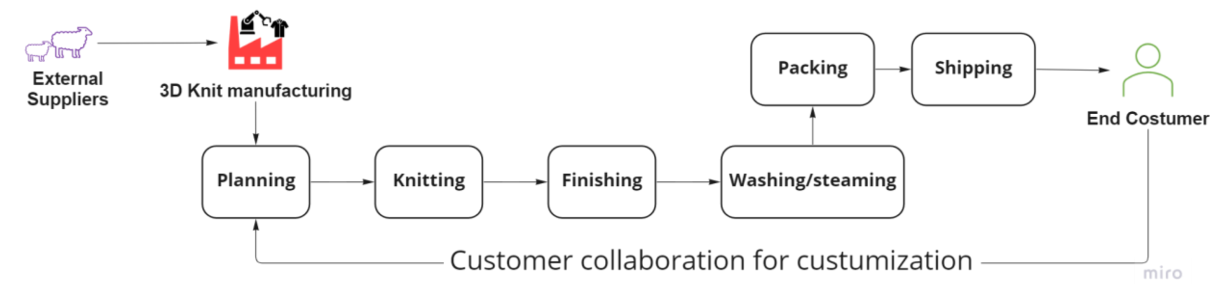


Figure 30 Proposed simplified VC for Nansen by Devold

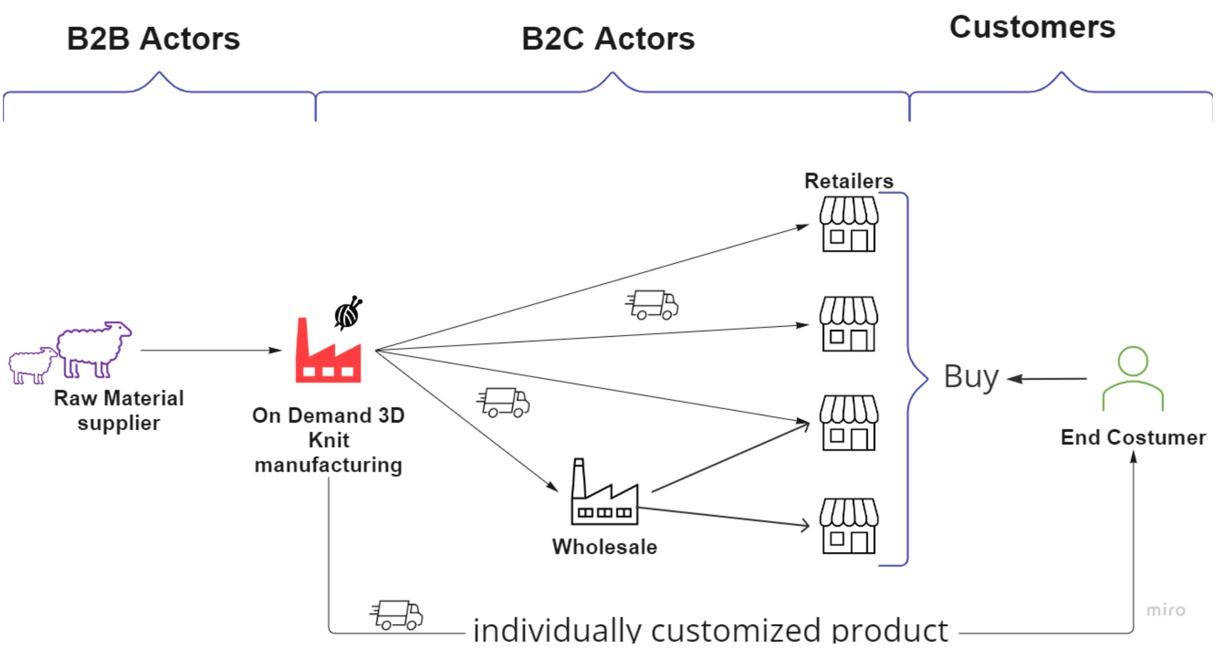


Figure 31 Proposed Simplified SC for Nansen by Devold

Since Nansen by Devold is a newly established subsidiary, there is not significant information about it to describe about their stakeholders. Therefore, the elaboration of stakeholders is only performed in the advanced case of Ekornes.

To conclude this research question, currently Devold and Ekornes has a vertical integrated SC, whereby the company owns and controls large parts of their processes (Nørstebø and Gjørtz 2014). The technology empowers quick transfer of real-time information, enabling quick decision making across the supply chain based on real time information, and it enables quick decomposition and reproducibility (Vaagen 2022).. With such technology, the customer orders in real time and information is (quickly) transferred from customer to design-production-planning-sampling-production. This is only possible if all stakeholders work on the same technology platform and are willing to share data. Sharing information across the stakeholders has both advantages and disadvantages. Advantages that appear with the technology is time and the possibility to produce exactly what the customers wants. The disadvantages are insight into strategic planning data, which is not information stakeholders generally want to share.

Regardless of whether Nansen and Ekornes have two different product groups, Nansen can learn a lot from the efficiency of Ekornes VC and SC. In our opinion, it will be useful for Devold of Norway to think about moving their production to Norway due to current issues that may affect their production location today. However, by implementing 3D knit technology, companies can move the production back to Norway. This will help prevent overproduction as production is closer to consumers. For Nansen by Devold, they will have an advantage of being new to the market and start with 3D-knit technology as it has no previous production history they must consider or change from. In addition, a shift in production will make production more environmentally friendly. In a supply chain view, the technology reduce cost, lead time, production, uncertainty and increase customized product, enables domestic production and increased control over their VC and SC (K. Foster and Istook 2017). Additionally, the technology eliminates waste, no requirements to sew the parts together as they do today. In addition to requiring smaller stock space and it providing the opportunity to have the production closer to the customer.

6.2 RQ2: What barriers do the companies face when implementing 3D- knit technology compared with the traditional supply chain.

With RQ2, the thesis attempts to connect barriers and drivers found in the findings along with those described by the literature. The barriers can be limitations of the companies deciding for adopting the technology. However, the barriers can also take form as challenges that will not cease the adoption process, but rather pose as something that needs to be addressed to be successful. The Drivers are factors that make the companies willing to decide to adopt. Opportunities are listed as potential use cases with the technology but are not main rationale for adoption.

Training and education

Ekornes and Nansen by Devold have some barriers that are common to both companies. A lack of technology “know how” or experience, programming skills (Mikahila 2021), education and knowledge for designers and operators halts a quick transition to production with 3D knit. One example of this was made by the technician during the observation at the 3D Knit lab. Stating that the machinery at Ekornes was suffering from lack of maintenance and lubrication before the technician arrived in Norway. The data from Huffa (2017) states that proper maintenance can be made into a source of reduced human failure. According to Ekornes, the knowledge barrier is highly relevant as there will be a demand for different kinds of workers, such as technicians, apprentices and operators. If the whole textile section of their production would need to be fired, around 180 workers would lose their jobs if not relocated to other duties.

During the SLR, the interviews, the visits and through the inquiries, it became apparent that the most common barrier for adoption has been the lack of training and availability of education (Knitting Industry 2021). Where the machinery supplier holds all of the technical manufacturing knowledge (Ekornes Interview 1 2022). The designers and workers in the client companies needs to be trained by the experienced operations of Shima Seiki to be able to operate smoothly. A demand is then created for skilled workers within 3D Knit technology.

Furniture SC barriers

The SC of Furniture industry specifically is complex, and researchers are uncertain if the 3D Knit technology brings simplicity or complexity (Michelsen and Fet 2010; Ekornes Interview 1 2022). As this industry already has experience with customization like combination of patterns and colours (Ranwat 2022). According to the literature, there is an issue of timely deliveries, a need to reduce inventories, and to decrease the cost of logistics and raw materials (Ranwat 2022). The results of this study indicate that these problems are not present for Ekornes and Nansen by Devold. But it is rather a general focus of the companies to maintain general competitiveness (Ekornes Interview 1 2022; Devold of Norway Interview 1 2022).

Ekornes' access to yarns and it is respected suppliers is another concern. For example, if the desired yarn is not produced in substantial volumes or its desired yarn compositions is not available (Norem and Pushparajah 2022a). The Supply barrier also poses as a new challenge for the purchasing department as new suppliers need to meet the same criteria as that of textile suppliers. Challenges that Ekornes might face is reduction or change in personnel. Since the sowing and cutting is believed to remain, the main issue to get a hand on workers with the correct knowledge or spending time and money on training personnel.

Barriers specific to Nansen by Devold are either to find establishing suppliers of yarns that is in line with their Scandinavian branding or the challenge of increased logistical costs with transporting yarns from Lithuania to Norway. The high cost of investing in the machinery is also a limiting factor for acquiring 3D Knit technology (Mikahila 2021).

If implementation is a total failure, there is less potential damage in Ekornes, as they have only 10% production concerning textile. The consequence of complete failure would be much larger for Nansen by Devold, as they are basing 100% of the production on the technology (Devold of Norway Interview 1 2022).

Sustainability

If looking at sustainability effects alone, the 3D knitting production is not more environmentally friendly than its traditional counterparts (van der Velden 2016). This also emphasized in the interviews with Devold of Norway, where it became apparent that their production already is extensively environmentally friendly, that it would not be any close to improve the already existing manufacturing (Devold of Norway Interview 1 2022). Although according to Maiti et al. (2022), the machinery has reduced energy consumption than conventional knitting.

A potential implementation of a CE mindset in the client companies is needed to be able to make use of new technologies (Y.-A. Lee 2022). But barriers that might emerge are high R&D costs, creation of support logistics and a disruption of an existing value chain (Realff 2006; Mathews 2015; Sandvik and Stubbs 2019). This is also represented in Ekornes has they have R&D founds in their organization as being a larger company.

The technology itself (as a driver and barrier)

3D knit is a technology driver that can help the companies to move towards industry 4.0 practices or advance already ongoing practices (McKinsey&Company 2015). But as discussed by Naghshineh and Carvalho (2022), the technology is considered disruptive, and can be a barrier if the supporting SC infrastructure and capability is not supporting it (Ivanov and Dolgui 2020). The data of this thesis suggests that the current limitation Ekornes has regarding this issue, is to get a hand on raw materials for their products. Nansen by Devold on the other hand, might not face any inner disruption, but might disrupt the market demand, with a change in customer behaviour (Devold of Norway Interview 1 2022). If Nansen by Devold is successful with their start-up, then other luxury brands might lose customers to Nansen, making the disruption having both a positive and negative effect. The 3D knitted product has a reduction in human error (Huffa 2017) because of less human interaction (K. Foster and Istook 2017) and an increase in quality is a result of this (K. Foster and Istook 2017; Maiti et al. 2022).

Production speed

Compared to traditional manufacturing, Peiner et al. (2022) states that there is a lower operating speed with 3D Knit technologies. This is a concern shared with the interviewees of Devold of Norway, and one of the reasons for not adopting 3D knit in the current manufacturing process of Devold of Norway is faster. As years of development and creating a system for knitting sweaters in parts is superior (Devold of Norway Interview 1 2022). The quick turnover speed of 3D Knit also results in reduced lead time (Bendt 2016).

Stakeholders

Addressing the different kinds of stakeholders is important (Freeman 1984; Donaldson and Preston 1995). And our results found that Ekornes substantiate this claim as they recognize that they have not involved the customer enough. During an informal conversation with product developer (Norem and Pushparajah 2022a), Ekornes are suffering the consequences of the customer not knowing the benefits of their 3D Knitted products. This is illustrated in the lack of sale figures for the 3D knit kitchen chair line-up. The strategic capability of product stewardships of the NRBV (Hart and Dowell 2011). Meaning that if Ekornes can find a way to gain customer awareness for their product, then it can lead to increased legitimacy of the products and the manufacturing method of 3D Knit.

Other barriers

A lack of transparency was found to be a barrier in the VC and SC by Mikahila (2021) and Power (2012). These suggestions are not applicable in our client companies as they have a focus on sustainable business proactive at all stages of their VC (Ekornes Interview 1 2022; Devold of Norway Interview 1 2022). Although it can be biased information to look good during the interviews, the information on their websites and the observations we made during our visit at the production facilities substantiates their claims (Devold of Norway 2022; Ekornes 2022c; Norem and Pushparajah 2022a).

The work of K. Foster and Istook (2017), and K.R. Foster (2017) in addition to Mechan et al. (2016) was the few academics attempting to specifically find the barriers and drivers for technology adoption in the SC. Mechan et al. (2016) found barriers to be: terminology, technology skills, machine capability and process awareness. Other barriers for adoption was unfamiliarity in consumers and a disruption in the SC (K. Foster and Istook 2017). In addition to underlining high investment cost and a slow technology adoption is hindering 3D Knit (Mikahila 2021).

As found by K.R. Foster (2017), the major drivers were cultural and operational, while the major barriers where knowledge and operational factors. This correlates to the findings in this study as customers are not aware of the 3D Knitted product advantages, making technology adoption slow. The lack of technology knowledge is also shown in the need for workers retraining or replacement due to lack of specified knowledge. As for Nansen by Devold' case, since it is a new startup, it might pose as a challenge to get enough knowledge built up in the company. The operation of 3D knit is shown as both a driver and a barrier for technology adoption, as there are several factors coming into play. As K.R. Foster (2017) concludes, the lack of knowledge and education is major barrier and is important for successful technology adoption. The companies in this thesis are addressing this, as both companies are still in the early stages of adoption, just on different levels. Ekornes sees this a future need for hiring workers with different competence, but in the future, if the technology is fully implemented (Ekornes Interview 2 2022).

The model made by K.R. Foster (2017) will be used to compare its findings, to the findings of SC technology adoption barriers and drivers presented in this research. Where Ekornes is depicted in figure 32 and Nansen by Devold is illustrated in figure 33.

Drivers and opportunities

The collaboration that Ekornes and Nansen by Devold has with the 3D Knit lab and Shima Seiki, is an important driver for successful implementation of the technology in their company as is a way of addressing the barrier of knowledge. Another common driver the companies face is that of reduced lead time, making the time from idea, through production to end costumer significantly reduced compared to the traditional SC. The reduction of lead time is formed by virtual sampling, short setup and manufacturing time and proximity to customers. The increased possibilities regarding design and quick response to fashion trends or customized demand is a significant driver for the transition to 3D Knit.

Nansen by Devold, faces a significant driver of higher quality products yielding better profits. This is both a result of the manufacturing process itself and the possibility to use higher quality yarns as well in the future.

Fashion Season: Devold of Norway and Nansen by Devold

Seasonal changes are common in the garment industry, where the ability to produce products closer the actual season is an advantage. The 3D knitting is making this possible by having OnDemand production and a decreased distance to end customer (Vaagen 2009). 3D Knit solves the unmatched demand and oversupply in the SC, all the while by using less resources in the process (Nachtigall 2021). The fact that production is OnDemand and can be produced locally and reshored back domestically also reduces transport emissions of the SC (Mikahila 2021; Maiti et al. 2022; Power 2012).

Customization as a driver

One of the most mentioned driver with the technology is that it provides easy customizability. The traditional SC has customization, but at a much slower rate than what is possible with 3D knit. According to Chung, Kim, and Jang (2020), a shift in the European market has been towards the competitiveness in design and innovativeness in the products. Making product on an individual basis is possible with 3D Knit, as it is cheaper than traditional methods that are tied up in complex systems. For example, by reducing logistics costs (Chung, Kim, and Jang 2020), The 3D Knitting machines equipped with digitally monitored feeding systems (Technican 3D Knit lab/ Shima Seiki 2022), opens up to using more diverse types of yarns (Mikahila 2021), and pattern versatility, further increasing the customizability (K. Foster and Istook 2017).

SC resilience

One benefit made from 3D knit technology is the creation of shorter and more resilient SCs (Dix 2021; Petersen 2017; United Nations 2015). Ekornes states that this is a major driver, as they can have control over the final product, by reducing the need for external production of textile fabrics and to quickly adopt to new customer demands. This means that 3D Knit technology can provide the customer with products that is to that specific want and need, bringing sedimental value to the product (Devold of Norway Interview 1 2022).

Waste

The waste situation in the traditional SC is complex. The literature states that having a constant focus on the entire SC helps to eliminate waste at an early stage (Mandel 2020). Of the many ways for reducing waste with 3D Knit technology, saving 20-30% raw material use (Knitting Industry 2021; K. Foster and Istook 2017) and decreased post processing is mentioned as a main point (Huffa 2017; Bendt 2016; Power 2012). But an enabler for reduced waste is the design process, where the designer no longer needs to have physical samples (Norem and Pushparajah 2022b). The reduced need for post processing is also discussed as a driver for both the companies for adoption, as time can be spent at different areas instead of adding edges, labels and other tedious work on the garments or fabrics.

The barriers and Drivers of the technology itself that are the same as the areas of influence found by Mechan et al. (2016) and K. Foster and Istook (2017). The dissertation of K.R. Foster (2017), separated the drivers and barriers as well. What is interesting is that based on the current situation, the current major driver for 3D knit adoption is the operational driver while the others are seemingly non present. This means that the customers are unaware of the benefits of the production method, demand is lacking and there are no strong cultural drivers either in society or internally other than the ones working with it. Since K.R. Foster (2017) stated that the two major drivers for this technology are operational and cultural. What Ekornes must focus on is the cultural change, while Nansen by Devold can start with both at the same time.

Comparing the model of Foster with the our findings, figure 32 and 33 (both included in large format in appendix D) shows that our study mostly aligns with its findings. Meaning that the work of this thesis in Norwegian companies show much of the same results as that of the US bases companies in the original and more extensive work of (K.R. Foster 2017). The barriers present may be more in numbers, but if the client companies focuses on mitigating them and highlight the drivers, the drivers are stronger than the barriers.

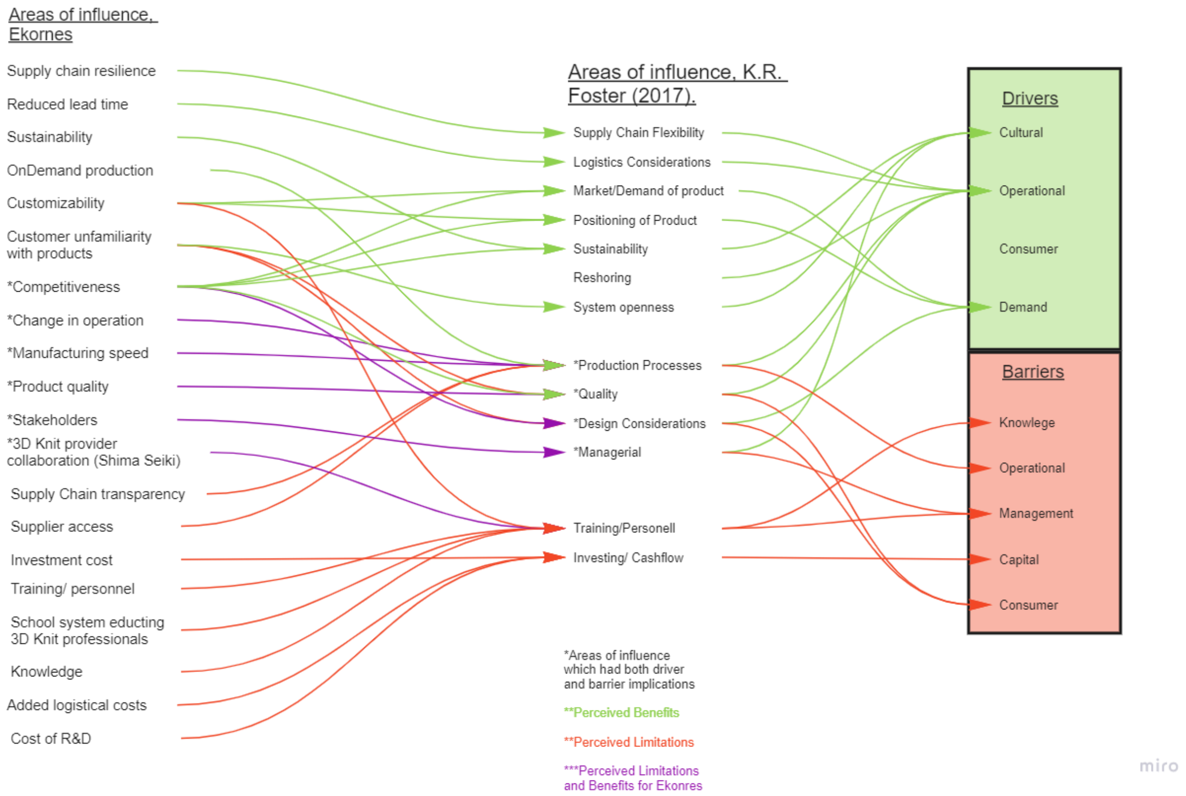


Figure 32 Ekornes areas of influence comparison to the model of K.R. Foster (2017).

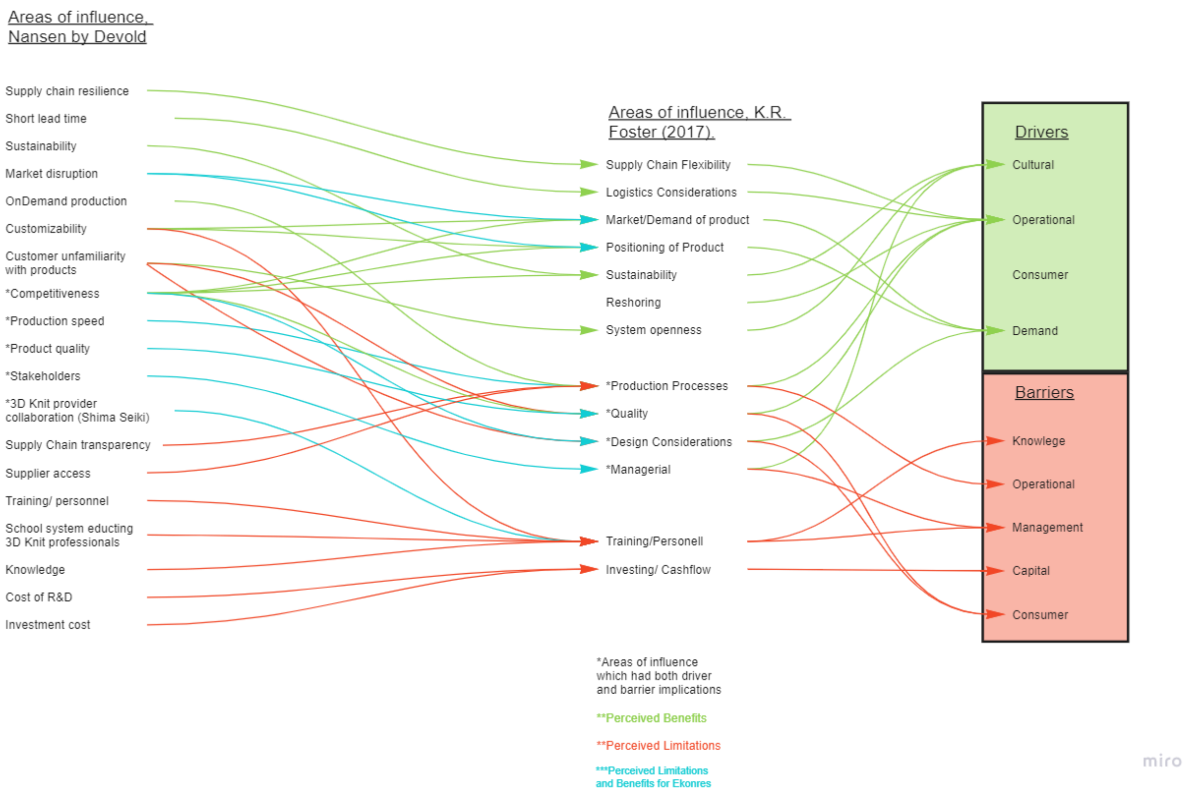


Figure 33 Nansen by Devold areas of influence comparison to the model of K.R. Foster (2017).

6.3 RQ3: How can the 3D knitting technology help Ekornes and Devold move from a linear economy towards circular economy?

In RQ1 a discussion was made about how the current supply chain would be affected by the implementation of the 3D knitting technology. In RQ3 an elaboration on the output from RQ1 in a circular economy perspective is done.

The findings support the theory by Diabat, Kannan, and Mathiyazhagan (2014), on the dominance of linear supply chains in the textile-based industries. Ekornes and Devold current VC is considered as a sustainable value chain and a widespread target to mitigate waste. Along with their comparable strategy, none of the client companies associate themselves as a part of the "fast-fashion" industry (Vaagen and Wallace 2010). The technology is an enabler to drive the companies towards circular economy, but *"technology alone is not enough to achieve a circular economy."(Tomra 2021)*. Below a discussion is made about the sustainability potential provided by the technology and the enables in Ekornes and Devolds current value chain. The discussion is placed within the context of four Rs --Reduce, Redirect, Rethink and Replace-- (Klepp 2015). A short summary is made in table 14 of each element on how 3D-knit technology enables circular economy before the in-depth discussion of the R's in relation to the findings.

Table 14 Summary of 3D Knit enablers of the 4 Rs.

The 4 Rs	
REDUCE	▪ Reduce production by producing to real orders (reduce/eliminated overproduction) ▪ Reduce material consumption – eliminate waste, zero waste ▪ Reduce foam plastic ▪ Reduces transport costs, emissions, and waste ▪ Reuse the material, make the product washable
REDIRECT	▪ Global vs local; Local production, with emphasis on ingredients, traditions, uniqueness, and innovation ▪ Increased work positions ▪ Reduce emission and pollution
RETHINK	▪ Customer-driven design (Collaborative consumer-driven business models) Involve users in the design process to personify the product and thereby increase perceived value. Increased customer value can increase the product's service life and service life.
REPLACE	▪ New business models

REDUCE

Interview results points out that Ekornes current production generate 20% waste, that indicates a significant high amount of waste as their textile production is 10% of their whole production.

This confirm that the waste proportion in the industry is between 6-25% (Maiti et al. 2022). The results provoke a clear perceptive that Devold has a significant lower level of waste emulate with Ekornes. The waste (from the cutting process) proportion that appears in Devold production is collected and sold to recycling. Devolds raw material (wool) has a high potential value regarding the costs and value. However, Devold makes the unprofitable waste to a profitable limited edition outlet product. It could be an idea to give the collected waste to Nansen by Devold where they can produce limited edition products with 3D-knit technology. The challenge they may face here is that the roughness of the sweater, but if they could recycle it into fine yarn, it can be used in the 3D knitting machine as well.

The 3D knitting technology provokes waste reduction that were confirmed in an informal conversation with the technician at the 3D knit lab. Also, the results from Ekornes points out a confirmation of the statement. This statement is also supported by existing evidence from Rosanna van Meer (Mikahila 2021), where the author states that production with 3D knitting have 30% less material waste. Moreover, 3D knitting brings up the possibility of dismantling and reuse raw materials, and this is a factor that cannot be done on Ekornes traditional production (Mikahila 2021). The result from the 3D-knit lab reinforced our opinion that 3D-knit machines reduce waste, since the machine produces exactly what is required. As of today, Devold knit each of the parts on the sweater separately and sew it together with help of human resources. With the 3D-knit machine, Devold of Norway can eliminate the process of sewing together the parts that requires human sources to accomplish. Compared to 3D – knitting, the traditional production will have a significant quantum of waste. Regardless of whether they sell remaining materials for reuse, they can take more use of the yarn they have. Another statement is that the textile rolls are woven together before it comes to Ekornes production, so it is more complicated to spin these to skeins of yarn again (reverse manufacturing) (Chemsec 2022).

Empirical findings suggest buying raw materials from a yarn supplier than with a textile supplier (eliminates outsourcing). Compared with the current production mapped in findings, Ekornes has the convenience to buy the raw materials (yarn) that are required to knit the desire product. Maiti et al. (2022) reinforces the argument that 3D-knitting machine are more environmentally friendly than Ekornes weaving counterpart, due to higher energy consumption and carbon dioxide emission in manufacturing in supplement to a need for just one machine (Maiti et al. 2022). 3D-knitting is contributing to lower waste and transport emissions, and the removal of post finishing operations (Maiti et al. 2022; Power 2012). Another applicable argument is that the technology can reduce inventory levels and inventory facilities. Also, it contributes to higher transport of raw materials compared with large textile rolls that might take up twice as much space in a truck. To store yarn, you can have a smaller shelf space compared to textile rolls that needs significantly larger storage area. In addition, Ekornes will have more control over the quality of the upholstery produced and meet the requirement for textile in the furniture industry.

The interview results point to no overproduction at Ekornes and Devold. Devold produces on forecasts, because they have managed to build quality products with trend values that remain more-or-less stable over time. Accordingly, to Ekornes, the planning department forecast and elaborate according to the costumers wish, and they produce close to market with the advantage of getting the accurate information on real time. These results are taken into account when considering the new line, Nansen by Devold. By implementing 3D-knit technology for a new established line without any historical production from before, gives the opportunity to eliminate the problematic of overproduction and large inventories. The literature review reinforces the argument such production requires shorter supply chain and on-demand production (Dyrnes 2021).

Above mentioned results and discussion suggest to considering customized production. According to the interviews, customization is not implemented in Ekornes and Devolds current value chain. Compared to our clinical companies, Nansen by Devold would have unchallenging to apply customization production as the new kid on the block. By involving consumers in the design process to personify the product can increase the perceived value (Vaagen 2017). Additionally, it can reduce the need to purchase new products, because customers have more ownership and see the value for the product, they have been involved in creating, and they get exactly the product they want.

Empirical findings suggest that Ekornes should rethink the problematic regarding foam plastic they are currently facing. 3D knitting technology enable designs that are complex for human sources (Shima Seiki 2022c). In an informal conversation and prototypes from 3D knit lab, they elaborated that foam plastic can be replaced with garment. Whereby the cover is kitted with raw materials (yarn) to get the foam plastic results. However, such solution is more environmentally friendly compared to the current foam plastic production (Norem and Pushparajah 2022a). Both Ekornes and Devold uses wool garments where Ekornes on their 3D-knitted covers for stressless chairs and Devold for their sweaters. Devolds sweaters are kept much longer, even down to generations (Dyrnes 2021). The yarn should be carefully selected to meet sustainability demands, either through organic yarns, made through a sustainable process or recycled material (Maiti et al. 2022). Both Ekornes and Devold uses wool garments whereby Ekornes on their 3D-knitted covers for stressless chairs and Devold for their sweaters. Devolds sweaters are kept much longer, even down to generations (Dyrnes 2021). The yarn should be carefully selected to meet sustainability demands, either through organic yarns, made through a sustainable process or recycled material (Maiti et al. 2022).We support that the company use wool and recycled yarn in their production. This should also be applicable for Nansen by Devold.

The interview results from Devold clarified that the fibres where washed in England, and thereby transported to the spinning facility in Lithuania. Mentioned process should be reconsidered in Nansen by Devold, with the reasoning of their localization. The suggestion is to execute the fibre washing in England, but find a supplier located locally for spinning. Mentioned suggestions is not viable for Devold, because their production is in Lithuania. Since Nansen by Devold is a new established line, they should clearly think about sustainability in every process. Considering this possibility would help Nansen by Devold to evaluate more sustainable sourcing alternatives compared with the logistics from England-Lithuania-Norway. Another suggestion for Nansen would be to buy raw materials from suppliers that have done the washing and spinning facility beforehand as Ekornes.

Compared to the traditional production, 3D-knitting provides less environmental impact and energy consumption (Maiti et al. 2022). Devold has entered into an agreement for their own solar panels on the roof that is conducted on their production factory in Lithuania (Ciobanu 2011). In addition, they have a green energy contract for electricity on everything they use, beside they have a heat pump. They work continuously to improve the carbon footprint. Likewise, they have a good dialogue with the suppliers and have demanded that the products they deliver requires positive carbon footprint (Maiti et al. 2022). This is a solution Ekornes and Nansen by Devold should bring with them.

REDIRECT AND RETHINK

Another viable argument to implement 3D knitting technology is to move the supply chain (outsourced activity) from global- to local production (Bendt 2016). Interview results points out that Ekornes have their production locally, but the advantages that develop by implementing the technology is the sustainable growth and design prospects. By moving the production locally, companies gain benefits such as local production, traditions, uniqueness, and innovation. In addition, major issues such as emissions, pollution by having smaller driving distances are eliminated (Bendt 2016; Vaagen 2017). Customers will also get the products faster compare to ordering online and the technology enables customization. Since numerous of individuals have little knowledge about the technology, it can lead to a barrier to get customers to buy a 3D-knitted product (K.R. Foster 2017). Cause of the barrier, it’s important to promote the solution in the best manners. Currently, Ekornes sells 3D knitting chairs at Møbelringen. In a formal conversation at Ekornes, it emerged that minority of the customers has the knowledge about 3D knitting. This causes decreased level of sale of the stressless dining chairs. The sales and marketing department should contribute to a better promoting techniques. Furniture is generally expensive, and for customers to buy it, it is important to argue with the right reasonings to make customers buy it (Ekornes Interview 1 2022). For example, the fact that they do not have to buy a new chair, but that they can only buy the cover. If, they refurbish a home, they can change only the cover or if they spill something on the cover, the cover is washable. This would be a good argument for families with children. In addition, this is a more environmentally friendly alternative than buying and throwing chairs for every occasion.

With the argument from Vaagen (2017), 3D-knit technology is a technology that can be a customer- driven design. Whereby Ekornes, Devold and Nansen by Devold can involve users in the design process to personify the product and thereby increase perceived value. Including customers in the design stage can give customers recognition of the product and ownership. Furthermore, customers can get exactly what they want from the design as 3D-knit technology enables advanced patterns. Increased customer value can increase the products service life (Vaagen 2017). Since Ekornes has a standardized and industrialized production, one can argue to the customers that the chairs can last for several generations because the quality is high, and the only thing they need to change is the upholstery. This can help to expand the product-life, without throwing it away. This will enable sustainability and eliminate the linear way of thinking.

REPLACE

With the discussion and collected results indicates several business models that can be elaborated by Ekornes and Devold. The most viable solution is Extension and recycling to expand the production life and common technology platform.

Extension and recycling to expand the product life.

The new solution contributes to 1) expending the product lifecycle, 2) quick reproducibility into similar products in "own" value chain or into new products in external value chains. The two business models can merge into one business model called "extension and recycling to expand the product life". At the observation at 3D knit lab, an important statement occurred. The knitted garment on 3D knitting machine is knitted in a way to pull out the yarn and tie it back as a raw material. This can then be produced again as a new product or the same as it was. That would be according to what the customer wish for, and this model follows the old way of reuse knitted yarn to produce a new garment. It enables faster recycling whether they do it in their own value chain (Closed loop). This means that there is a value chain in Norway that recycles all the 3D-knitted products. Faster recycling is an important part of the 3D knitwear model.

The interview results points out that Ekornes has a significant number of waste in their current value chain. Moreover, the cover is not designed to replaced or washed if customers were to be unlucky to ruin it. With the 3D-knitting technology Ekornes gets the opportunity to knit the dining chairs covers elastic enough so the customers get the opportunity to wash or change if they accidently ruin it. This also minimizes customers to buy a whole new chair, since the quality of the chairs are high. This result build on existing evidence made by Bulathsinghala (2022) in their article where the product that are knitted with the 3D-knit machine has the possibility for stretch and bending. Such solution will contribute to increase the products lifecycle.

Another element that can help the companies (Ekornes, Devold and Nansen) to increase the products lifecycle is by applying consumer-driven design and production. Such solution contributes to increase the human psychology of customers need within uniqueness. Since the customer would not see the same product in a different store, and the product automatically get a personal touch on it. The study and our observation at the 3D-knit lab, also strengthen our result, because according to W.-S. Choi and Lee (2010) the 3D-knit machine can make complex structure due to its possibility to utilize different knitting techniques. Accordingly, the customers get a wide choice of designs and options to design their own product.

Collaborative Consumption (Sharing technology platform)

According to the results and the collected studies, the technology is less explored, additionally the market and the customers have little knowledge regarding the technology. With the results we see the emergence of individual initiatives where customers are offered service rather than goods, such as a bundle of product-service attributes. However, the idea is to share a common technology platform across several businesses illustrated in figure 34 below.

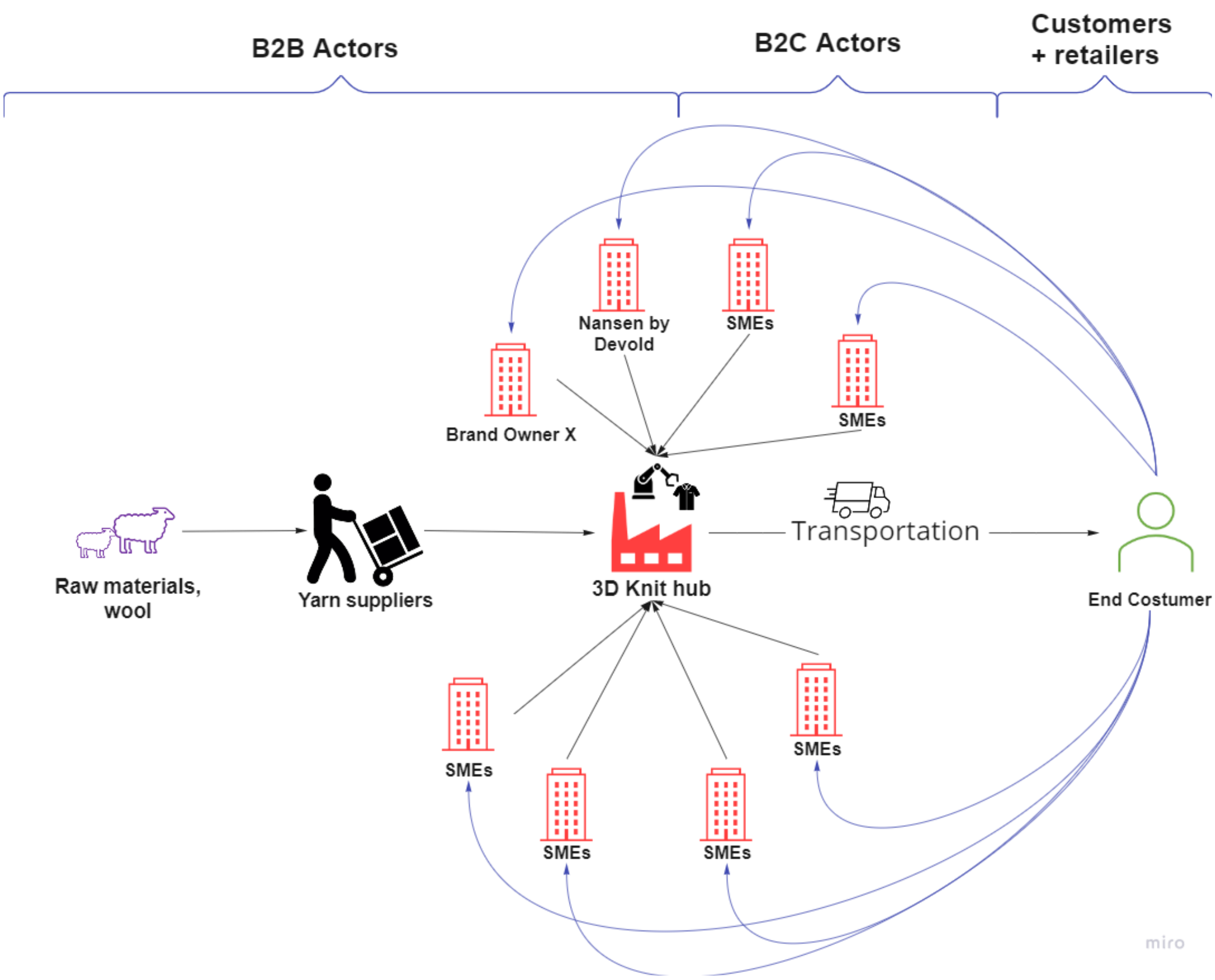


Figure 34 Proposal of 3D Knit hub solution of Norwegian textile-based industry.

One idea could be to establish a design platform where the customers can connect and design their own product. Whereby they get the opportunity to contribute to the small changes where they can design the product they wish for according to preferences and wish. The major changes need to be done by expertise like 3D-knit lab. From the results, the companies today dispatch the design to the 3D-knit lab, but if the knowledge increases then there are many actors who also will contribute. However, the production with the 3D-knit technology itself is capital demanding regardless to invest in 3D knitting equipment. By creating such a hub, where many small manufacturers and designers can connect to print their own products. As today, 3D-knit lab has the expertise with technical design that make it more advanced. The goal is to build a platform and increase the competencies so that the technical and technological competence is transferred to more people so that the hub becomes just a production hub. A suggestion is to see this as a future perspective to enable 3D-knit production through a hub. The background of such argument is that there are not many manufacturers who have the capacity. However, they can buy the machine, but the machine alone is not enough to produce. As informant two from Ekornes mentioned that the companies also need expertise who knows the technology. By having a hub with numerous machines where the actors can connect by themselves would be an applicable solution. It's also important to take into consideration to increase the knowledge within the technology, since Ekornes has one expertise who knows the most about the technology and in the long run its important to train more people.

A 3D knit hub across multiple SMEs is one potential future solution to implement the 3D knit technology in Norway in an economically sustainable manner. Otherwise, the investment costs may exceed the potential benefits for SMEs. Such model is applicable for actors who are not as capital strong as Ekornes for example. However, large actors always build their own production capacity, compared to small actors who do not have as much capital to build a factory. As of today, most of the small actors buy the design in Norway and the production in Asia (Ferdows 1997). Such solution will in a way move the production to Norway. It will not be a big change form how it is today, but the fact that it is a 3D knitting machine that can be moved closer to the market. Hence, the location makes it a more sustainable value chain, and companies (as Devold and Nansen) will automatically get the control over the activates than outsource the production abroad where the company have limited information. By moving the production would also help the companies to reach the UN sustainability goals within the issues in the industry of child labour, low wages, and lacking health and safety, unnecessary waste of water and use of pesticides in farming, harmful substances pollution, waste of raw material in production of finished material and long-distance transports in between facilities and end customer (Mikahila 2021). 3D-knit eliminate the uncertainty because the production is nearby and not outsourced (Vaagen 2017).

For many years, it has been a strategy to move technical and technological expertise out of Norway in all industries, but now the strategy is to move it back to Norway. Such technology can contribute to enable the growth of the technical and technological in Norway. Also, they must build technical skills, technological skills, machine learning, etc., to move these skills back and not outsourced. As a revenue the country would get more jobs to offer locally, decrease the transport because both products and raw materials are not moved throughout the globe (Vaagen 2017). However, moving production back to Norway is an important sustainable aspect. It is socially-, environmentally-, additionally is also contributed to economic sustainability. As Vaagen (2016) mentioned and we are agreeing that there are shortage of raw materials and being self-deserving of producing for your own use have a huge negative affect in a long run.

3D knit design enables personalize design, increased product life cycle replaces foam plastic in sitting furniture with solutions that enable similar functionalities. Hence, 3D knit design contributes to Reduce, Rethink, Reuse and Replace. The data integration/data sharing platform allows for close to market production in (close to) real time. This contributed to reduce overproduction by producing to real orders. Also allows for quick supplier selection according to specific design and supply chain criteria regarding choice of “local” suppliers, sustainable suppliers, etc. Since 3D knit technology enable to move production from global to local production, decrease the emission and pollutions that elaborate from transportation.

7 Conclusion

This section presents the summary of the thesis research, including a discussion on theoretical and managerial implications. Limitations of the presented research and possible areas for future research are given.

7.1 Research summary

The main objective in this thesis has been to find out to what extent 3D Knit technology could enable sustainable design-production in Ekornes As and Devold of Norway. Along the research process it became apparent that implementation of 3D Knit for Devold would not happen in the current manufacturing line, but rather to be a newly established company called Nansen by Devold. The process is somewhat different for each of the client companies, but what is found as areas of concern in Ekornes is expected to be applicable for a new 3D Knit enabled production line for Nansen by Devold. The clinical management methodology approach was applied. The main conclusions and feasible solutions this research have contributed is summarized below:

RQ1:
The 3D Knit contributes to supply chain integration from the traditional SC by completely integrating digital sampling and design, production planning and the possibility to have real-time data available for decision makers. A challenge that could arise is to what extent the customers are going to be a part of the design process and what parameters they should be allowed to change. As a result of a move towards mass customization and modularization principles.

RQ2:
The integrative nature of the technology is restricted to the stakeholders lack of willingness to share strategic information and data. Such as customer data in the mass customization. An in depth understanding of the customers are needed to uncover what gives the customer value and makes them willing to buy. Other main barriers are customers unfamiliarity with the technology and its products, the great investment cost of the machinery and training and education.

RQ3:
This research found that a CE approach in Ekornes and Nansen by Devold is a viable option when utilizing 3D Knit technology. The reduction of waste and new product opportunities drives the move from LE to CE. To conclude with a CEBM for the companies, Ekornes suit an "extension and recycling to expand the product life" business model. Nansen by Devold is recommended to a BM of using a 3D Knit hub in collaboration with other SMEs in Norway.

7.2 Managerial implications

This section sums up the main takeaways for managers in the client companies and the research objective gets a definite answer. Key takeaways are listed below for managers in the client companies or other companies wanting to introduce 3D Knit technology.

- A change in behaviour and increased awareness of the technology is needed both from manufactures and customers.

- The technology also makes it possible to utilize waste.
- A general focus is needed on building knowledge of 3D Knit in current workers or hiring new employees with suitable competence.
- Sales and Marketing department should promote and create awareness of the 3D Knit products and production process is needed for both customers, retailers and employees.
- Individualized/personalization is possible through customizability potential in design with 3D Knit. Implying new revenue streams.
    - Ekornes can have a campaign where they go to Møbelringen and accept customer orders for 3D-knitted covers. This will help to promote the company in the best possible way.
    - Ekornes: More neutral colours on the chairs and rather give customers the choice to choose other upholstery. That they can buy the chair for themselves, and the cover can be chosen according to the customer's wishes. For example, by having a catalogue with different designs and colours. Prototypes that show what choice they have.
    - Ekornes: They can promote themselves by supplying promotional chairs to companies or restaurants with their designs. This can attract the attention of other companies as well as customers.
    - Ekornes: The product developers/designers should recommend to make use of the innovation possibility of the technology and create new types of products instead of just replacing and improving existing products.
- The most disruptive and time-consuming process of 3D Knit adoption is finding new suppliers of raw materials. Market awareness is deemed an important element.
- Collaboration with stakeholders is critical.
- For Nansen by Devold, and other companies wanting to utilize 3D Knit technology, the formation of a 3D Knit hub can be a solution for an industry wide collaboration, with minimized risk and investment costs.
- Nansen by Devold should create customer awareness of the customization ability by having a mobile design group traveling around Norway to promote the technology. This makes customers able to get a hands on feel for being their "own designers" and making the end product more valuable for them.
- There is a need for new or exploring existing yarn suppliers. Preferably finding Norwegian/Scandinavian (local) alternatives for yarn.

The listed implications are the main takeaways managers of the client companies can bring with them in further research and development of producing with 3D Knit technology.

7.3 Limitations

The thesis is a part of the Master of Science programme in logistics during the last semester of the study. Meaning that the scope of the thesis is time limited to around 5-6 months.

Other limitations we have faced is a lack of response to inquiries, believed to have several explanations. Sick leaves as a result of covid-19 pandemic, increased workload as a result of supporting this thesis becoming tiering, too ambitious goals from us of what is expected from the participants and the worry of supply and transportation because of the ongoing conflict between Ukraine and the Russian federation. Consequently, this study is oriented heavily towards a qualitative research as the access to hard numbers were limited. At the start of the thesis, a goal was to have balance of half and half of both qualitative and quantitative research as the qualitative would depict the interactions while the quantitative would give hard evidence to back up the qualitative claims. The lack of time and information sharing was particularly noticeable at Nansen by Devold, as they are at the time of writing, still in a learning phase.

The focus on only two companies is also a deliberate limitation. As this project was presented to us to be solved by the two companies, restricting the number of firms to involve in the process. Although it is better than just focusing on one company, in one industry, the findings of this study might only be applicable to our client companies and not transferrable to other companies or industry practices.

The same assumption can be applied to only focusing on one machine supplier. Where other suppliers could solve the problem differently, either for better or worse.

7.4 Suggestions for further research

As elaborated in the limitations for this thesis, a focus on the quantitative aspect of technology adoption was lacking. Focusing on comparing the economic, environmental and social cost using essentially a cost benefit model could help make managers aware of the potential advantages or disadvantages from an economic viewpoint.

A study on just one company of the economic viability of the technology investment, product life cycle can be beneficial. This research lacks framework for a company to share confidential information, resulting in a more general approach.

The solution proposed to Nansen by Devold of participating in a 3D Knitting hub is an area that should be explored by future researchers. Using the technology in innovative way is also important to fully utilized its potential, such as attempting to improve sustainability by substituting foam plastics with waste yarn from 3D Knit production.

The 3D flat knitting machinery could also become or already be an obsolete technology. Technology development happens quickly, and other solutions could solve the same issues in an easier, more efficient or in a different way. The next step after industry 4.0 is society 5.0, research should be done to see if other competing technologies could surpass 3D Knitting.

This thesis is also mainly focusing on the perspective of the manufacturer and/or the brand owners. Future research could focus on including all stakeholders to uncover different perspectives of why the technology is not mainstream in the garment industry. This to make a more holistic view of the impact must use the technology. What is important is to include all stakeholders, from governmental bodies, consumers, retailers, manufactures, politicians and suppliers to transporters to name a few.

Bibliography

15writers.com. 2022. "Understanding the Research Onion." Accessed 18 May. https://15writers.com/research-onion/.

Adams, J., H.T.A. Khan, and R. Raeside. 2014. *Research Methods for Business and Social Science Students*. SAGE Publications.

Agrawal, Narendra, and Stephen A. Smith. 2009. *Retail Supply Chain Management*. 1 ed.*International Series in Operations Research & Management Science*: Springer New York, NY.

Akhtar, Dr Md Inaam. 2016. "Research design." *Research Design (February 1, 2016)*. https://d1wqtxts1xzle7.cloudfront.net/62246374/BookChapters20200301-122180-179cqp9-with-cover-page-v2.pdf?Expires=1652991936&Signature=PiCdOL34FbV3mhmyBsG0aKQLUPW83KzdULvsPLNo-FntWW53Q6Q4Q0NdMWePxqS99vUfQ7Og1pEdoYzUahybtOWLOLtLXddFEvRs8XBvPPBMRVl99o24vc5bqd67WcvZaUQnx~HHI29cPhhKpSWFnecHyTtaQi7-UGoULkwxAlORXWsT8bxrFB-bgia7sKqM3xzN2oGrxW~PNlplg0~AjOBStzrZOSWkFMwoWAj3wDaZxKJIQtK5x3O47oygx0rSL6Y8hlUiI5GCuyCjYBWLLFNXuuPz4bPhd-QU73pk8Fd3lsAyLli37yisLOmJxJlznmSHY7v-oxnBZCchl9VtQw__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA.

AllassignmenthelpUK. 2019. "Understanding the Saunders Research Onion." AllassignmenthelpUK. Last Modified 10 December 2019. Accessed 18 May. https://www.allassignmenthelp.co.uk/blog/saunders-research-onion/.

Badawi, M Sc Said Sobhey. 2008. "Development of the weaving machine and 3D woven spacer fabric structures for lightweight composites materials." PhD, Technischen Universität Dresden. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.944.9077&rep=rep1&type=pdf.

Bagchi, Prabir K., Byoung Chun Ha, Tage Skjoett-Larsen, and Lars Boege Soerensen. 2005. "Supply chain integration: a European survey." *The International Journal of Logistics Management* 16 (2): 275-294. https://doi.org/10.1108/09574090510634557. https://doi.org/10.1108/09574090510634557.

Baker, L. 2020. *Data Collection*. Lee Baker.

Bakker, Conny, Feng Wang, Jaco Huisman, and Marcel Den Hollander. 2014. "Products that go round: exploring product life extension through design." *Journal of cleaner Production* 69: 10-16.

Barney, Jay. 1991. "Firm resources and sustained competitive advantage." *Journal of management* 17 (1): 99-120.

Bellman, Richard, Charles E. Clark, Donald G. Malcolm, Clifford J. Craft, and Franc M. Ricciardi. 1957. "On the Construction of a Multi-Stage, Multi-Person Business Game." *Operations Research* 5 (4): 469-503. https://doi.org/10.1287/opre.5.4.469. https://doi.org/10.1287/opre.5.4.469.

Bendt, E. 2016. "Shape and Surface: The challenges and advantages of 3D techniques in innovative fashion, knitwear and product design." *IOP Conference Series: Materials Science and Engineering* 141: 012016. https://doi.org/10.1088/1757-899x/141/1/012016. http://dx.doi.org/10.1088/1757-899X/141/1/012016.

Bowen, Glenn A. 2009. Document Analysis as a Qualitative Research Method. [Fitzroy, Vic.] :.

Bulathsinghala, Rameesh Lakshan. 2022. "Investigation on material variants and fabrication methods for microstrip textile antennas: A review based on conventional and novel concepts of weaving, knitting and embroidery." *Cogent Engineering* 9 (1): 2025681. https://doi.org/10.1080/23311916.2022.2025681. https://doi.org/10.1080/23311916.2022.2025681.

Calkins, Susanna, and Matthew R. Kelley. 2007. "Evaluating Internet and Scholarly Sources Across the Disciplines: Two Case Studies." *College Teaching* 55 (4): 151-156. https://doi.org/10.3200/CTCH.55.4.151-156. https://doi.org/10.3200/CTCH.55.4.151-156.

Charles, Oliver. 2022. "3D-Knitting = 0 Seams, 0 Waste." Oliver-charles.com. Accessed 11 March. https://www.oliver-charles.com/pages/3d-knitting.

Charles Sturt University. 2022. "Literature Review: Systematic literature reviews." Accessed 16 May. https://libguides.csu.edu.au/review/Systematic.

Chemsec, Textile Guide. 2022. "The textile process." Accessed 16 May. https://textileguide.chemsec.org/find/get-familiar-with-your-textile-production-processes/.

Cherry, Kendra. 2020. How Applied Research Is Used in Psychology. Accessed 16 May 2022.

Chesbrough, Henry, and Richard S. Rosenbloom. 2002. "The Role of the Business Model in Capturing Value from Innovation: Evidence from Xerox Corporation's Technology Spin-Off Companies." *Industrial and Corporate Change* 11: 529-555. https://doi.org/https://doi.org/10.1093/ICC%2F11.3.529.

Choi, Kyoung-Me, Jong-Jun Kim, and Na-Gun Song. 2012. "A study on the analysis of 3D scanning of knit stitches and modeling system-jersey, rib, and cable stitches." *Journal of Fashion Business* 16 (3): 125-135. https://www.koreascience.or.kr/article/JAKO201224963706943.pdf.

Choi, Won-Seok, and Youn-Hee Lee. 2010. "Development of three-dimensional knit models through rib & purl structures." *The Research Journal of the Costume Culture* 18 (1): 109-117. https://www.koreascience.or.kr/article/JAKO201017337338284.pdf.

Christensen, Jonas. 2018. "Ekornes selges til kinesisk selskap." Dagens Næringsliv. Last Modified 23 May 2018. Accessed 19 May. https://www.dn.no/bors/kina/olav-holst-dyrnes/huatai-zijin-investment/ekornes-selges-til-kinesisk-selskap/2-1-341450.

Christopher, Martin. 2016. *Logistics & supply chain management*. 5th ed. London: FT Publishing International.

Chung, Do-Seung, Kwan-Bae Kim, and Jung-Sik Jang. 2020. "A study on 3D printer design for clothing printing: Focusing on knitted wearable clothing output." *International journal of advanced smart convergence* 9 (1): 82-89. https://doi.org/10.7236/IJASC.2020.9.1.82. http://koreascience.or.kr/article/JAKO202009863558606.page.

Ciobanu, Luminita. 2011. "Development of 3D Knitted Fabrics for Advanced Composite Materials." IntechOpen.

Colli, Michele. 2020. *Designing the transformation towards a digital supply chain: How to match the Industry 4.0 agenda to contextual needs and translate it into value*. PhD. Aalborg Universitetsforlag.

Croxton, Keely L., Sebastian J. Garcia-Dastugue, Douglas M. Lambert, and Dale S. Rogers. 2001. "The supply chain management processes." *International Journal of Logistics Management* 12 (2): 13-36. https://doi.org/https://doi.org/10.1108/09574090110806271. https://www.proquest.com/scholarly-journals/supply-chain-management-processes/docview/235873785/se-2?accountid=40814 http://openurl.bibsys.no/openurl?issn=09574093&aulast=Croxton&aufirst=Keely&title=International+Journal+of+Logistics+Management&atitle=The+supply+chain+management+processes&volume=12&issue=2&date=2001&pages=13&isbn=.

DaSilva, Carlos M., and Peter Trkman. 2014. "Business Model: What It Is and What It Is Not." *Long Range Planning* 47 (6): 379-389. https://doi.org/https://doi.org/10.1016/j.lrp.2013.08.004. https://www.sciencedirect.com/science/article/pii/S0024630113000502.

De Marchi, Valentina, Eleonora Di Maria, and Stefano Ponte. 2013. "The greening of global value chains: Insights from the furniture industry." *Competition & Change* 17 (4): 299-318. https://doi.org/https://doi.org/10.1179%2F1024529413Z.00000000040. https://journals.sagepub.com/doi/full/10.1179/1024529413Z.00000000040.

DeCarlo, Matthew. 2018. "Scientific inquiry in social work."

Devold of Norway. 2022. "It's a choice." Accessed 19 May. https://www.devold.com/en-gb/campaigns-devold/its-a-choice/.

Devold of Norway informant 1. 2022. "Email Inquiry." 20 April 2022.

Devold of Norway Interview 1. 2022. Interview 1 Devold of Norway. edited by Jonas Lie Norem and Jasetha Pushparajah.

DFKI, Henning Kagermann, Wolf-Dieter Lukas, and Wolfgang Wahlster. 2011. "Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution." *VDI nachrichten* 13 (1): 2-3. https://www.dfki.de/fileadmin/user_upload/DFKI/Medien/News_Media/Presse/Presse-Highlights/vdinach2011a13-ind4.0-Internet-Dinge.pdf.

Diabat, Ali, Devika Kannan, and K. Mathiyazhagan. 2014. "Analysis of enablers for implementation of sustainable supply chain management – A textile case." *Journal of Cleaner Production* 83: 391-403. https://doi.org/https://doi.org/10.1016/j.jclepro.2014.06.081. https://www.sciencedirect.com/science/article/pii/S0959652614006696.

Dix, Morgan. 2021. "How to Manage Furniture Supply Chain Disruption." *DCI Furniture*. 15 May. https://dcifurn.com/furniture-supply-chain-disruption/.

Donaldson, Thomas, and Lee E. Preston. 1995. "The Stakeholder Theory of the Corporation: Concepts, Evidence, and Implications." *The Academy of Management Review* 20 (1): 65-91. https://doi.org/10.2307/258887. http://www.jstor.org/stable/258887.

Dudovskiy, John. 2022a. "Pragmatism Reserach Philosophy." Accessed 18 May. https://research-methodology.net/research-philosophy/pragmatism-research-philosophy/.

---. 2022b. "Research Philosophy." Accessed 18 May. https://research-methodology.net/research-philosophy/.

Durach, Christian F, Joakim Kembro, and Andreas Wieland. 2017. "A new paradigm for systematic literature reviews in supply chain management." *Journal of Supply Chain Management* 53 (4): 67-85.

Dyrnes, Tjodunn. 2021. "Norsk strikkegigant: - Maskinen spytter ut genseren ferdig med ermer." Minmote.no. Accessed 01 January. https://www.minmote.no/mote/klaer/a/y4Od6E/norsk-strikkegigant-maskinen-spytter-ut-genseren-ferdig-med-ermer.

Eckert, Claudia. 2001. "The Communication Bottleneck in Knitwear Design: Analysis and Computing Solutions." *Computer supported cooperative work* 10 (1): 29-74. https://doi.org/10.1023/A:1011280018570. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.474.2515&rep=rep1&type=pdf.

Einarsdòttir, Eide, Ida Elise. 2020. "H&M sin Looop og Monki sin Green Machine vil forandre moten, men ekspertene er kritiske." Last Modified 1 desember 2020. Accessed 18 May. https://melkoghonning.no/hm-sin-looop-og-monki-sin-green-machine-vil-forandre-moten-men-ekspertene-er-kritiske/.

Ekornes. 2022a. "Historien om Ekornes." Accessed 20 May. https://www.ekornes.com/nb-no/om-ekornes/historien-om-ekornes.

---. 2022b. "Om Ekornes." Accessed 16 May. https://www.ekornes.com/nb-no/om-ekornes.

---. 2022c. "Sustainability." Accessed 19 May. https://www.ekornes.com/en/sustainability.

Ekornes informant 1. 2022. "Email Inquiry." 08 March 2022.

Ekornes Interview 1. 2022. Interview 1 with Ekornes. edited by Jonas Lie Norem and Jasetha Pushparajah.

Ekornes Interview 2. 2022. Interview 2 With Ekornes. edited by Jonas Lie Norem and Jasetha Pushparajah.

Elkington, John. 2013. "Enter the triple bottom line." In *The triple bottom line: Does it all add up?*, 1-16. Routledge.

Ellram, Lisa M. 1996. "The use of the case study method in logistics research." *Journal of Business Logistics* 17 (2): 93-138. https://www.proquest.com/scholarly-journals/use-case-study-method-logistics-research/docview/212652718/se-2?accountid=40814
http://openurl.bibsys.no/openurl?issn=07353766&aulast=Ellram&aufirst=Lisa&title=Journal+of+Business+Logistics&atitle=The+use+of+the+case+study+method+in+logistics+research&volume=17&issue=2&date=1996&pages=93&isbn=.

Erboz, Gizem. 2017. "How To Define Industry 4.0: Main Pillars Of Industry 4.0." Managerial trends in the development of enterprises in globalization era., Slovak University of Agriculture in Nitra, Slovakia. https://www.researchgate.net/publication/326557388_How_To_Define_Industry_40_Main_Pillars_Of_Industry_40.

European Comission. 2022. "EU strategy for sustainable and circular textiles." Accessed 16 May. https://ec.europa.eu/environment/strategy/textiles-strategy_en.

Ferdows, Kasra. 1997. "Making the Most of Foreign Factories." Harvard Business Review. Accessed 22 May. https://hbr.org/1997/03/making-the-most-of-foreign-factories.

Fielt, Erwin. 2013. "Conceptualising business models: Definitions, frameworks and classifications." *Journal of Business Models*: 85-105. https://doi.org/https://doi.org/10.5278/ojs.jbm.v1i1.707. https://eprints.qut.edu.au/75316/.

Fischer, Jona Yorick, and Mona Koster Johannesen. 2021. "Fra nisje til regime: En analyse av sømløs strikketeknologi i en norsk SMB ved bruk av Geels' multi-level perspective." Høgskulen på Vestlandet.

Fomunyam, Kehdinga George. 2020. "Pure and Applied Research as the Epicenter of Research in Engineering Education." *International of Engineering Reserach and Technology* 13 (9): 7. https://doi.org/https://dx.doi.org/10.37624/IJERT/13.9.2020.2402-2408. https://www.ripublication.com/irph/ijert20/ijertv13n9_36.pdf.

Foster, Karis, and Cynthia Istook. 2017. "3D Knitting Technology: A Decision-Making Model." International Textile and Apparel Association Annual Conference Proceedings.

Foster, Karis R. 2017. "Factors influencing the adoption of 3D Knitting technologies by US companies: A case-study analysis." PhD Dissertation, North Carolina State University. https://repository.lib.ncsu.edu/bitstream/handle/1840.20/34853/etd.pdf?sequence=1&isAllowed=y.

Fox, Nick. 2009. "Using interviews in a research project." *The NIHR RDS for the East Midlands/Yorkshire & the Humber* 26. https://www.rds-yh.nihr.ac.uk/wp-content/uploads/2013/05/15_Using-Interviews-2009.pdf.

Franco, Maria A. 2017. "Circular economy at the micro level: A dynamic view of incumbents' struggles and challenges in the textile industry." *Journal of cleaner production* 168: 833-845. https://doi.org/10.1016/j.jclepro.2017.09.056.

Freeman, R Edward. 1984. *Strategic Management: A Stakeholder Approach*. Cambrdige University press, New York.

Frunze, Valentina. 2019. "The future belongs to the knitwear." http://www.repository.utm.md/bitstream/handle/5014/3146/Conf_UTM_2019_II_pg467-470.pdf?sequence=1&isAllowed=y.

Garousi, Vahid, Michael Felderer, and Mika V. Mäntylä. 2019. "Guidelines for including grey literature and conducting multivocal literature reviews in software engineering." *Information and Software Technology* 106: 101-121. https://doi.org/https://doi.org/10.1016/j.infsof.2018.09.006. https://www.sciencedirect.com/science/article/pii/S0950584918301939.

Giglio, Andrea, Ingrid Paoletti, and Giovanni Maria Conti. 2022. "Three-Dimensional (3D) Textiles in Architecture and Fashion Design: a Brief Overview of the Opportunities and Limits in Current Practice." *Applied Composite Materials* 29 (1): 187-204. https://doi.org/10.1007/s10443-021-09932-9. https://doi.org/10.1007/s10443-021-09932-9.

Gill, P., K. Stewart, E. Treasure, and B. Chadwick. 2008. Methods of data collection in qualitative research: interviews and focus groups. [London] :.

Godin, Katelyn, Jackie Stapleton, Sharon I. Kirkpatrick, Rhona M. Hanning, and Scott T. Leatherdale. 2015. "Applying systematic review search methods to the grey literature: a case study examining guidelines for school-based breakfast programs in Canada." *Systematic Reviews* 4 (1): 138. https://doi.org/10.1186/s13643-015-0125-0. https://doi.org/10.1186/s13643-015-0125-0.

Gordon, Jason. 2022. "Abductive Reasoning - Explained." The business professor. Last Modified 15 May 2022. Accessed 19 May. https://thebusinessprofessor.com/en_US/management-leadership-organizational-behavior/abductive-reasoning-definition.

Gorichanaz, Tim, Kiersten F. Latham, and Elizabeth Wood. 2018. "Lifeworld as "unit of analysis"." *Journal of Documentation* 74 (4): 880-893.

https://doi.org/https://doi.org/10.1108/JD-12-2017-0174. https://www.proquest.com/scholarly-journals/lifeworld-as-unit-analysis/docview/2034291824/se-2?accountid=40814
http://openurl.bibsys.no/openurl?issn=00220418&aulast=Gorichanaz&aufirst=Tim&title=Journal+of+Documentation&atitle=Lifeworld+as+%26ldquo%3Bunit+of+analysis%26rdquo%3B&volume=74&issue=4&date=2018&pages=880&isbn=.

Greenpeace International, Madeline Cobbing, and Yannick Vicaire. 2017. Fashion at the Crossroads. 108. Accessed 16 May 2022.

Hansen, Andreas Hareide, and Tobias Wilhelm Wingaard. 2021. "The Effect of Additive Manufacturing on Supply Chain Resilience: A Case Study of the Norwegian Oil, Gas, and Renewables Industry." Master of Science, Høgskolen i Molde - Vitenskapelig høgskole i logistikk.

Harris, Joshua D, Carmen E Quatman, MM Manring, Robert A Siston, and David C Flanigan. 2014. "How to write a systematic review." *The American journal of sports medicine* 42 (11): 2761-2768. https://doi.org/https://doi.org/10.1177%2F0363546513497567.

Hart, Stuart L. 1995. "A natural-resource-based view of the firm." *Academy of management review* 20 (4): 986-1014.

Hart, Stuart L, and Glen Dowell. 2011. "Invited editorial: A natural-resource-based view of the firm: Fifteen years after." *Journal of management* 37 (5): 1464-1479.

Hedman, Jonas, and Thomas Kalling. 2003. "The business model concept: theoretical underpinnings and empirical illustrations." *European Journal of Information Systems* 12 (1): 49-59. https://doi.org/10.1057/palgrave.ejis.3000446. https://doi.org/10.1057/palgrave.ejis.3000446.

Hedrick, Terry Elizabeth, Leonard Bickman, and Debra J Rog. 1993. *Applied research design: A practical guide*. Sage Publications.

Hox, Joop J, and Hennie R Boeije. 2005. "Data collection, primary versus secondary." http://joophox.net/publist/ESM_DCOL05.pdf.

Huffa, Connie. 2017. "Is 3D knitting Worth it?". Accessed 10 February. https://fabdesigns.com/is-3d-knitting-worth-it%3F-1.

Hugos, Michael H. 2018. *Essentials of supply chain management*. John Wiley & Sons.

Immerman, Graham. 2020. Emerging industry 4.0 technologies with real-world examples.

Ivanov, Dmitry. 2020. "Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case." *Transportation Research Part E: Logistics and Transportation Review* 136:

101922. https://doi.org/https://doi.org/10.1016/j.tre.2020.101922. https://www.sciencedirect.com/science/article/pii/S1366554520304300.

Ivanov, Dmitry, and Alexandre Dolgui. 2020. "Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak." *International Journal of Production Research* 58 (10): 2904-2915. https://doi.org/https://doi.org/10.1080/00207543.2020.1750727. https://www.tandfonline.com/doi/full/10.1080/00207543.2020.1750727.

Jaber, Mohammad, Amin Fakhereldine, Mahdi Dhaini, and Ramzi A. Haraty. 2021. "Chapter 11 - A novel privacy-preserving healthcare information sharing platform using blockchain." In *Security and Privacy Issues in IoT Devices and Sensor Networks*, edited by Sudhir Kumar Sharma, Bharat Bhushan and Narayan C. Debnath, 245-261. Academic Press.

Jacobsen, Dag Ingvar. 2015. *Hvordan gjennomføre undersøkelser? : innføring i samfunnsvitenskapelig metode*. 3. utg. ed. Oslo: Cappelen Damm akademisk.

Jin, Byoungho Ellie, and Daeun Chloe Shin. 2021. "The power of 4th industrial revolution in the fashion industry: what, why, and how has the industry changed?" *Fashion and Textiles* 8 (1): 31. https://doi.org/10.1186/s40691-021-00259-4. https://doi.org/10.1186/s40691-021-00259-4.

Johnson, Mark W, Clayton M Christensen, and Henning Kagermann. 2008. "Reinventing your business model." *Harvard business review* 86 (12): 57-68.

Johnson, Mark W, and Alan G Lafley. 2010. *Seizing the white space: Business model innovation for growth and renewal*. Harvard Business Press.

Kallio, Hanna, Anna-Maija Pietilä, Martin Johnson, and Mari Kangasniemi. 2016. Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. Oxford.

Karlsson, Christer. 2016. *Research methods for operations management*. Vol. 2. Routledge New York, NY.

Kirchherr, Julian, Denise Reike, and Marko Hekkert. 2017. "Conceptualizing the circular economy: An analysis of 114 definitions." *Resources, Conservation and Recycling* 127: 221-232. https://doi.org/https://doi.org/10.1016/j.resconrec.2017.09.005. https://www.sciencedirect.com/science/article/pii/S0921344917302835.

Kirsch, Gesa, and Patricia A Sullivan. 1992. *Methods and methodology in composition research*. SIU Press.

Klepp, Ingun Grimstad. 2015. *Mapping sustainable textile initiatives: And a potential roadmap for a Nordic actionplan*. Nordic Council of Ministers.

Kmet, Leanne M, Linda S Cook, and Robert C Lee. 2004. "Standard quality assessment criteria for evaluating primary research papers from a variety of fields." https://doi.org/https://doi.org/10.7939/R37M04F16. https://era.library.ualberta.ca/items/48b9b989-c221-4df6-9e35-af782082280e.

Knitting Industry. 2021. "Flat Knitting

France gets its first 3D knit factory with 3D-TEX." Knitting Industry. Accessed 10 February. https://www.knittingindustry.com/france-gets-its-first-3d-knit-factory-with-3dtex/.

Koprulu, Asli, and M Murat Albayrakoglu. 2007. "Supply chain management in the textile industry: a supplier selection model with the analytical hierarchy process." Proceeding of the International Symposium on the Analytic Hierarchy Process.

Koszewska, Malgorzata. 2018. "Circular economy—Challenges for the textile and clothing industry." *Autex Research Journal* 18 (4): 337-347.

Krystofik, Mark, Allen Luccitti, Kyle Parnell, and Michael Thurston. 2018. "Adaptive remanufacturing for multiple lifecycles: A case study in office furniture." *Resources, Conservation and Recycling* 135: 14-23. https://doi.org/https://doi.org/10.1016/j.resconrec.2017.07.028. https://www.sciencedirect.com/science/article/pii/S0921344917302070.

Kumar, Vijay, Carina Hallqvist, and Daniel Ekwall. 2017. "Developing a framework for traceability implementation in the textile supply chain." *Systems* 5 (2): 33.

Kuzmina, Ksenija, Sharon Prendeville, Dale Walker, and Fiona Charnley. 2019. "Future scenarios for fast-moving consumer goods in a circular economy." *Futures* 107: 74-88. https://doi.org/https://doi.org/10.1016/j.futures.2018.12.001. https://www.sciencedirect.com/science/article/pii/S0016328718301381.

Kvadsheim, Nina Pereira. 2020. "The Curcular economy what does this mean for supply chains?".

Lam, Jimmy K. C., and R. Postle. 2006. "Textile and apparel supply chain management in Hong Kong." *International Journal of Clothing Science and Technology* 18 (4): 265-277. https://doi.org/10.1108/09556220610668491. https://doi.org/10.1108/09556220610668491.

Lambert, Douglas M, Martha C Cooper, and Janus D Pagh. 1998. "Supply chain management: implementation issues and research opportunities." *The international journal of logistics management* 9 (2): 1-20.

Lambert, Douglas M., and Martha C. Cooper. 2000. "Issues in Supply Chain Management." *Industrial Marketing Management* 29 (1): 65-83. https://doi.org/https://doi.org/10.1016/S0019-8501(99)00113-3. https://www.sciencedirect.com/science/article/pii/S0019850199001133.

Lawson, Stephanie. 2021. "The future is here: Industry 4.0 dominates at ITMA Asia + CITME." Accessed 10 February. https://www.knittingindustry.com/the-future-is-here-industry-40-dominates-at-itma-asia-citme/.

Le, Ngo My Ngan. 2017. "Possibility of applying the rental-sevice based business model in the medium and high-end fashion industry in Norway. A case study: Moods of Norway." Master of Science, Høgskolen i Molde-Vitenskapelig høgskole i logistikk.

Lee, Gina. 2019. Extending product life to build a circular economy. Accessed 18 May 2022.

Lee, Jay, Behrad Bagheri, and Hung-An Kao. 2014. *Recent Advances and Trends of Cyber-Physical Systems and Big Data Analytics in Industrial Informatics*.

Lee, Kyung Eun. 2017. "Environmental Sustainability in the Textile Industry." In *Sustainability in the Textile Industry*, edited by Subramanian Senthilkannan Muthu, 17-55. Singapore: Springer Singapore.

Lee, Young-A. 2022. *Leading Edge Technologies in Fashion Innovation.Palgrave Studies in Practice: Global Fashion Brand Management*: Palgrave Macmillan.

Liu, Yige, Li Li, and Philip Yuan. 2019. *A Computational Approach for Knitting 3D Composites Preforms*.

Mackenziecorp. 2014. "Phase #2: Clearly Define Your Research Strategy." Accessed 19 May. https://www.mackenziecorp.com/phase-2-clearly-define-research-strategy/.

Mahbub, Rana, Lijing Wang, and Lyndon Arnold. 2014. "Design of knitted three-dimensional seamless female body armour vests." *International Journal of Fashion Design, Technology and Education* 7 (3): 198-207. https://doi.org/10.1080/17543266.2014.956152. https://doi.org/10.1080/17543266.2014.956152.

Mahood, Quenby, Dwayne Van Eerd, and Emma Irvin. 2014. "Searching for grey literature for systematic reviews: challenges and benefits." *Research synthesis methods* 5 (3): 221-234. https://doi.org/https://doi.org/10.1002/jrsm.1106. https://onlinelibrary.wiley.com/doi/full/10.1002/jrsm.1106?casa_token=2SJZAxaA2cMAAAAA%3A9yOgmesYCv0GdtUXmqp2D_2JHKibLYcCvdSCSk7d7l4lHVcVszZ-mAIIILKvmprBlzTYuVHYrckaoqV.

Maiti, Saptarshi, Subhankar Maity, Pintu Pandit, Sankar Roy Maulik, and Kunal Singha. 2022. "20 - Sustainability analysis for knitting process and products." In *Advanced Knitting Technology*, edited by Subhankar Maity, Sohel Rana, Pintu Pandit and Kunal Singha, 657-671. Woodhead Publishing.

Mandel, Michael. 2020. "The Coronavirus Pandemic Showed Why We Need Shorter, Simpler Supply Chains." Forbes Magazine. Last Modified 12 May 2020. Accessed 15 May. https://www.forbes.com/sites/michaelmandel1/2020/05/12/the-need-for-shorter-simpler-supply-chains/?sh=124776905290.

Mangan, John, and Chandra Lalwani. 2016. *Global logistics and supply chain management*. John Wiley & Sons.

Mathews, Brett. 2015. "Closing the loop." *available at: www. circle-economy. com/wp-content/uploads/20* 16 (05).

Mathison, Sandra. 2016. "methodology as recipe." *Qualitative research*. 18 May. https://blogs.ubc.ca/qualresearch/methodology-as-recipe/.

McKinsey&Company. 2015. Industry 4.0

How to navigate digitization

of the manufacturing sector. 62. Accessed 11 February 2022.

McNally, Ginger. 2013. "Busniess model: External Environment."

Mechan, J, G Housley, E Keefe, and J Earnshaw. 2016. "Defining a Theoretical Model: The Application of 3D Printing as a Disruptive Technology, Explored Through the Analysis of the Process of Creative Garment Development." https://e-space.mmu.ac.uk/613028/1/Creative%20Cut%202016%20Mechan%20et%20al%203D%20Printing%20Theoreticla%20Model.pdf.

Mentzer, John T., William DeWitt, James S. Keebler, Soonhong Min, Nancy W. Nix, Carlo D. Smith, and Zach G. Zacharia. 2001. "DEFINING SUPPLY CHAIN MANAGEMENT." *Journal of Business Logistics* 22 (2): 1-25. https://doi.org/https://doi.org/10.1002/j.2158-1592.2001.tb00001.x. https://doi.org/10.1002/j.2158-1592.2001.tb00001.x.

Michelsen, Ottar, and Annik Magerholm Fet. 2010. "Using eco-efficiency in sustainable supply chain management; a case study of furniture production." *Clean Technologies and Environmental Policy* 12 (5): 561-570. https://doi.org/https://doi.org/10.1007/s10098-009-0266-8. https://www.proquest.com/scholarly-journals/using-eco-efficiency-sustainable-supply-chain/docview/807413415/se-2?accountid=40814 http://openurl.bibsys.no/openurl?issn=1618954X&aulast=Michelsen&aufirst=Ottar&title=Clean+Technologies+and+Environmental+Policy&atitle=Using+eco-efficiency+in+sustainable+supply+chain+management%3B+a+case+study+of+furniture+production&volume=12&issue=5&date=2010&pages=561&isbn=.

Middleton, Fiona. 2019. "Reliability vs Validity in Research | Differences, Types and Examples." Scribbr. Last Modified 03 May 2022. Accessed 19 May. https://www.scribbr.com/methodology/reliability-vs-validity/.

Mikahila, L. 2021. "3D Knitwear: How 3D Printing Is Revolutionizing the Fashion Industry." 3D Natives. Accessed 10 february. https://www.3dnatives.com/en/3d-printing-knitwear-220720215/#!

Mohajan, Haradhan Kumar. 2018. "Qualitative research methodology in social sciences and related subjects." *Journal of Economic Development, Environment and People* 7 (1): 23-48. https://mpra.ub.uni-muenchen.de/85654/.

Mora, Manuel. 2012. *Research methodologies, innovations and philosophies in software systems engineering and information systems*. IGI Global.

Morgan, David L. 2014. "Pragmatism as a paradigm for social research." *Qualitative inquiry* 20 (8): 1045-1053.

Moss, Pamela A. 1994. "Can there be validity without reliability?" *Educational researcher* 23 (2): 5-12.

Mouritz, A. P., M. K. Bannister, P. J. Falzon, and K. H. Leong. 1999. Review of applications for advanced three-dimensional fibre textile composites. [Oxford, UK] :.

Mwesiumo, Deodat, Nina Pereira Kvadsheim, and Bella Belerivana Nujen. 2020. "The Potential for Purchasing Function to Enhance Circular Economy Business Models for ETO Production." Advances in Production Management Systems. Towards Smart and Digital Manufacturing, Cham, 2020//.

Nachtigall, Troy. 2021. *Data as a material for fashion*. Amsterdam: Hogeschool van Amsterdam.

Naghshineh, Bardia, and Helena Carvalho. 2022. "The implications of additive manufacturing technology adoption for supply chain resilience: A systematic search and review." *International Journal of Production Economics* 247: 108387. https://doi.org/https://doi.org/10.1016/j.ijpe.2021.108387. https://www.sciencedirect.com/science/article/pii/S0925527321003637.

Nansen by Devold informant. 2022. "Email Inquiry." 17 March 2022.

Napier, Elizabeth, and Francesca Sanguineti. 2020. "Fashion Merchandisers' Slash and Burn Dilemma: A Consequence of Over Production and Excessive Waste?".

National Research Council. 2000. *Surviving Supply Chain Integration: Strategies for Small Manufacturers*. Washington, DC: The National Academies Press.

NFV, Norsk forening for vedlikehold, Ruben Ravnå, and Per Schjølberg. 2016. *Industry 4.0 and Maintenance*https://nfv.no/images/Temahefter/Industry_4_0_and_Maintenance-revised_-_27.10.16.pdf.

Norem, Jonas Lie, and Jasetha Pushparajah. 2022a. "Observation during visit to Ekornes." 14 March 2022.

---. 2022b. "Observations during visit to 3D Knit Lab." 14 january 2022.

Norilia. 2022. "Ull." Accessed 18 May. https://www.norilia.no/ull.

NSD. 2022. "Personverntjenester." Norsk senter for forskningsdata. Accessed 15 May. https://www.nsd.no/personverntjenester.

Nørstebø, Gunnar, and Malin Gjørtz. 2014. "Hva er riktig forsyningskjede for Devold sine produkter?" Masters of Science, Norwegian University of Life Sciences, Ås.

Orheim, Martin, and Anette Utvær. 2021. Supply Response to Low Probability, High Impact Events - The Case of Covid-19. edited by Deodat Edward Mwesiumo: Høgskolen i Molde - Vitenskapelig høgskole i logistikk.

Ortt, J Roland. 2010. "Understanding the pre-diffusion phases." *Gaining momentum managing the diffusion of innovations*: 47-80. http://catalog.lib.ncsu.edu/record/NCSU3638293.

Oxborrow, Lynn, and Clare Brindley. 2014. "Disintermediation in the apparel supply chain." *Journal of Fashion Marketing and Management* 18 (3): 252-268. https://doi.org/https://doi.org/10.1108/JFMM-10-2011-0071. https://www.proquest.com/scholarly-journals/disintermediation-apparel-supply-chain/docview/2126565885/se-2?accountid=40814

http://openurl.bibsys.no/openurl?issn=13612026&aulast=Oxborrow&aufirst=Lynn&title=Journal+of+Fashion+Marketing+and+Management&atitle=Disintermediation+in+the+apparel+supply+chain&volume=18&issue=3&date=2014&pages=252&isbn=.

Paez, Arsenio. 2017. "Gray literature: An important resource in systematic reviews." *Journal of Evidence-Based Medicine* 10 (3): 233-240.

Palm, David, Maria Elander, David Watson, Nikola Kiørboe, Hanna Salmenperä, Helena Dahlbo, Katja Moliis, Kari-Anne Lyng, Clara Valente, and Stefán Gíslason. 2014.

Towards a Nordic textile strategy: Collection, sorting, reuse and recycling of textiles. Nordic Council of Ministers.

Parschau, Christian, and Jostein Hauge. 2020. "Is automation stealing manufacturing jobs? Evidence from South Africa’s apparel industry." *Geoforum* 115: 120-131. https://doi.org/https://doi.org/10.1016/j.geoforum.2020.07.002. https://www.sciencedirect.com/science/article/pii/S0016718520301871.

Patton, Paul. 2015. "Postmodernism: philosophical aspects." In *International Encyclopedia of the Social & Behavioural Sciences*, 684-689. Elsevier.

Pawson, Ray. 2002. Evidence-based Policy: The Promise of `Realist Synthesis'. [Thousand Oaks, Calif.] :.

Peiner, Christoph, Henning Löcken, Leon Reinsch, and Thomas Gries. 2022. "3D Knitted Preforms Using Large Circular Weft Knitting Machines." *Applied Composite Materials* 29 (1): 273-288. https://doi.org/10.1007/s10443-021-09956-1. https://doi.org/10.1007/s10443-021-09956-1.

Petersen, Moritz. 2017. "Considering sustainability in the development of consumer goods." Technische Universität Hamburg.

Pettit, Timothy J., Keely L. Croxton, and Joseph Fiksel. 2019. "The Evolution of Resilience in Supply Chain Management: A Retrospective on Ensuring Supply Chain Resilience." *Journal of Business Logistics* 40 (1): 56-65. https://doi.org/https://doi.org/10.1111/jbl.12202. https://doi.org/10.1111/jbl.12202.

Pieroni, Marina P. P., Tim C. McAloone, and Daniela C. A. Pigosso. 2021. "Circular economy business model innovation: Sectorial patterns within manufacturing companies." *Journal of Cleaner Production* 286: 124921. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.124921. https://www.sciencedirect.com/science/article/pii/S0959652620349659.

Porter, Michael E. 1985. "Competitive Advantage, The Free Press, New York, 1985." *PorterCompetitive Advantage1985*.

Power, Jess. 2012. "Sustainable developments in knitting." *International Journal of Business and Globalisation* 9 (1): 1-11. http://eprints.hud.ac.uk/id/eprint/13814/1/Power01_-_2012_Sustainable_developments.pdf.

QuestionPro. 2022. "Research Design: Definition, Characteristics and Types." Accessed 19 May. https://www.questionpro.com/blog/research-design/.

Raian, Shahriar, Syed Mithun Ali, Md Rayhan Sarker, Bathrinath Sankaranarayanan, Golam Kabir, Sanjoy Kumar Paul, and Ripon Kumar Chakrabortty. 2022. "Assessing sustainability risks in the supply chain of the textile industry under uncertainty." *Resources, Conservation and Recycling* 177: 105975. https://doi.org/https://doi.org/10.1016/j.resconrec.2021.105975. https://www.sciencedirect.com/science/article/pii/S092134492100584X.

Ranwat, Lokendra. 2022. "7 Ways the Furniture Supply Chain is Different from Other Industries." architectandinteriorsinida.com. Last Modified 7 August 2021. Accessed 10 February. https://www.architectandinteriorsindia.com/insights/22934-7-ways-the-furniture-supply-chain-is-different-from-other-industries.

Rauma Collection. 2022. "Først i verden med avansert strikketeknologi." Accessed 18 May. https://www.raumacollection.no/nyheter/verdens-mest-avanserte-strikketeknologi.

Raycheva, Regina, and Desislava Angelova. 2019. "KNITWEAR: FROM CLOTHING TO FURNITURE." 2/2018: 48-60. https://www.researchgate.net/publication/330599073_KNITWEAR_FROM_CLOTHING_TO_FURNITURE.

Realff, M. 2006. "Systems planning for carpet recycling." *Recycling in textiles*: 46-57.

Salmi, Aleksi. 2021. "Transition to Circular Business Models: a Multiple-case Study on Finnish Clothing Brands." Masters of Science, Master's Programme in Industrial Engineering and Management, Aalto University. https://aaltodoc.aalto.fi/bitstream/handle/123456789/108301/master_Salmi_Aleksi_2021.pdf?sequence=2&isAllowed=y.

Sandvik, Ida Marie, and Wendy Stubbs. 2019. "Circular fashion supply chain through textile-to-textile recycling." *Journal of Fashion Marketing and Management* 23 (3): 366-381. https://doi.org/https://doi.org/10.1108/JFMM-04-2018-0058. https://www.proquest.com/scholarly-journals/circular-fashion-supply-chain-through-textile/docview/2269907140/se-2?accountid=40814

http://openurl.bibsys.no/openurl?issn=13612026&aulast=Sandvik&aufirst=Ida&title=Journal+of+Fashion+Marketing+and+Management&atitle=Circular+fashion+supply+chain+through+textile-to-textile+recycling&volume=23&issue=3&date=2019&pages=366&isbn=.

SAS. 2022. "Big Data." Accessed 15 May. https://www.sas.com/en_ca/insights/big-data/what-is-big-data.html.

Saunders, Mark, Philip Lewis, Adrian Thornhill, and Alex Bristow. 2019. ""Research Methods for Business Students" Chapter 4: Understanding research philosophy and approaches to theory development." 128-171.

Saunders, Mark N. K., Philip Lewis, and Adrian Thornhill. 2016. *Research methods for business students*. 7th ed. Harlow: Pearson.

Sayer, Kate, Jacquie Wilson, and Simon Challis. 2006. "Seamless Knitwear - the Design Skills Gap." *The Design Journal* 9 (2): 39-51. https://doi.org/10.2752/146069206789377113. https://dx.doi.org/10.2752/146069206789377113.

Schein, Edgar H. 1987. *The clinical perspective in fieldwork*. Sage Publications, Inc.

Scott, Jane, Romy Kaiser, and Paula Nerlich. 2021. "Building Couture; Knitting as a Strategy for Bespoke Bio Architecture." Resilient Materials 4 Life (RM4L2021). https://eprints.ncl.ac.uk/file_store/production/277285/B08C93DF-DEEE-4733-8E86-47F8B5123C48.pdf.

Seeram, Euclid. 2019. "An overview of correlational research." *Radiologic technology* 91 (2): 176-179.

Shima Seiki. 2022a. "Category Fashion." Accessed 18 May. https://www.shimaseiki.com/product/category/fashion/.

---. 2022b. "Category Furniture." Accessed 18 May. https://www.shimaseiki.com/product/category/furniture/.

---. 2022c. "Wholegarment business." Accessed 18 May. https://www.shimaseiki.com/wholegarment/business/.

Simonis, K., Y. S. Gloy, and T. Gries. 2017. "3D knitting using large circular knitting machines." *IOP Conf. Ser.: Mater. Sci. Eng* 254 (9): 92004. https://doi.org/10.1088/1757-899X/254/9/092004.

Smith, Amanda Elizabeth. 2013. "Seamless knitwear: Singularities in design." Auckland University of Technology. http://hdl.handle.net/10292/5761.

SOG, Scandinavian outdoor group. 2022. "About SOG." Accessed 19 May. https://www.scandinavianoutdoorgroup.com/about/.

Spens, Karen M., and Gyöngyi Kovács. 2006. "A content analysis of research approaches in logistics research." *International Journal of Physical Distribution & Logistics Management* 36 (5): 374-390. https://doi.org/10.1108/09600030610676259. https://doi.org/10.1108/09600030610676259.

Stewart, Raphaëlle, and Monia Niero. 2018. "Circular economy in corporate sustainability strategies: A review of corporate sustainability reports in the fast-moving consumer goods sector." *Business Strategy and the Environment* 27 (7): 1005-1022. https://doi.org/https://doi.org/10.1002/bse.2048. https://doi.org/10.1002/bse.2048.

Strategyzer. 2019. "Business models." Accessed 18 May. https://www.strategyzer.com/expertise/business-models.

Sukamolson, Suphat. 2007. "Fundamentals of quantitative research." *Language Institute Chulalongkorn University* 1 (3): 1-20. https://www.researchgate.net/profile/Vihan-Moodi/post/What_are_the_characteristics_of_quantitative_research/attachment/5f3091d0ed60840001c62a27/AS%3A922776944787456%401597018576221/download/SuphatSukamolson.pdf.

Sukati, Inda, Abu Bakar Abdul Hamid, Rohaizat Baharun, Huam Hon Tat, and Fazila Said. 2011. "A study of supply chain management practices: An empirical investigation on consumer goods industry in Malaysia." *International Journal of Business and Social Science* 2 (17): 166-176. http://ijbssnet.com/journals/Vol_2_No_17/23.pdf.

Tan, Rui, Guoliang Xing, Xue Liu, Jianguo Yao, and Zhaohui Yuan. 2013. "Adaptive calibration for fusion-based cyber-physical systems." *ACM Transactions on Embedded Computing Systems (TECS)* 11 (4): 1-25.

Taylor, Jane. 2015. "The technical designer: A new craft approach for creating seamless knitwear." PhD, Nottingham Trent University (United Kingdom). http://irep.ntu.ac.uk/id/eprint/28318/1/Jane.Taylor2016excl.3rdpartymaterial.pdf.

Taylor, Jane, and Katherine Townsend. 2014. "Reprogramming the hand: Bridging the craft skills gap in 3D/digital fashion knitwear design." *Craft Research* 5 (2): 155-174.

Taylor, Steven, J., Robert Bogdan, and Marjorie DeVault. 2015. *Introduction to Qualitative Research Methods: A Guidebook and Resource*. Wiley.

Team Leverage Edu. 2021. "Reserach Design." https://leverageedu.com/blog/research-design/.

Technican 3D Knit lab/ Shima Seiki. 2022. "Email inquiry." 04 May 2022.

The Chicago manual of Style Online. 2022. "Unattributed interviews." Accessed 22 May. https://www.chicagomanualofstyle.org/book/ed17/part3/ch14/psec212.html.

Tobiasson, Tone. 2020. Devold of Norway. Accessed 16 May 2022.

Tomra. 2021. "TECHNOLOGY ALONE IS NOT ENOUGH TO ACHIEVE A CIRCULAR ECONOMY." Last Modified 04 August 2021. Accessed 19 May. https://newsroom.tomra.com/technology-alone-is-not-enough-to-achieve-a-circular-economy/.

Tranfield, David, David Denyer, and Palminder Smart. 2003. "Towards a methodology for developing evidence-informed management knowledge by means of systematic review." *British journal of management* 14 (3): 207-222.

Trondstad, Sverre. 2019. "Møbelindustri." Store norske leksikon. Last Modified 01 November 2019. Accessed 20 May. https://snl.no/m%C3%B8belindustri.

Tudelft. 2022. "4.2.1 Slowing, Closing and Narrowing Resource Loops." Accessed 18 May. https://ocw.tudelft.nl/course-readings/4-2-1-slowing-closing-and-narrowing-resource-loops/.

Tviland, Marion. 2021. "Ull er fornybart."

Underwood, Jenny. 2009. "The design of 3D shape knitted preforms." PhD, RMIT University. https://s3-ap-southeast-1.amazonaws.com/ap-st01.ext.exlibrisgroup.com/61RMIT_INST/storage/alma/C9/5D/BE/52/4F/99/04/C9/F0/10/2A/2D/D9/DF/29/07/Underwood.pdf?response-content-type=application%2Fpdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20220228T122646Z&X-Amz-SignedHeaders=host&X-Amz-Expires=119&X-Amz-Credential=AKIAJN6NPMNGJALPPWAQ%2F20220228%2Fap-southeast-1%2Fs3%2Faws4_request&X-Amz-Signature=2d611746009f65c1d64ed4447752322f3d58e3c74fc78ea1bd8d17f11f5b4d82.

United Nations. 2015. "The 17 goals." United Nations. Department of economic and social affairs. Last Modified 17.05.2022. Accessed 17.05. https://sdgs.un.org/goals.

Vach, Werner, Eric Bibiza, Oke Gerke, Patrick M. Bossuyt, Tim Friede, and Antonia Zapf. 2021. "A potential for seamless designs in diagnostic research could be identified." *Journal of Clinical Epidemiology* 129: 51-59. https://doi.org/10.1016/j.jclinepi.2020.09.019. https://dx.doi.org/10.1016/j.jclinepi.2020.09.019.

van der Velden, N. M. 2016. "Making Fashion Sustainable - The Role of Designers (doctoral thesis, Delft University of Technology)." PhD. https://www.researchgate.net/publication/311808029_Making_Fashion_Sustainable_-_The_Role_of_Designers_doctoral_thesis_Delft_University_of_Technology.

Veolia. 2022. "The Circular Economy: Product as a Service Business Model." https://blog.veolianorthamerica.com/circular-economy-product-as-a-service-business-model.

Viramgama, Ashutosh. 2019. "Kniterate – The Automatic Knitting/Sewing Machine – 3D Printer." *Ashutoshvirmgama*. 10 February. https://ashutoshviramgama.com/kniterate-the-automatic-knittingsewing-machine-3d-printer/.

Voxco. 2022. Accessed 19 May. https://www.voxco.com/blog/research-design/.

Vaagen, Hajnalka. 2009. "Assortment planning under uncertainty." 2009:2, Molde University College.

---. 2016. "Circular Economy in textiles and sporting goods."

---. 2017. "Innspill tekstiler KM Departementet."

---. 2022. "tekst og referanser til introduksjonen."

Vaagen, Hajnalka, Michal Kaut, and Stein W. Wallace. 2017. "The impact of design uncertainty in engineer-to-order project planning." *European Journal of Operational Research* 261 (3): 1098-1109. https://doi.org/https://doi.org/10.1016/j.ejor.2017.03.005. https://www.sciencedirect.com/science/article/pii/S0377221717301844.

Vaagen, Hajnalka, and Stein W Wallace. 2010. "The Value of Information in Quick Response Supply Chains: An Assortment Planning View." In *Innovative Quick Response Programs in Logistics and Supply Chain Management*, 91-121. Springer.

Vaagen, Hajnalka, and Stein W. Wallace. 2008. "Product variety arising from hedging in the fashion supply chains." *International Journal of Production Economics* 114 (2): 431-455. https://doi.org/https://doi.org/10.1016/j.ijpe.2007.11.013. https://www.sciencedirect.com/science/article/pii/S0925527308000534.

Vaagen, Hajnalka, Stein W. Wallace, and Michal Kaut. 2011. "Modelling consumer-directed substitution." *International Journal of Production Economics* 134 (2): 388-397. https://doi.org/https://doi.org/10.1016/j.ijpe.2009.11.012. https://www.sciencedirect.com/science/article/pii/S0925527309004149.

Wallach, Omri. 2022. "Industry 4.0: What Manufacturing Looks Like in the Digital Era." Visualcapitalist. Accessed 18 April 2022. https://www.visualcapitalist.com/industry-4-0-what-manufacturing-looks-like-in-the-digital-era/.

Walters, David, and Mark Rainbird. 2004. "The demand chain as an integral component of the value chain." *The Journal of Consumer Marketing* 21 (7): 465-475. https://doi.org/https://doi.org/10.1108/07363760410568680. https://www.proquest.com/scholarly-journals/demand-chain-as-integral-component-value/docview/220125909/se-2?accountid=40814

http://openurl.bibsys.no/openurl?issn=07363761&aulast=Walters&aufirst=David&title=The+Journal+of+Consumer+Marketing&atitle=The+demand+chain+as+an+integral+component+of+the+value+chain&volume=21&issue=7&date=2004&pages=465&isbn=.

Weill, Peter, and Michael Vitale. 2001. *Place to space: Migrating to eBusiness Models*. Harvard Business Press.

Wen, Xin, Tsan-Ming Choi, and Sai-Ho Chung. 2019. "Fashion retail supply chain management: A review of operational models." *International Journal of Production Economics* 207: 34-55. https://doi.org/https://doi.org/10.1016/j.ijpe.2018.10.012. https://www.sciencedirect.com/science/article/pii/S0925527318304250.

WKS™. "WKS™ Knitwearrevolution." Accessed 11 March. https://www.wks-cifra.com/3d-knit-breakthrough.

Yang, Sooyung. 2010. "A creative journey developing an integrated high-fashion knitwear development process using computerized seamless v-bed knitting systems." PhD, Curtin University. http://hdl.handle.net/20.500.11937/1253.

Yarnbank, Shima Seiki. 2022. "yarnbank." Accessed 18 May. https://yarnbank.shimaseiki.com/.

Yin, R.K. 2009. *Case Study Research: Design and Methods*. SAGE Publications.

Yin, Robert K. 2014. *Case study research : design and methods*. 5th ed.*Case study research and applications : design and methods*. Los Angeles, Calif: SAGE.

Zalando. 2022. "adidas by Stella McCartney

ULTRABOOST 3D KNIT - Nøytrale løpesko." Accessed 11 March. https://www.zalando.no/adidas-by-stella-mccartney-ultraboost-3d-knit-noeytrale-loepesko-core-blacksignal-orange-ad741a059-q11.html.

Zero waste Scotland. 2022. "What are circular economy business models?". Accessed 18 May. https://www.zerowastescotland.org.uk/content/what-are-circular-economy-business-models.

Zhang, Chen, and Suhong Li. 2006. "Secure information sharing in internet-based supply chain management systems." *Journal of Computer Information Systems* 46 (4): 18-24.

Zott, Christoph, Raphael Amit, and Lorenzo Massa. 2011. "The business model: recent developments and future research." *Journal of management* 37 (4): 1019-1042.

Appendices

The different appendices found here is a supplement to the reader to understand concepts elaborated in the thesis more clearly. It also lists the questions, figures and pictures from the visits.

Appendix A: Examined in the systematic literature review for 3D knitting technology

This contains the reviewed literature in the systematic literature review approach.

Appendix A, table 1 Examined literature on "3D Knit" and " Supply Chain Management".

	Title	Author(s)	Published (Month if available and Year)	Publisher/Journal (academic literature)	Publisher/company (Grey literature)
1.	Reprogramming the Hand: Bridging the craft skills gap in 3D/digital fashion knitwear design	Jane Taylor and Katherine Townsend	October 2014	Craft Research	
2.	Is 3D knitting Worth it?	Connie Huffa	2017		Fabdesigns, Inc.
3.	Impact Resistance and Comfort Properties of Textile Structures for Sportswear	Rajkishore Nayak, Sinnappoo Kanesalingam, Arun Vijayan, Lijing Wang, Rajiv Padhye and Lyndon Arnold	January 2020	Fibers and Polymers	
4.	Kniterate – The Automatic Knitting/Sewing Machine – 3D Printer	Ashutosh Viramgama	January 2019		Ashutosh Viramgama (Blogpost, freelancer)
5.	France gets its first 3D knit factory with 3D-TEX	Knitting industry	Accessed 11.03.2022		Knitting Industry
6.	Meet Kniterate	Kniterate	Website accessed 22. February 2022		Kniterate
7.	Prospect of 3D Warp Knitted Spacer Fabric and its Effect on	Ikra Shuvo, Darion Toutant and Kajama Chakma	January 2018	Journal of textile	

	Pressure Relieve for Reducing the Prevalence of Pressure Ulcers for Immobile Patients			Science & engineering	
8.	3D Knitting Technology: A Decision-Making Model	Karis Foster and Cynthia Istook	Januar 2017	Internationa l Textile and Apparel Association, Inc. ITAA Proceedings , #74	
9.	CLO | 3D Fashion Design Software (clo3d.com)	CLO3D	Website accessed 22. February 2022		CLO3D
10.	3D knitting using large circular knitting machines	K Simonis, Y-S Gloy and T gries	2017	IOP Conference Series: MaterialsSc ience and Engineering	
11.	Jonas Forsman uses 3D knitting to create folding Shift Chair for Moooi	Benedikt Hobson	March 2016		De Zeen
12.	Development of 3D Knitted Fabrics for Advanced Composite Materials	Luminaita Ciobanu	March 2011	InTechOpen	
13.	3D Knitwear: How 3D Printing Is Revolutionizing the Fashion Industry	Mikahila L.	July 2021		3D Natives
14.	Norsk strikkegigant: – Maskinen spytter ut genseren ferdig med ermer | MinMote	Tjodunn Dyrnes	December 2021		Minmote. no
15.	The future is here: Industry 4.0 dominates at ITMA Asia + CITME	Stephanie Lawson	June 2021		Knitting Industry
16.	Assessing sustainability risks in the supply chain of the textile industry under uncertainty	Raian, Ali Mithun Syed, Sarker Md. Rayhan, Sankaranarayanan Bathrinath, Kabir	February 2022	Resources, Conservatio n and Recycling	

		Golam, Paul Kumar Sanjoy, Chakrabortty Kumar Ripon			
17.	The Communication Bottleneck in Knitwear Design: Analysis and Computing Solutions	Claudia Eckert	2001	Computer Supported Cooperative Work	
18.	Seamless knitwear: singularities in design	Amanda Elizabeth Smith	2013	Auckland University of technology	
19.	A creative journey developing an integrated high-fashion knitwear development process using computerized seamless v-bed knitting systems	Sooyung Yang	2010	Curtin University of Technology	
20.	Development of Three-Dimensional Knit Models through Rib & Purl Structures	Wonseok Choi and Youn Hee Lee	2010	The Research journal of the Costume culture	
21.	A Computational Approach for Knitting 3D composites Preforms	Yige Liu, Li Li and Philip F. Yuan	2020		CDRF 2019, proceedings of the 2019 DigitalFUTURES
22.	3D Knitted Preforms Using Large Circular Weft Knitting Machines	Christoph Peiner, Henning Löcken, Leon Reinsch and Thomas Gries	October 2021	Applied Composite Materials	
23.	A study on the Analysis of 3D Scanning of Knit Stitches and Modeling System	Choi Kyoungme, Kim Jongjun and Song Nagun	2012	Journal of Fashion business	
24.	Shape and Surface: The challenges and advantages of 3D techniques in innovative fashion, knitwear and product design	E Bendt	2016		IOP Conference Series: Materials Science and

					Engineering
25.	A Study on 3D Printer Design for Clothing Printing: Focusing on Knitted Wearable Clothing Output	Chung Do-Seung, Kwan-Bae Kim and Jung-Sik Jang	2020	International Journal of Advanced Smart Convergence	
26.	Three-Dimensional (3D) Textiles in Architecture and Fashion Design: a Brief Overview of the Opportunities and Limits in Current Practice	Andrea Giglio, Ingrid Paoletti and Goivanni maria Conti	July 2021	Applied Composite Materials	
27.	Defining a Theoretical Model: The Application of 3D Printing as a Disruptive Technology, Explored Through the Analysis of the Process of Creative Garment Development	Jayne Mechan, John Earnshaw, Georgina Housley and Edmund Keefe	2016		Manchester Metropolitan University
28.	Design of knitted three-dimensional seamless female body armour vests	Rana Mahbub, Lijing Wang and Lyndon Arnold	September 2014	International Journal of Fashion Design, Technology and Education	
29.	Building Couture: Knitting as a Strategy for Bespoke Bio Architecture.	Jane Scott, Romy Kaiser and Paula Nerlich	September 2021		RM4L2020 International Conference
30.	Wearable sensors modeling for healthcare	Raluca Maria Aileni, Pascal Bruniaux and Rodica Strungaru	November 2014		2014 International Symposium on Fundamentals of Electrical engineering

31.	The future belongs to the knitwear	Valentina Frunze	2019		Technical University of Moldova
32.	Bespoke Solutions for Eliminating Ableist Bias in the Apparel Industry	Nicholas Paganelli	February 2021	The journal of Design, Creative process & the Fashion Industry	
33.	Knitted jewellery: extending the limits of technology	Lila Macies Pires, Ana Maria Rocha and Andrè Paulo Almedia Whiteman Catarino	November 2014		Conference: Transition: Re-thiniking textiles and Surfaces At: University of Hudersfield
34.	Knitwear: From clothing to furniture	Regina Raycheva, Desislava Angelova	2018	Innovation in woodworking industry and engineering design	
35.	Factors Influencing the Adoption of 3D Knitting Technologies by U.S. Companies: A CaseStudy Analysis	Karis R. Foster	2017		Dissertation submitted to North Carolina State University
36.	The Design of 3D shape knitted preforms	Jenny underwood	November 2009		School of fashion and textiles design and social context portfolio RMIT University
37.	The power of 4th industrial revolution in the fashion industry:	Byoungho Ellie Jin and Daeun Chole Shin	October 2021	International Journal of interdiscipli	

	what, why, and how has the industry changed?			nary Research	
38.	Data as a material for Fashion: Fashion Research &technology	Troy Nachtigall	2021		Amsterdam University of applied Sciences
39.	The Technical Designer: A new craft approach for creating seamless knitwear	Jane Taylor	September 2015		Thesis submitted to Nottingham Trent University
40.	Investigation on material variants and fabrication methods for microstrip textile antennas: A review based on conventional and novel concepts of weaving, knitting and embroidery	Rameesh Lakshan Bulathsingahala	February 2022	Cogent Engineering	
41.	Circular fashion supply chain through textile-to-textile recycling	Ida Marie Sandvik and Wendy Stubbs	January 2019	Journal of fashion marketing and management	
42.	Sustainability analysis for knitting process and products	Saptarshi maiti, Subhankar Maity, Puntu Pandit, Sankar Roy Maulik and Kunal Singha	2022	Advanced Knitting technology	
43.	Environmental Sustainability in the Textile Industry	Kyung Eun Lee	2016	Sustainability in the textile Industry	
44.	Disintermediation in the apparel supply chain	Lynn Oxborrow, Clare Brindley	2014	Journal of Fashion marketing and management	
45.	Impact of Additive Manufacturing on Supply Chain Network Structure	M Salman and W Mushtaq	2018		Master thesis at NTNU Aalesund

46.	Sustainable developments in knitting	Jess Power	2012	International Journal of Business and Globalisation	
47.	Regional Resilience in Recessionary Times: A case study of the East Midlands	Lynn Oxborrow, Burton Street and Professor Clare Brindley	2012	International Journal of Retail & Distribution	
48.	Corporate Sustainability in Fashion and Luxury Companies	Elisa Arrigo	2015	Emerging Issues in Management	
49.	Leading Edge Technologies in Fashion Innovation: Product Design and Development Process from Materials to the End Products to Consumers	Young-A Lee	2022		Palgrave Macmillan
50.	Adaptive remanufacturing for multiple lifecycles: A case study in office furniture	Mark Krystofik, Allen Luccitti, Kyle Parnell and michael Thurston	August 2018	Resources, conservation and recycling	
51.	Is automation stealing manufacturing jobs? Evidence from South Africa's apparel industry	Christian Parschau and Jostein Hauge	October 2020	Geoforum	
52.	Designing the transformation towards a digital supply chain	Michele Colli	2020		Ph. D Dissertation submitted to Aalborg University
53.	COVID-19 and the global value chain: Immediate dynamics and long-term restructuring in the garment industry	Md Imtiaz Mostafiz, martina Musteen, Abrarali Saiyed and Mujtaba Ahsan	February 2022	Journal of Business research	
54.	Making Fashion Sustainable The Role of Designers	Natashca M. van der Velden	2016		PhD thesis Delft university of Technology

55.	How Does Sustainability Affect Consumer Choices in the Fashion Industry?	Landro Pareira, rita Carvalho, Alvaro Dias, Renato Costa and Nelson Antonio	April 2021	Resources	
56.	Transition to Circular Business Models: a Multiple-case Study on Finnish Clothing Brands	Aleksi Salmi	May 2021		Master thesis submitted to Alto University
57.	adidas by Stella McCartney ULTRABOOST 3D KNIT - Nøytrale løpesko	Zalando.no	Accessed 11.03.2022		Zalando.no
58.	3D-KNITTING "WHOLEGARMENT®"	Oliver Charles	Accessed 11.03.2022		Oliver Charles
59.	WKS TM KNITWEAR REVOLUTION	WKS	Accessed 11.03.2022		WKS
60.	Polestar O_2 The redefinition of a sports car	Polestar	Published 02.03.2022 Accessed 11.03.2022		

Appendix B: Interview guide

In this subchapter, we have included the interview guides that where distributed to the companies who have participated in the interviews. The interview guide made it possible for the interview objects to prepare and invite relevant employees in the field in beforehand. Below we have divided into three subchapters representing the guide customized to the company of knowledge of the interviewed persons. The questions are translated to English, but the interviews were carried out in Norwegian. The interview guide was divided according to the supply chain in guide one and two. Guide two was a follow up from the observation at Ekornes.

Interview Guide One customized for Ekornes

General question

1. What is your position, and how long have you worked in the company?
2. You mentioned that you are utilizing 3D knitting technology today. How does it work?
3. How much do you take use of the machine, and is it staffed by personnel who has the design knowledge?
4. What do you use 3D knitting technology for? (Ex. Product group)
5. As a long-term goal, what do you plan to use 3D knitting technology for?

Planning

1. How do you plan the different activity in the supply chain?
2. Do you focus on the entire life cycle of the product in the planning phase?
3. How do you plan the whole lifecycle of a product in the planning phase according to environmental requirements?
4. During the planning phase, what sustainability goals do you focus on? (In terms of product, material selection, etc.)

Production

1. Where is the company's production location located?
2. Textile involved products, are they produced in the mentioned location, or do you have any specific location for the production?
3. How many employees do you have in the different locations?
4. What does the level of competence amount the employees, and is any kind of special competence that are required to fulfil the work on the various stations?
5. What machines/equipment do you have as of today?
6. How many machines are required to execute the current production?
7. How technological is the production today? Is there any kind of assembly line?
8. How many product groups do you have today?
9. Which product category should we focus on in out master thesis, and why?

Environmental focus in production

1. How do you carry out forecasting to reveal the level of production? Is it any forecasting methods used?
2. Have you experience overproduction in the company?
3. Do you aim to use environmentally friendly products? If so, how do u executing it as a focus area?
4. What do you do with the products and materials that are left during the production? Is it an idea to use these materials again? Or sell it to other manufacturers?

5. What is the main complication in the production? What changes do you think will help prevent such a problem?

Supplier

1. How many suppliers do you have for the different product groups?
2. Where are the suppliers located?
3. How are the raw materials transported to the production site(s)?
4. Who are their suppliers?
5. What environmental requirements do you present to the suppliers? How is the follow-up been executed today? Is this something you specify in the tender documents?
6. Do you have long-term contract with the suppliers?
7. Do you have a single supplier from whom you buy the raw materials from? Or are there several suppliers you buy the same raw materials from?
8. How is the supplier market within the raw materials you need?
9. Is there any possibilities for you to send an overview of who you suppliers are, and a overview of what materials you buy form them?
10. Do you have the power to influence changes in the supplier's activities? For example, by requiring a change in the quality of the materials.
11. The suppliers may not always have the capacity or ability to deliver all the goods, but they use subcontractors. Do you know of any subcontractors in the current supplier list? Is it any environmental requirements for subcontractors as well?

Distributors, business, and end customers

1. Do you have an inventory, or is the goods produced according to the orders that has been placed?
2. Do you have the problematic of mass production?
3. When we place an order on their website, it comes up that we have to choose a business. Do end customers have the opportunity to order goods directly from you without going through an intermediary?
4. How many stores do you ship products to? Do you have an overview you can send over to us?
5. Where are the stores located?
6. How are the goods transported from the factory? (transport mode)
7. If several factories: How is the transport planned? Is it the nearest factory that sends to the specified customer?
8. How often do you have deliveries?
9. Do you want to open up for customers to design their own desired product?

Stakeholders

1. Who are your stakeholders?
2. How do you collaborate with your stakeholders? (Internal and external stakeholders)
3. Do you have an overview of your stakeholders? By chance, could you send the overview to us?

Interview Guide One customized for Devold

General question

1. What is your position, and how long have you worked in the company?

Planning

1. When new ideas occur, who is involved in the start-up phase to create new products? (eg. Designers, textile engineers, customers, selection etc.)
2. During the planning phase, what sustainability goals do you focus on? (In terms of product, material selection, etc.)
3. Do you focus on the entire life cycle of the product in the planning phase?
4. When planning other activities in the supply chain, how is this implemented? Who is involved in the process?

Production

1. Where is the company's production location located?
2. Textile involved products, are they produced in the mentioned location, or do you have any specific location for the production?
3. How many employees do you have in the different locations?
4. What does the level of competence amount the employees, and is any kind of special competence that are required to fulfil the work on the various stations?
5. What machines/equipment do you have as of today?
6. How many machines are required to execute the current production?
7. How technological is the production today? Is there any kind of assembly line?
8. How many product groups do you have today?
9. Which product category should we focus on in out master thesis, and why?

Environmental focus in production

1. How do you carry out forecasting to reveal the level of production? Is it any forecasting methods used?
2. Have you experience overproduction in the company?
3. Do you aim to use environmentally friendly products? If so, how do u executing it as a focus area?
4. What do you do with the products and materials that are left during the production? Is it an idea to use these materials again? Or sell it to other manufacturers?
5. Research shows that the textile industry has a tendency to overproduction (due to mass production) and as a consequence this is burned or thrown away. This is an environmentally harmful practice. Is this a challenge in your company? Items that are not sold / shipped, what happens to these?
6. What is the main complication in the production? What changes do you think will help prevent such a problem?

Supplier

1. How many suppliers do you have for the different product groups?
2. Where are the suppliers located?
3. How are the raw materials transported to the production site(s)?

4. Who are their suppliers?
5. What environmental requirements do you present to the suppliers? How is the follow-up been executed today? Is this something you specify in the tender documents?
6. Do you have long-term contract with the suppliers?
7. Do you have a single supplier from whom you buy the raw materials from? Or are there several suppliers you buy the same raw materials from?
8. How is the supplier market within the raw materials you need?
9. Are there any possibilities for you to send an overview of who you suppliers are, and a overview of what materials you buy form them?
10. Do you have the power to influence changes in the supplier's activities? For example, by requiring a change in the quality of the materials.
11. The suppliers may not always have the capacity or ability to deliver all the goods, but they use subcontractors. Do you know of any subcontractors in the current supplier list? Is it any environmental requirements for subcontractors as well?

Distributors, business, and end customers

1. We see that it is possible to order products on their website. Is this only for end customers and / or an order page for companies?
2. Are the goods produced after an order has been placed or do you have an inventory?
3. Do you produce more than you need? (mass production)
4. Do you have an overview of your end customers and companies? (E.g. the defence, consumer, sport1, XXL etc.) Do you have the opportunity to send this by e-mail afterwards?
5. How many stores do you ship products to?
6. Where are the stores located?
7. Do you send products directly to the end customer, without intermediaries?
8. How are the goods transported from the factory? (transport mode)
9. If several factories: How is the transport planned? Is it the nearest factory that sends to the specified customer?
10. How often do you have deliveries?

Stakeholders

1. Who are your stakeholders?
2. How do you collaborate with your stakeholders? (Internal and external stakeholders)
3. Do you have an overview of your stakeholders? By chance, could you send the overview to us?

Interview Guide Three customized for Ekornes

3D knitting technology

1. Which customers do you sell the 3D knit chairs to?
2. What type of feedback have you received from customers?
3. What kind of challenges do you think you will face with 3D knitting compared to regular textile production?
4. If we remember correctly, did it take 70 minutes to produce each of the parts on the dining chairs?

5. How large a production volume of 3D knit chairs do you have today?
6. Will the transport of 3D Knit chairs be coordinated with the transport of all other products?

Comparison questions

To compare the traditional textile part of the production with 3D knitting, we would like answers to the following questions:

1. For example, if you have 10 chairs in the production,
2. How many textile rolls do you need to produce 10 chairs?
3. How much does it cost per roll?
4. Does the cost vary based on the colour / quality of the fabric?
5. Have you analysed the market for textiles if they have environmentally friendly alternatives?
6. Approx. how much waste do you have on today's production?
7. Do you have textile suppliers in Norway?
8. How much production capacity do you have to produce chairs in one working day (7.5 hours) regardless of customer order? (TEXTILE)
9. If we now compare this with 3D knitting, how much yarn do you need to produce 1 chair?
10. What does each of the skeins of yarn cost you?
11. Where do you buy the yarn from?
12. How much production capacity do you have to produce in one working day (7.5 hours) regardless of customer order? (3D elastic) Are 3 machines enough to produce as many covers as textiles?
13. What transport option do you use to transport the yarn to Sykkylven?
14. If the supplier you have today is not able to deliver the yarn due to various reasons, do you have a backup supplier?

Other question regarding the observation

1. What do you have the greatest demand for? Skin or textile?
2. What is the percentage? (This is to map how much demand you have for the options you offer)

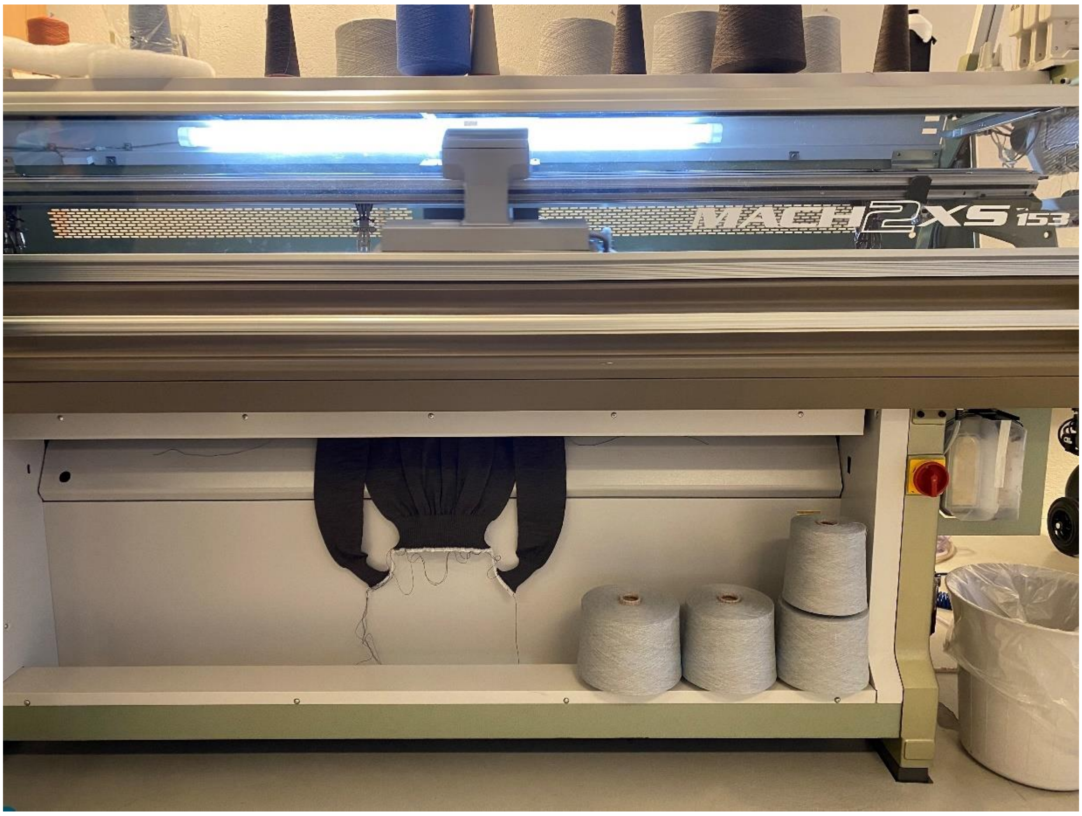
Appendix C: Pictures from the observation

Visit at the 3D knitting and technology lab

Appendix C figure 1 3D knitting machines at 3D knitting & technology lab

Appendix C figure 2 Collection of yarn assortment

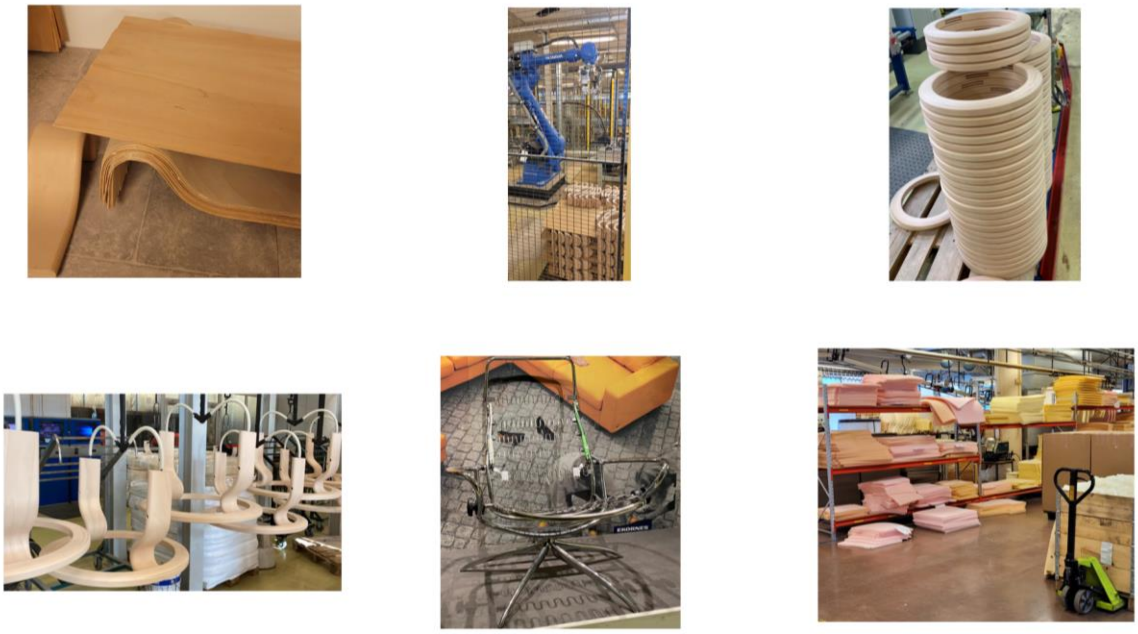
Appendix C figure 3 Illustration of a label sweater(left) and prototype of different solutions



Appendix C figure 4 Producing a sweater with the 3D knitting machine

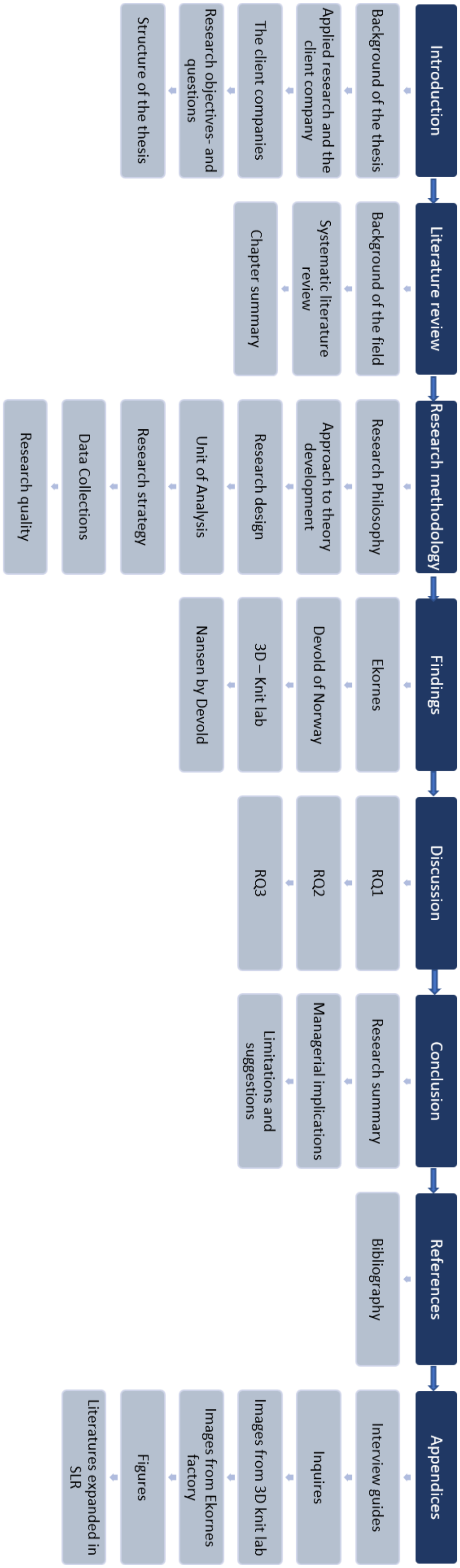
Visit at the Ekornes

Appendix C figure 5Prototype of different chairs at Ekornes AS

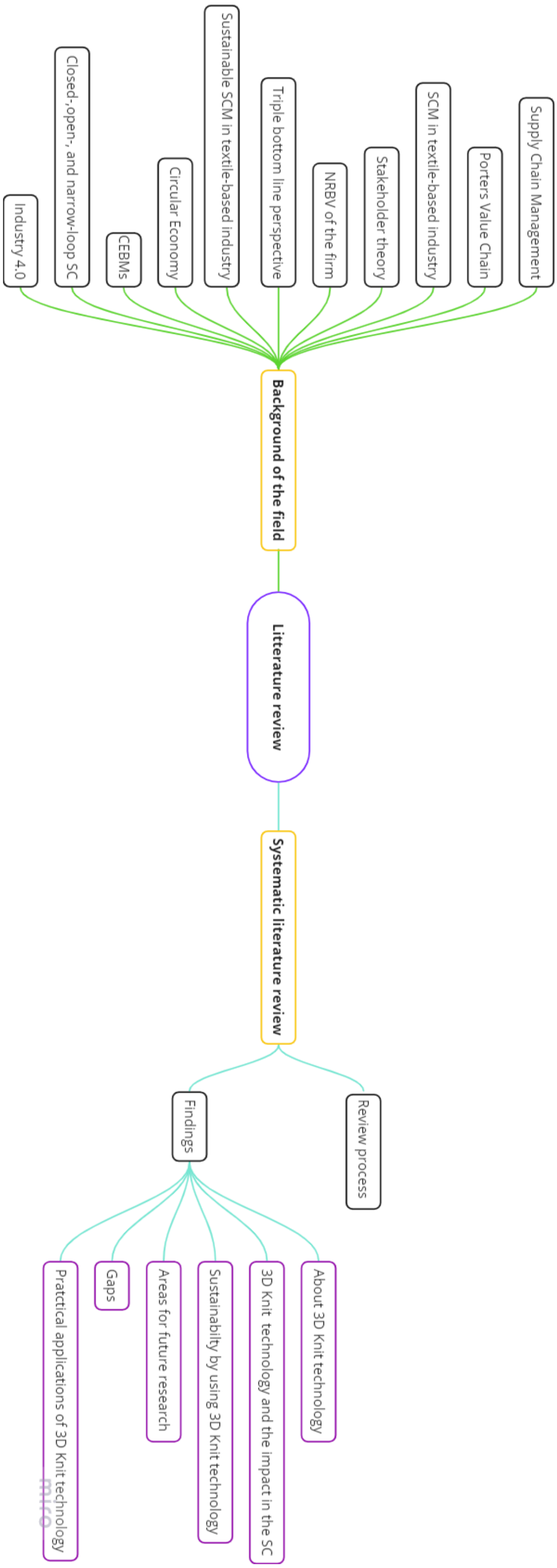


Appendix C figure 6 The process of how the chairs is made at Ekornes.

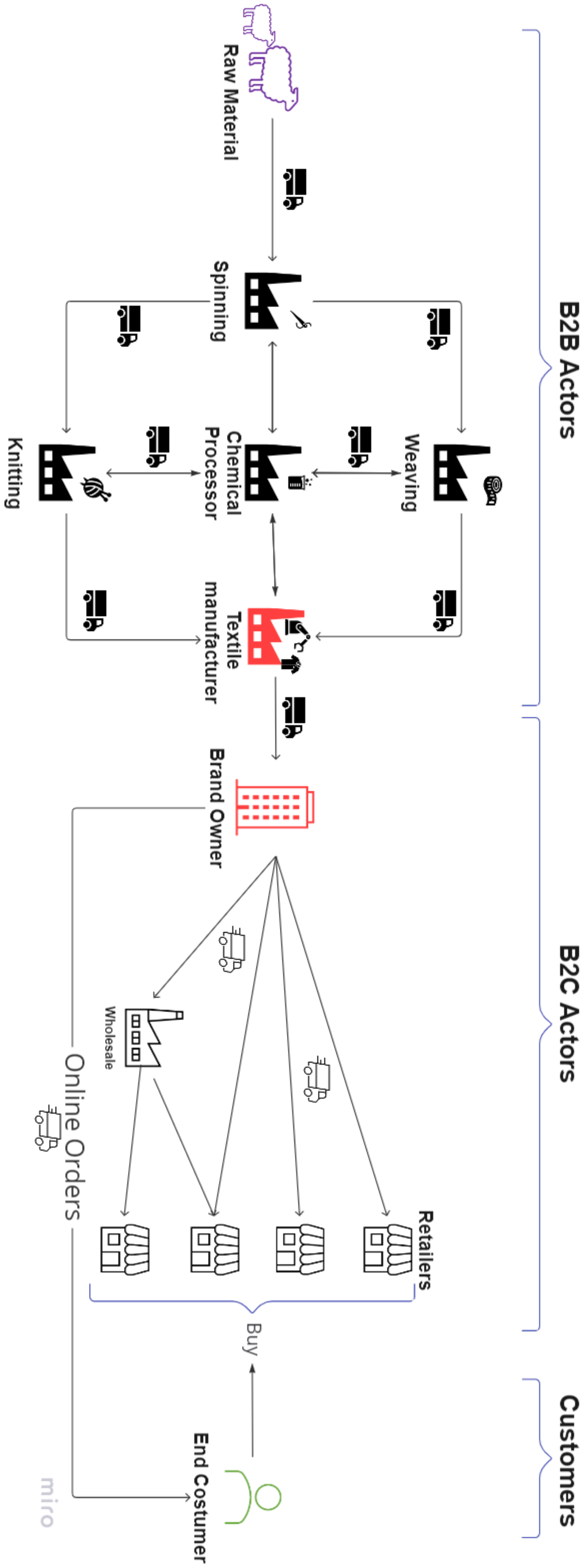
Appendix D: Figures in large format



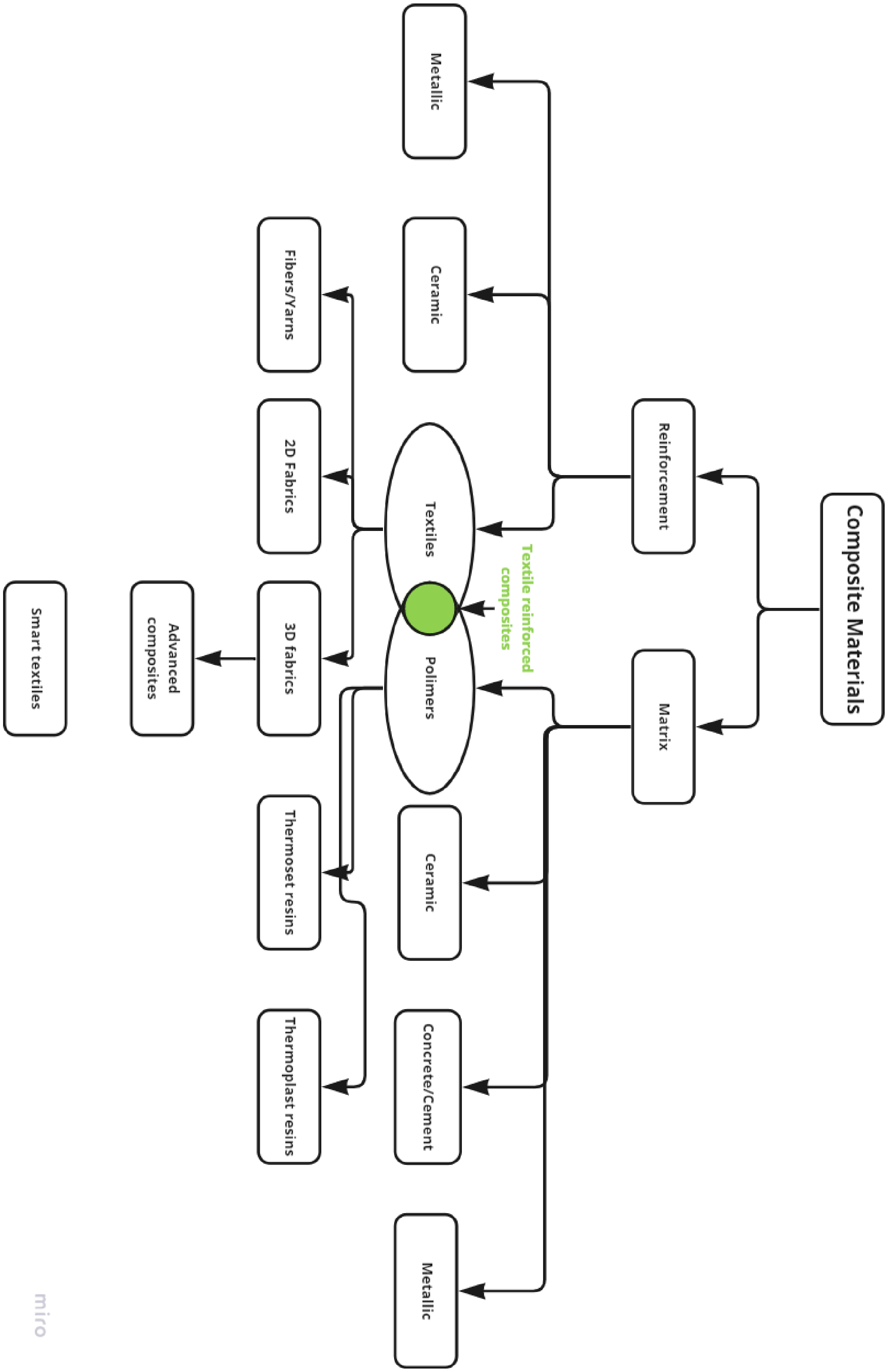
Appendix D figure 1 A holistic overview of the structure in the thesis.



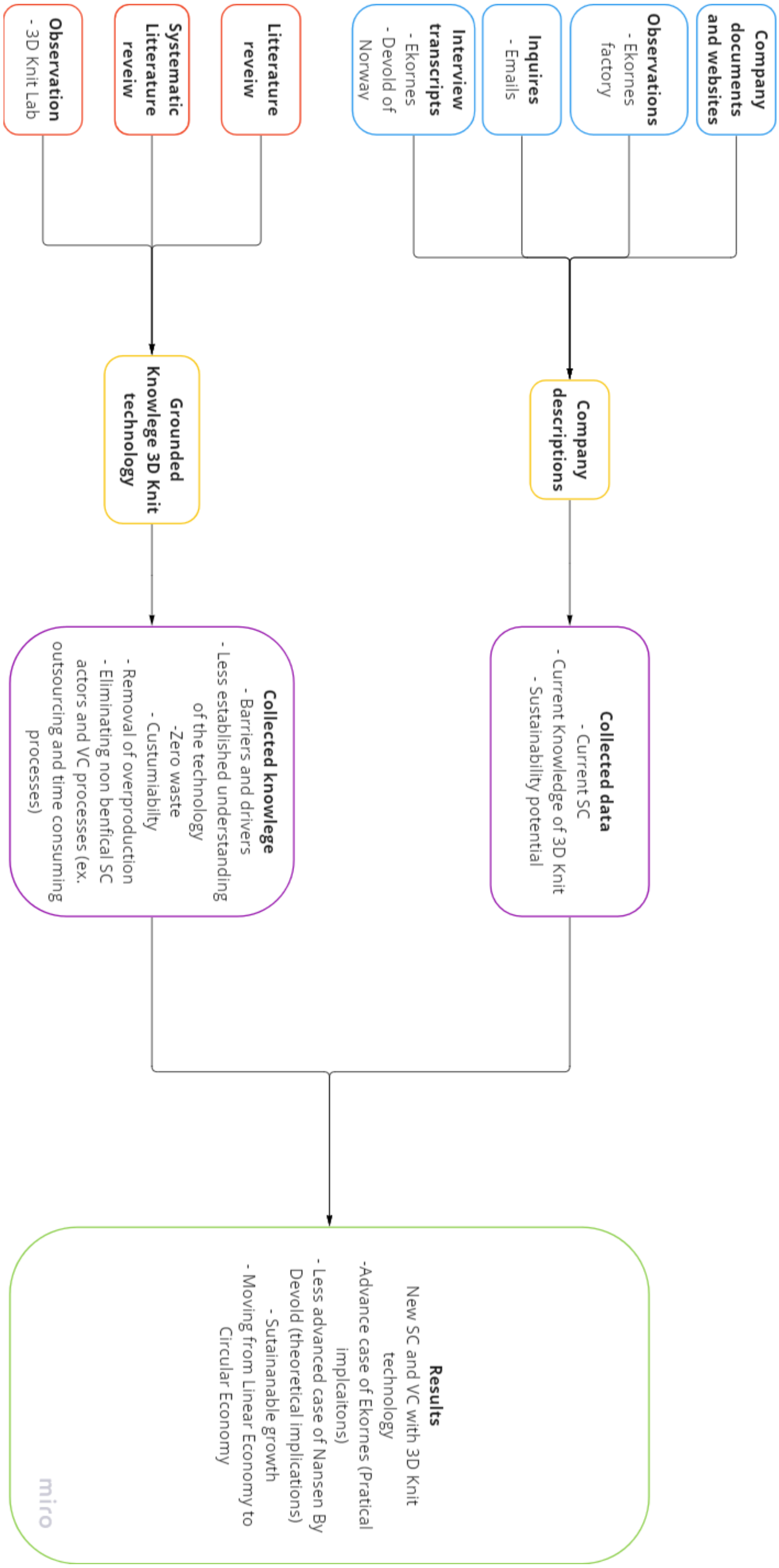
Appendix D figure 2 Overview of the different sections in the literature review.



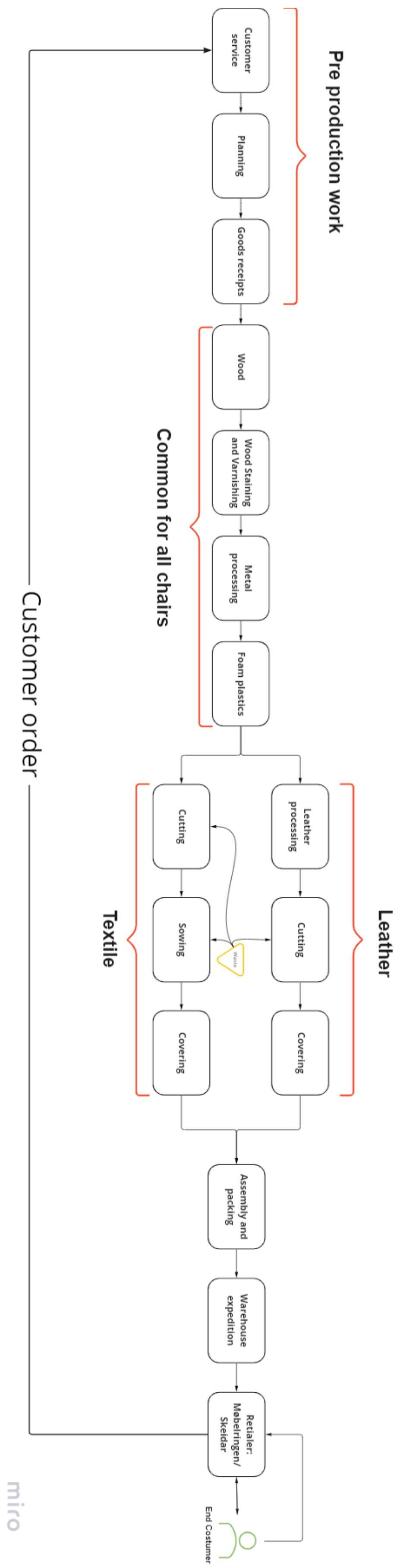
Appendix D figure 3 Illustration of the textile supply chain network, adapted from Kumar, Hallqvist, and Ekwall (2017).



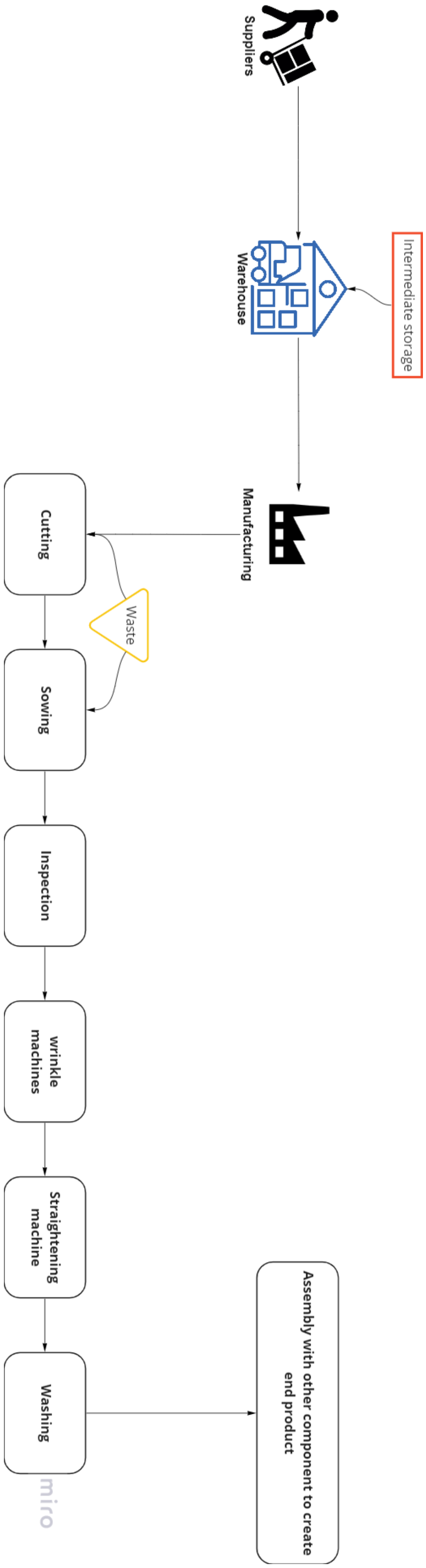
Appendix D figure 4 The structure of composite materials: Source Ciobanu (2011, 1).



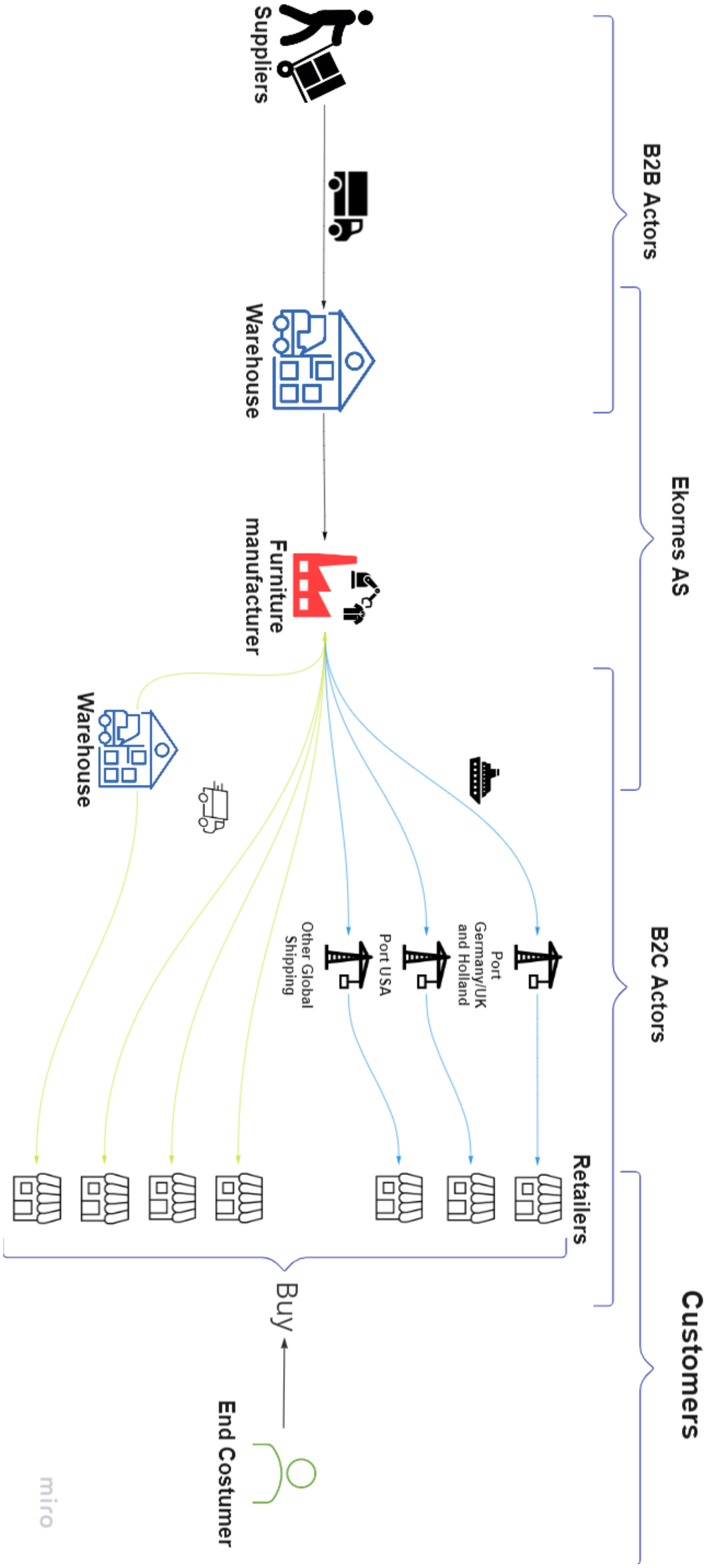
Appendix D figure 5 Summary of the data collection, created by the authors.



Appendix D figure 6 Process map of Ekornes production of Stressless dining chairs.

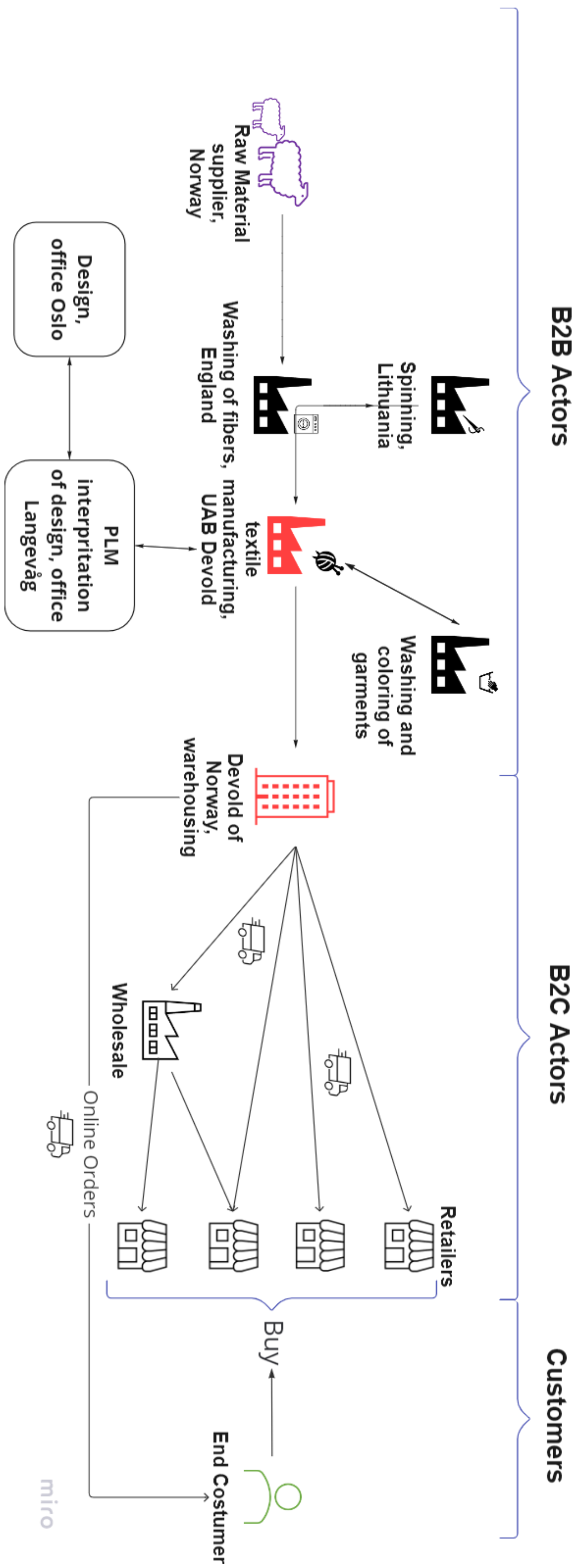


Appendix D figure 7 Textile production in Ekornes.

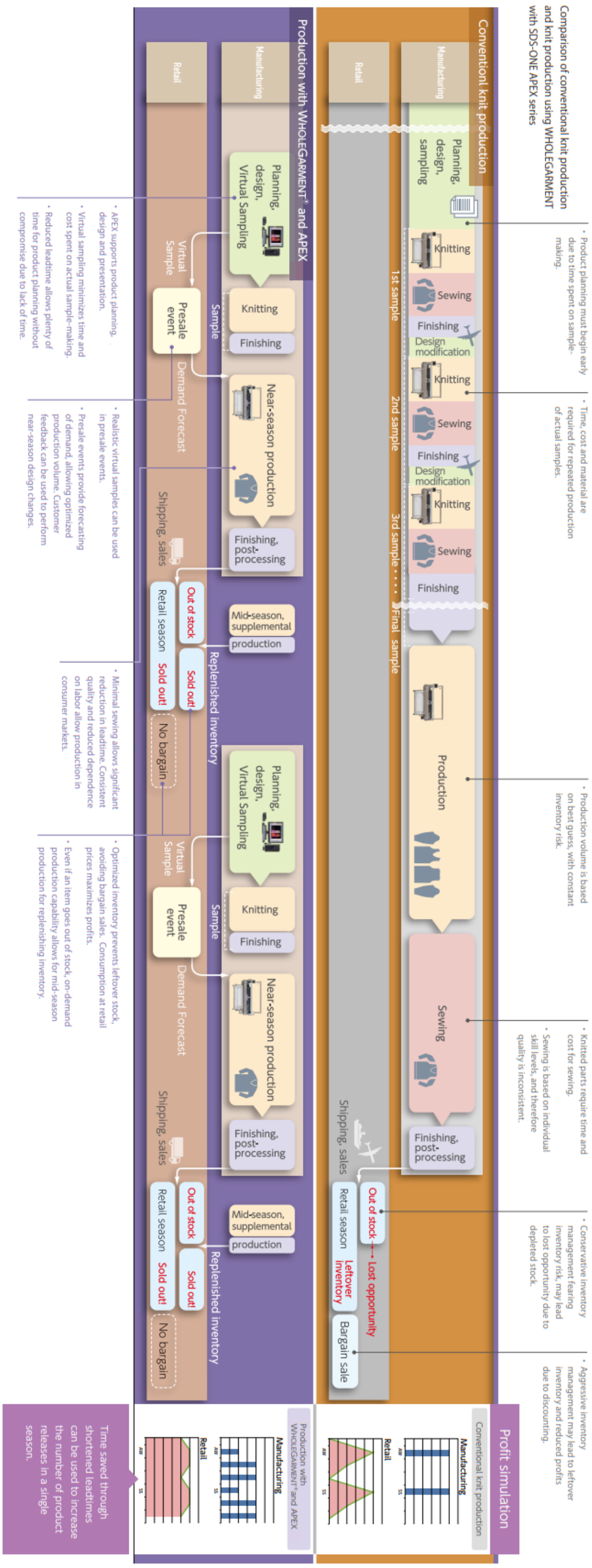


Appendix D figure 8 Ekornes current supply chain.

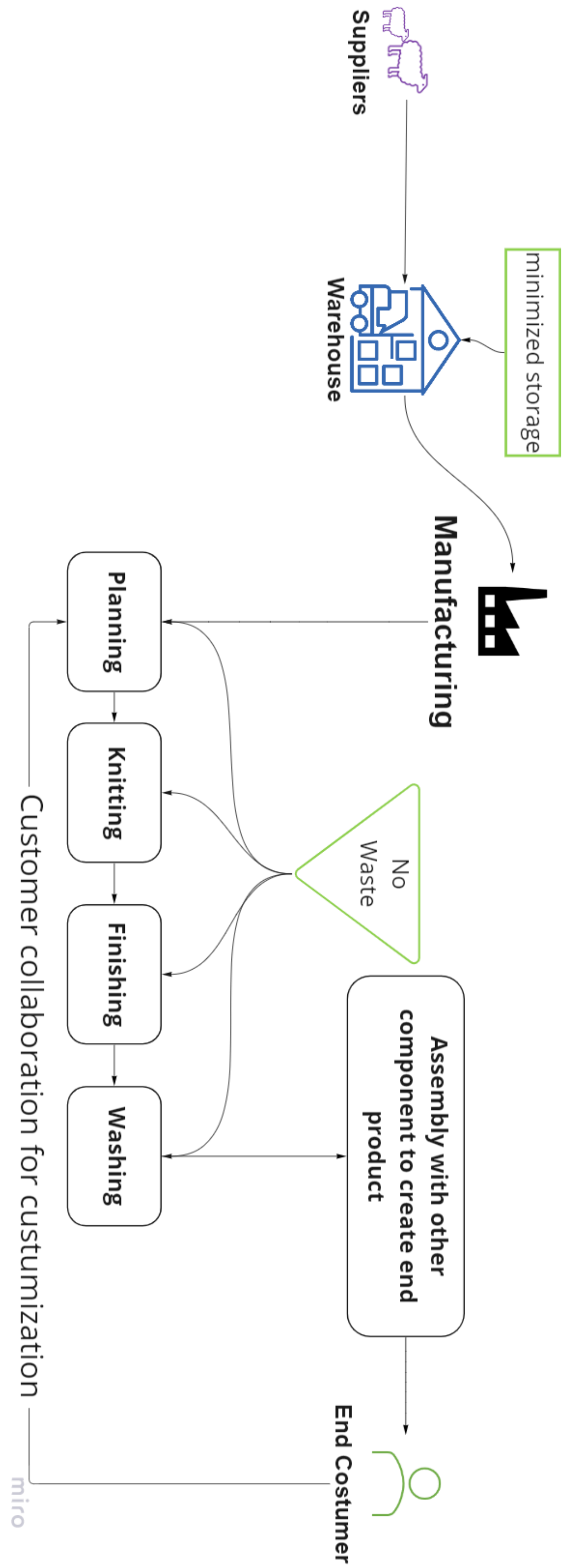
Appendix D figure 9 The current value chain of sweaters in Devold of Norway.



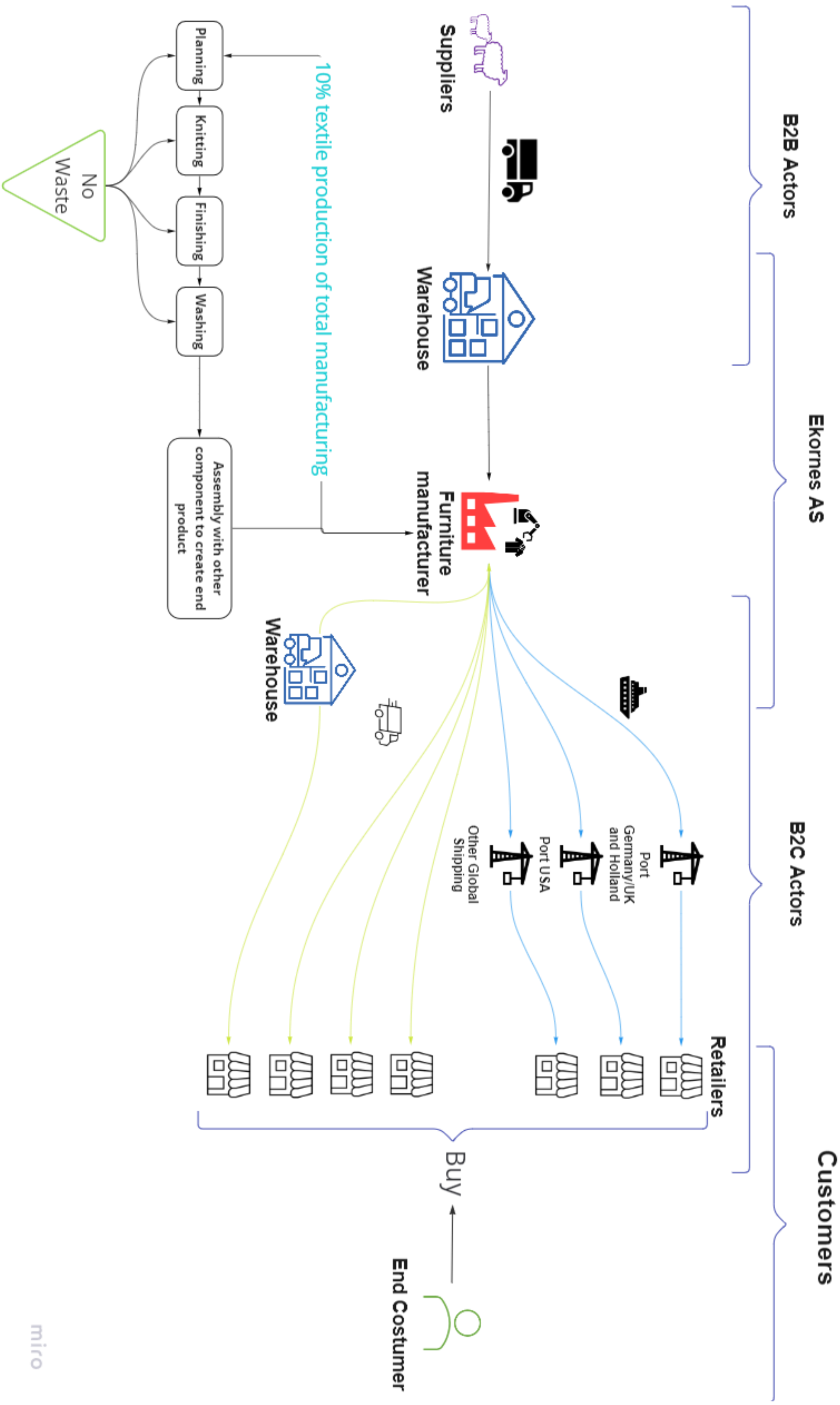
Appendix D figure 10 Current supply chain for Devold of Norway.



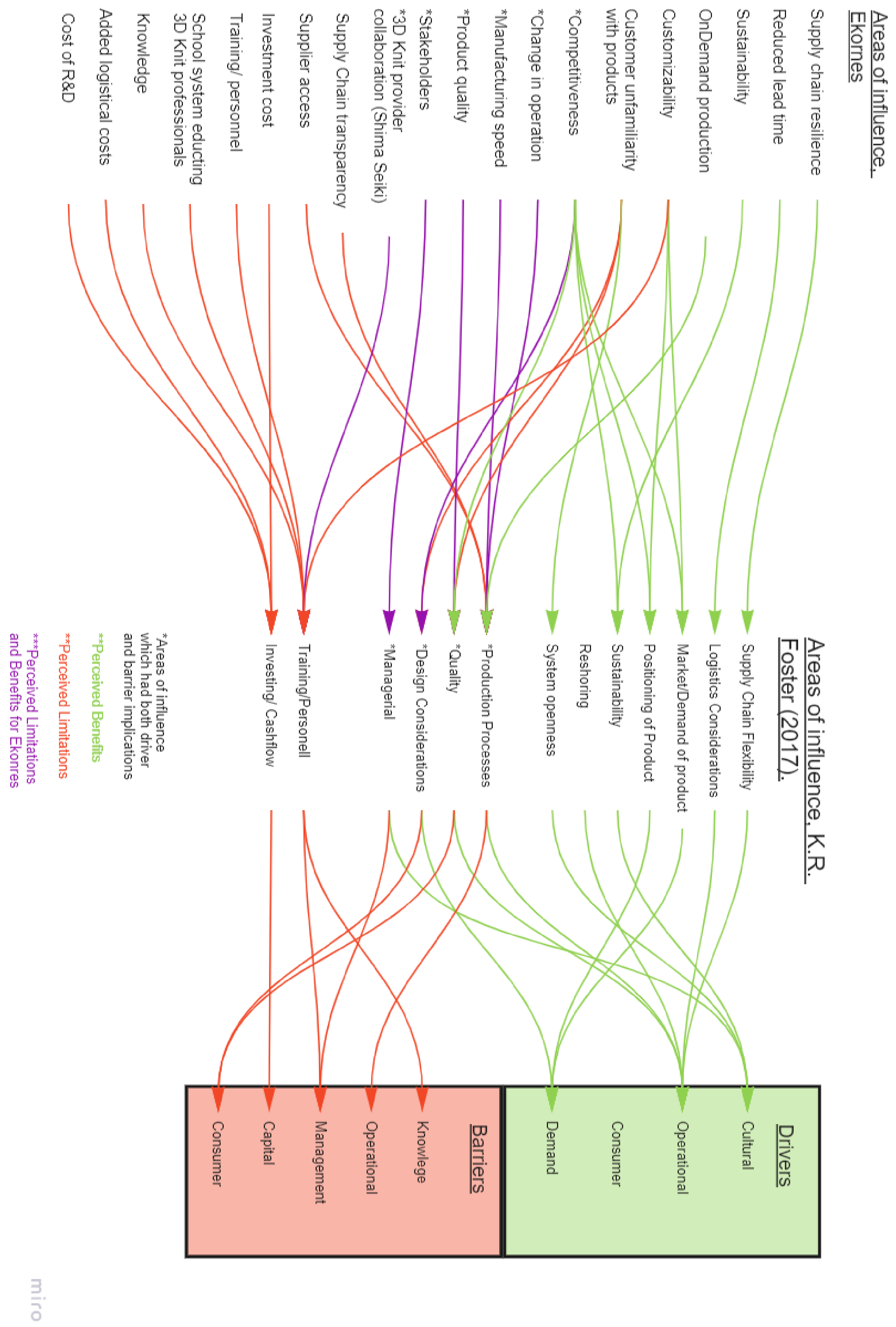
Appendix D figure 11 Shima Seikis Wholegarment SC comparison to tradtional SC. Source: (Shima Seiki 2022c).



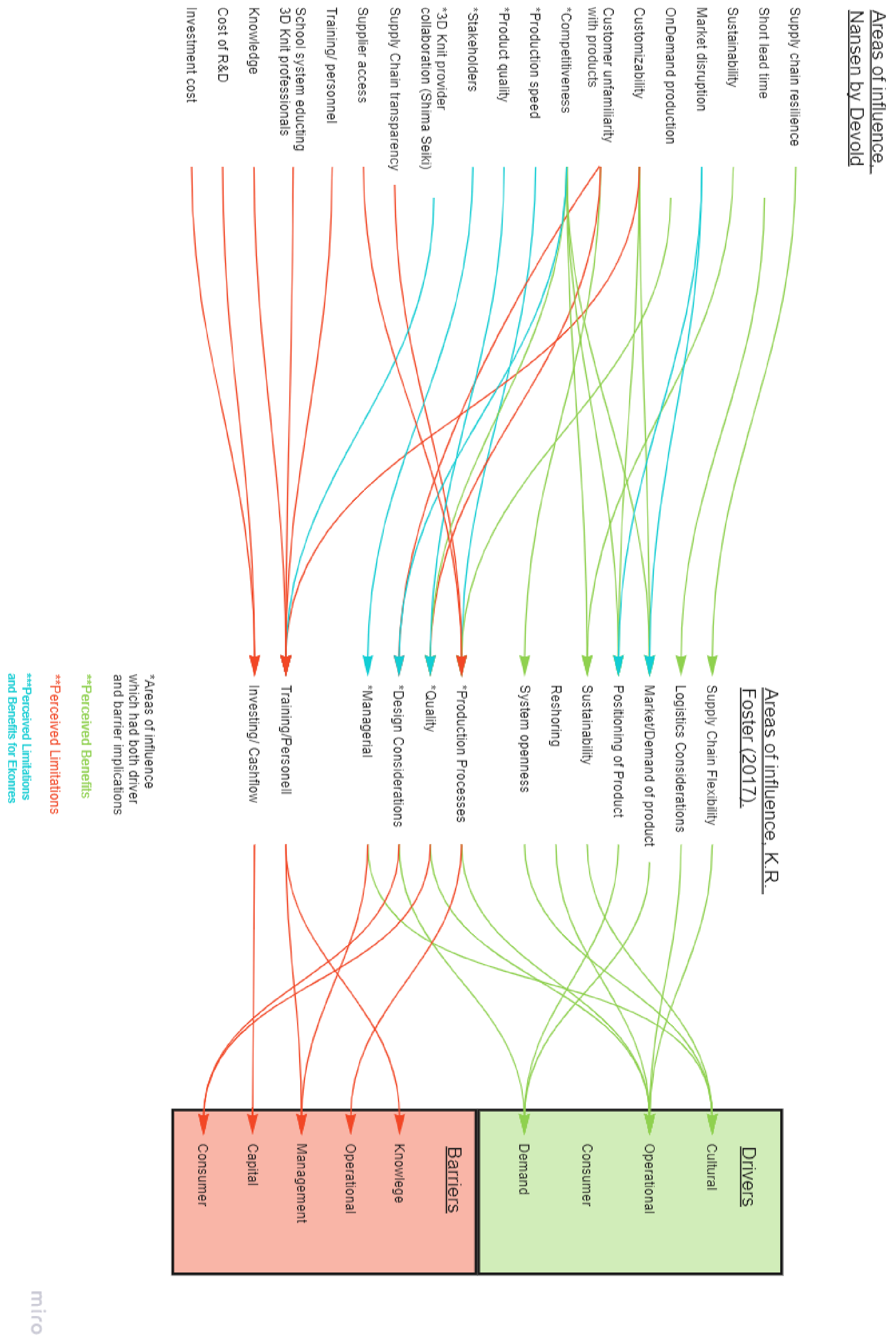
Appendix D figure 12 Ekornes 3D Knit textiles VC.



Appendix D figure 13 Ekornes 3D Knit SC.



Appendix D figure 14 Ekornes areas of influence comparison to the model of K.R. Foster (2017).



Appendix D figure 15 Nansen by Devold areas of influence comparison to the model of K.R. Foster (2017).