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Master Thesis

Thesis Master of Science

Can Blockchain Technology Enable Circular Construction Supply Chains?

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Acknowledgements

This master thesis is the final part of our Master of Science in Business, focusing on Logistics, Operations and Supply Chain Management at BI Norwegian Business School. In this thesis we have been exploring how blockchain could enable circular construction supply chains, and this has been very engaging. We have gained valuable insights on the importance of circular economy, the potential of blockchain, and how these two phenomena could contribute to supply chains.

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Abstract

Circular economy (CE) practices have gained more attention as it has become increasingly important to focus on environmental practices for supply chains. As one of the largest industry sectors in Norway, the construction industry accounts for approximately 40 percent of the country's extracted resources- and yearly produced waste. It can therefore be argued that reducing wastage by incorporating circular practices is highly important. However, in order to transition to CE business models such as circular construction supply chains (CCSC), it is crucial with supply chain visibility. This is problematic for the construction industry as supply chains are characterised as being fragmented and complex, and the industry suffers from low levels of digitalization compared to other industries. However, digitalization could provide increased visibility and thereby aid the transition to CCSC.

Therefore, in this master thesis, we wanted to study blockchain technology (BCT) as one of the main characteristics is to provide transparency and traceability. BCT is a relatively new technology we wanted to study the potential the technology offers in the enablement of CCSC. We have therefore conducted a qualitative study with expert interviews to increase understanding of how BCT could aid the construction industry in becoming a part of the CE. Based on this, our research question is; *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?* In order to answer this research question, we first examined the current industry situation with regards to CE practises, supply chain visibility, and the level of digitalization. Following this, we studied the drivers, conditions and barriers for BCT adoption towards CCSC.

Our study shows that the most efficient way to use BCT to enable CCSC, is to exploit the technology's ability to create material passports through digital tokens, and smart contracts with incentive systems. The technology could provide the supply chain with increased visibility, in addition to further incentivising actors to employ CE practices. The potential of the technology to aid CCSC is interesting, however, we the study concludes with the fact that BCT is still premature. It would therefore be interesting to further investigate the potential application for the construction industry, and conduct use-cases to prove the relevance for companies and supply chains.

Table of Content

List of Figures

List of Tables

List of Abbreviations

- AI - Artificial intelligence
- BCT - Blockchain technology
- BIM - Building information model
- CCSC - Circular construction supply chains
- CE - Circular economy
- CSC - Circular supply chain
- CSCM - Circular supply chain management
- EMF - Ellen Macarthur Foundation
- ERP - Enterprise resource planning
- GDPR - General Data Protection Regulation
- IFC - Industry Foundation Classes
- IoT - Internet of Things
- P2P – Peer-to-peer
- RFID - Radio-frequency identification
- UNEP - United Nations Environment Programme

1.0 INTRODUCTION

For this master thesis we have conducted a qualitative study with expert interviews in order to investigate how increased supply chain visibility through blockchain technologies (BCT) could enable circular construction supply chains (CCSC) in the construction industry. Therefore, our research topic is; *blockchain enabling circular construction supply chains through increased supply chain visibility.* In this introductory chapter we will first go through the motivation and background for studying this topic, followed by the research question and aim of the study. Thereafter, we will discuss the research contribution, and lastly, we will present the structure which the thesis will follow.

1.1 Motivation and Background for Thesis

In 2019, the total global energy related CO2 emissions from the building and construction industry sector constituted 38 percent of the global CO2 emissions, being the highest level of CO2 emissions ever recorded, according to the United Nations Environment Programme (UNEP) report (UNEP, 2020). In addition, the construction industry greatly contributes to pressuring virgin resources, and the materials used in buildings increases emissions further during the building's lifecycle (Material Economics, 2020). On a global scale, the resources extracted to utilize in housing, construction, and infrastructure account for roughly 40-50 percent. In other words, almost half of the extracted resources (de Wit, Hoogzaad, Rumjumar, Friedl, & Douma, 2018). On the other hand, almost 40 percent of these extracted resources end up in a linear supply chain as waste materials annually. In Europe, waste generated from the construction industry therefore makes up for almost 25-30 percent (UNEP, 2020). Looking towards Norway, the construction industry is one of the four largest industries, and accounts for roughly 40 percent of all extracted resources, 15 percent of the CO2 emissions, as well as 40 percent of the produced waste yearly (Digitalt veikart, 2017; SSB, 2021; Klima- og miljødepartementet, 2021). The yearly produced waste is also expected to increase with 20 percent within 2030 if the industry does not take action to prolong materials in buildings and reduce the material extraction (Klima- og miljødepartementet, 2021).

The high level of CO_2 emissions illustrates the urgency and need to reduce the industry's climate impact (UNEP, 2020). Moreover, combining this with the fact that the industry also consumes almost half of the extracted resources nationally and globally every year, underlines the importance of transitioning to closed material loop systems in order to reduce both CO_2 emissions and virgin material extraction. As environmentally friendly practices have become increasingly important, the Norwegian government presented their new strategy for CE practices on the 16th of June, 2021. The goal for this strategy is for Norway to become a pioneering country for CE strategies as this will reduce the need to extract new resources and thereby contribute to improving the environmental footprint (Klima- og miljødepartementet, 2021). Implementing CE strategies in the Norwegian construction industry is estimated to reduce utilization of building materials by almost 20 percent and emissions with almost 10 million tons of CO_2 (Klima- og miljødepartementet, 2021). In addition, green buildings have been deemed one of the greatest global investment opportunities in the next decade, reaching 24,7 trillion dollars within 2030 estimated by International Finance Corporation (2020).

Due to the importance of aiding the construction industry to take part in a circular supply chain (CSC), this study will focus on how this could be achieved. One central issue connected to the establishment of circular business models is that it is paramount to have effective information systems which support supply chain visibility (Korhonen et al., 2018b). The lack of effective information systems has therefore been identified as one of the most important challenges to overcome when implementing CE strategies (Mittal & Sangwan, 2014; Demestichas & Daskalakis, 2020; Mastos et al., 2021). Thus, looking into how the construction industry could become more in line with CE strategies and business models is interesting because it could be argued that the industry has low levels of supply chain visibility. This could be because the supply chain structure is often quite fragmented as the industry consists of multiple and complex supply chain networks, completing a series of unique projects where a new supply chain is formed for each new project (Ribeirinho et al., 2020).

On the other hand, there has been a considerable emphasis on digitalizing the industry recently, as the industry historically has had lower levels of digitalization compared to other industries (Digitalt veikart, 2017; Whyte, 2019; Bartlett, Blanco, Johnson, Fitzgerald, Mullin & Ribeirinho, 2020). As a result, there has been an extensive growth within venture-capital investments during the last five years. *"From 2014 to 2019, investors poured $25 billion into engineering and construction technology, up from $8 billion over the previous five years"* (Bartlett et al., 2020). With the considerable attention to digitalization, there are now multiple options for technologies which could improve how to capture information about the construction components. Furthermore, finding new ways to work with digitalization has been identified as one of the most important means for improving the environmental status in the industry as it will contribute to reducing excess usage of global resources (Digitalt veikart, 2017; Kouhizadeh, Zhu & Sarkis, 2019; Demestichas & Daskalakis, 2020; UNEP, 2020; Mastos et al., 2021; Klima- og miljødepartementet, 2021). In their global status report, UNEP (2020) argues that development and implementation of new technologies could enable CE in the construction industry because it could reduce demand for new materials. This is because materials could be traced, which could make it possible to prevent excessive usage. This is also supported by the Norwegian government's CE strategy report, as they are also stating that having life-time information regarding buildings and their materials are needed in order to facilitate CE.

One of the new technologies that have emerged and received much attention is recently is BCT. This is a distributed ledger technology which was originally used as the foundation for Bitcoin. However, it has become increasingly popular to look at how BCT could be utilized in other contexts due to the large potential application, such as in the supply chain (Vishal & Gaiha, 2020). Using blockchain, one could obtain one single source of information and truth due to the immutable records of transactions which are maintained by the supply chain and could be shared with all who interact with this supply chain (Bai & Sarkis, 2020; Zheng, Xie, Chen & Wang, 2017; Puthal, Malik, Mahanth, Kougianos & Yang, 2018; Carlozo, 2017). Penzes (2018) argues that applying BCT in the construction industry has the possibility to increase transparency through managing the projects, traceability through immutable record keeping, and collaboration through interoperability and cooperation with other technologies (Penzes, 2018; Batra, Olson, Pathak, Santhanam & Soundararajan, 2019). Thereby one has the possibility to reduce the fragmentation and complexity for the construction supply chains through increased supply chain visibility. With increased supply chain visibility, it is also possible to improve tracking and tracing of materials from production to construction, throughout the life cycle to deconstruction. Additionally, due to the immutability the technology provides, one can be sure that the materials which are used have the predicted qualities to comply with sustainable and environmental requirements (Penzes, 2018).

This study will investigate how digitalization and new technology, such as BCT, could be used to increase the supply chain visibility in order to enable CCSC. Looking at digitalization and its capabilities to increase supply chain visibility as well as facilitating for CE practices in the construction industry is interesting due to the historically low levels for digitalization in this sector. However, recently, there has been a new focus on digitalization in this sector (Whyte, 2019), and the industry is concerned with finding technologies which could aid better information flow between entities (Digitalt Veikart, 2020). As of now, building information model (BIM) is the most prominent technology within construction, however, with the new focus on technology, other technologies might surface and contribute in new ways. It is therefore interesting to look at BCT, as this technology has the potential to increase supply chain visibility due to its immutability and decentralized data structure. We believe that improving the visibility could then aid the transition to CCSC and more circular practices in the construction industry.

1.2 Research Question & Aim

The purpose of this master thesis is to explore what potential BCT has to improve the information flow during a building's lifetime, and thereby affect the supply chain visibility in order to enable a transition in the construction industry towards CCSC. The main research question will therefore be as follow;

> ***RQ:*** *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?*

In order to answer this research question, our main focus will be to study CE practices and the supply chain visibility in the construction industry. Our goal is to investigate whether BCT can improve tracking and documenting the processes of material flow of the industry, and if it can provide the industry with more accurate, real-time data, that can be utilized to nudge the industry towards more circularity. To answer our research question properly, we consider it necessary to investigate the current situation of the construction industry, and the potential drivers, conditions, and barriers for establishing BCT to aid CCSC. In order to do so, we were compelled to construct two sub-questions to our main research question. These were;

1. *How is the current industry situation regarding circular economy practises, visibility, and digitalization?*
2. *What are the potential drivers, conditions, and barriers for blockchain technologies to aid circular construction supply chains?*

As previous research on our research topic is limited, we decided to divide our research question into the two sub-questions to increase the understanding of the current industry situation and the specific drivers, conditions and barriers the technology would face. Increasing the understanding with regards to the two sub-questions was seen as essential for the research, and to answer our primary research question. The collected data is primarily based on qualitative expert interviews from actors in the industry, and previously published literature. The study will follow a systematic combining approach, where we seek to explore and enhance the understanding of how BCT could contribute to improved visibility, and how this visibility is important to enable circular usage of materials.

1.3 Relevance

As mentioned, blockchain is a relatively new technology which has recently gained more attention, and research has started to probe its potential for other uses than cryptocurrencies. It is therefore possible to argue that the utilization of the technology in industries such as construction has barely started. In turn, there is limited prior academic research in general, and especially from the construction industry, on the topic. CE, on the other hand, has come further in terms of research. Norwegian companies are currently implementing some circular solutions, however, the transition towards a CCSC is far from complete. To encourage companies to become “green”, the Norwegian government has recently proposed a strategy for Norwegian industries to transition towards CE solutions. Here the construction industry is marked as one of the industries with most to gain from implementing circular practices. However, the industry has yet to take action, as more research is still needed in order to find the most effective solutions for optimizing circular practices.

This research topic is therefore interesting as the aim of this study is to provide input through previously literature and knowledge from experts on how BCT can increase the supply chain visibility and enable implementation of the CSC model in the construction industry. The study is therefore proactive, as it explores how a new phenomenon could contribute to aid the transition to incorporate values of another new phenomenon in the future. The study could therefore enable readers to get an increased understanding of the phenomena BCT, CE and CCSC, and how these phenomena are connected and could influence each other. The data for this research was mainly collected through qualitative expert interviews with actors from different parts of the construction industry and the overall construction industry value chain, which we expected had experiences or at least thoughts about CE, BCT, and the relationship between them. Additionally, we have read previously conducted research with both phenomena, to increase our knowledge of the research topic. Both methods were used to broaden the knowledge of the topic. Through this study we hope to contribute to the literature regarding increasing the knowledge of drivers for application, and the conditions and barriers to overcome for BCT to enable CCSC in the construction industry.

The actors that we have interviewed form the Norwegian construction industry have not yet been eager to engage in processes to try out and test BCT on large scales, nor to take part in use-cases to test the technology. However, many have tried to understand how the technology could benefit the sector. This research could therefore provide a holistic view of the various perceptions of the construction industry actors, as the empirical findings presented are derived from the actors' views, beliefs and industry knowledge. Additionally, this thesis seeks to provide knowledge about the phenomena and their potential and challenges. This is done through providing the basic understanding of how utilizing BCT could provide a system for construction projects where information regarding *what* and *where* materials are in supply chain processes and stored in the building throughout its life cycle. Additionally, how the technology could provide smart contracts with incentive systems, in order to incentivise industry actors to partake in CE business models such as CSC.

1.4 Thesis Structure

This master thesis consists of six main chapters. In this first chapter, we have provided an introduction of the background for studying this topic, as well as the research question and aim, and the relevance of the topic. In the second chapter, we will describe the research methodology and method, in terms of strategy, design and data collection that was used throughout this thesis. The third chapter of our thesis, will go through the theoretical background for our chosen topic, based on previous literature of the phenomena and supply chain concepts. This section will also present our theoretical framework. In the fourth chapter, we will present the empirical findings from the qualitative expert interviews we conducted with key actors. In the fifth chapter of this thesis, we will discuss our main findings, and compare them with the research presented in our theoretical background. This leads to the final chapter, where we will present our main conclusions to the research question, in addition to discussing limitations and future research.

2.0 RESEARCH METHODOLOGY

In this chapter of the thesis, we will elaborate on the methodology and methods used in order to answer our research question; *How can blockchain technology enable circular construction supply chains through increased supply chain visibility*? We will first go through the chosen research strategy, qualitative research, and the reasoning behind this choice. After this, the research design will be explained, where we have chosen to do a qualitative study with expert interviews. Then we will go through how we collected the data in terms of both sampling and semi-structured interview methods, in addition we will explain how we analysed the collected data in terms of a thematic analysis. Lastly, we will discuss how we have ensured the quality of this research through trustworthiness and authenticity.

2.1 Research Strategy

In this section, we will discuss why we have chosen a qualitative research strategy with systematic combining. We will first go through what qualitative research is, and then we will go through why we have chosen systematic combining as our research approach.

Bell, Bryman & Harley (2019) describes research strategy as the general approach to the research adapted in a study. For this research study, we chose a qualitative research strategy, which is a strategy that focuses on words and images, rather than quantifiable numbers, in the data collection (Bell et al., 2019). This is due to the fact that our overall goal of this study is to increase the understanding of how BCT could potentially aid supply chain visibility, and thereby enable companies to transition to CCSC in the construction industry. In addition, the phenomena are still relatively new, and it could therefore be difficult to find enough quantifiable data to these phenomena. Choosing a qualitative research strategy is therefore beneficial, because we could conduct interviews with different participants in the construction industry with relevant knowledge to increase understanding. All the collected data in this study is therefore of qualitative character. Another reason for choosing a qualitative strategy is because we want to explore key viewpoints on the industry situation regarding supply chain visibility through BCT to enable CE. It is still important to collect information which could make these phenomena less puzzling in terms of how they could be used, and what they can contribute to within businesses and their supply chains.

2.1.1 Research Approach

The scientific approach we have chosen to utilize to conduct this research is *systematic combining*. Dubois & Gadde (2002, p. 556) describes systematic combining as a *"non-linear, path dependent process of combining efforts with the ultimate objective of matching theory and reality."* This approach is connected to the growing abductive reasoning approach, which is a combination of the deductive and inductive research approaches (Bell et al., 2019). Using a systematic combining approach means moving back and forth between the previous literature and research findings, which implies that the approach evolves simultaneously with the research work (Dubois & Gadde, 2002). This approach is therefore chosen because it makes the research more flexible because it is possible to move between theory and findings and develop and refine the literature background based on our findings. As BCT and CE are relatively new concepts in the construction industry, choosing this approach is useful because we could start with theory research, get increased understanding from interviews, and in doing so, develop theoretical insights of how BCT could both improve supply chain visibility and enable CCSC.

When looking through previous research for our theoretical background, we started with reaching for articles connected to some key words such as; Blockchain, Circular economy, construction industry, and supply chain visibility. After this, we started connecting the key words in order to find more specific data on the relevant topics and their connection to the construction industry. In addition, we sought to review the citations of any previous research study that we found relevant, in order to broaden our horizons and find more research that could provide value to our thesis. After we had held some interviews, we went back to the literature and refined our theoretical background. This way the previous literature and our theoretical background was more in line with how the master thesis evolved. This process was then repeated throughout the rest of the process.

2.2 Research Design

The research design can be explained as a framework, and it is what guides the collection and analysis of data. The research method is the way data is collected. Thus, the design is what directs the execution of the chosen research method (Bell et al., 2019).

Finding the most suitable research design for this study has been somewhat difficult. This is due to the fact that the research topic is relatively new, and therefore there is a limited amount of previous research and use-cases to look at. In addition, as BCT is a relatively new technology, there are still few who understand the technology fully. At first, we believed that it could be beneficial to look at this as a case-study, since we are looking at a general construction supply chain, and how BCT could enable CCSC. However, using a case-study method became difficult due to the premature thesis topic, and the lack of use-cases to study. Using the research method, qualitative cross-sectional design, could also have been a possibility. However, this is usually used for quantitative studies when researchers are trying to reveal patterns in the findings. Due to a limited timeframe when conducting this master thesis, we did not perceive it as possible to collect enough interviews to be able to have a cross-section design. In addition, finding a pattern was not the main goal of this study, but rather to enhance the understanding of the topic.

Due to the thesis topic being relatively new, and this being an experimental and proactive study, where we want to investigate how something potentially could be improved and implemented in the future, we would argue that the most suitable research design is having a qualitative study with expert interviews. Bogner, Littig & Mintz (2009) argued that expert interviews are interviews defined by their object, as the interviewee possesses expertise over the subject at hand. Due to the nature of the research topic being relatively new, we have chosen to employ this method of information gathering as Bogner et al. (2009) describes the method as a way to shorten time-consuming data gathering processes in situations that might prove difficult to gain access to the required information. According to Brinkmann and Kvale (2015) the goal of conducting qualitative research interviews is to understand the world according to the interview subjects' point of view, to unfold their experiences, and uncover their understanding of the world prior to scientific explanations. Furthermore, in a qualitative interview, the researcher defines and controls the interview, because the researcher introduces the topics and has the possibility to critically follow up on interesting answers (Brinkmann & Kvale, 2015).

We wish to explore *how* increased visibility in the supply chain through BCT could enable circular usage of materials in the construction supply chain. As mentioned, there is little research on both BCT and CE, and how to combine the two phenomena in the construction industry. Therefore, to examine this topic, it is important to collect data on how BCT and CE functions, and their main drivers and challenges in order to increase understanding of the phenomena on their own, and how they could be utilized in a CCSC. Conducting a qualitative study based on expert interviews to provide further understanding of the phenomena could then be beneficial. This is because interviewing key industry actors and experts could contribute to making the research topic less puzzling, and highlight their understanding, which the researchers could compare and contrast in the findings and discussion of the thesis.

2.3 Data Collection

In this section, we will present how data was collected in this thesis. According to Bell et al. (2019) the purpose of any research is to collect data in order to be able to answer the research question. In this study, we have collected mainly primary data, however, there are also some additional sources, namely previously published research and a seminar. We will first thoroughly present how we conducted the interviews, and provide a shorter description for the additional sources. Primary data is when *"the researcher who collected the data conducts the analysis"* (Bell et al., 2019, p. 12). Primary data was collected through in-depth expert interviews with key actors from the Norwegian construction industry, and experts on BCT and CE in the construction industry. As the abductive reasoning approach, systematic combining, is chosen, we were then able to move back and forth between the gathered findings from interviews and the literature review presented on the chosen topic. This way it is possible to attain an in-depth analysis and discussion of previous literature and our own findings.

2.3.1 Sampling

Sampling refers to how the researchers are identifying the relevant people to interview in order to obtain the relevant information that is needed to answer the research question. For qualitative research, Bell et al. (2019) identifies purposive sampling as most relevant. The purpose of purposive sampling is to identify participants who are relevant to answer the research questions in a strategic way. As we had limited knowledge about the construction industry, and which actors who would have insight into the topic, the purposive sampling method *Snowball sampling* was utilized. *"With this approach to sampling, the researchers make initial contact with a small group of people who are relevant to the research topic and use these to establish contacts with others"* (Bell et al., 2019, p. 395). Through our supervisor, we were set in contact with one key interviewee connected to material selection in construction projects, who had strong connections to the rest of the industry. This interviewee could name three other interview objects believed to be of interest for this study. This process was then continued for the rest of the interviews. The target groups were; key actors in the construction supply chain with both national and international insight into either the materials used in projects, digital practices, and environmental competence.

In total, we have conducted eleven interviews, with 13 interviewees as there were both individual interviews and some group based – *see table 1*. The average length of each interview was 45 minutes. All the actors interviewed are connected to the construction industry, which is beneficial as it is possible to get industry specific answers from all interviewees. Thus, we see the sample size to be adequate to get enough data and variation in the answers. The interviewees covered different perspectives such as general supply chain perspectives, owner perspectives, advisement perspectives, and digital solutions for the construction industry, and all were believed to have had experiences or at least thoughts about CE, BCT, and the relationship between them. Two of the participants are experts within the field of using BCT in the construction industry. These two participants are also foreign, and could therefore provide international perspectives. We have also interviewed an actor with specific knowledge of CE and environmental practices in the construction industry. However, a limitation to the study is that none of the interviewees represent the production side, that is contractors and construction companies. On the other hand, since all interviewees had knowledge and insight into both construction and digitalization, the study is not compromised.

Identifier Code	Area of Expertise	Interview Date
C1	Construction SC	23.02.2021
C2	Construction SC	05.03.2021
C3	Construction SC	05.03.2021
C4	Construction SC	10.03.2021
D1	Digitalization in Construction	08.03.2021
D2.1, D2.2, D2.3	Digitalization in Construction	09.03.2021
D3	Digitalization in Construction	09.03.2021
D4	Digitalization in Construction	16.04.2021
B1	BCT in Construction	23.04.2021

B2	BCT in Construction	23.04.2021
E1	CE in Construction	27.04.2021

Table 1 - Sampling overview

2.3.2 Semi-Structured Interviews

When conducting interviews, we used a semi-structured interview guide as preparation and guideline for the interview. Semi-structured interviews are when the researchers have a small list of questions connected to the different specific topics for the interview. The interviewee can then choose how they want to respond (Bell et al., 2019). Furthermore, it is possible to ask follow-up questions and explore aspects not considered by us, if the participants touch upon interesting and relevant topics (Bell et al., 2019). This way it was possible for both us and the interviewees to give additional information if needed. We were therefore able to achieve more in-depth knowledge as new, and unexpected topics were introduced through some of the interviews. Nevertheless, having guiding questions connected to the topics are important to be able to uncover the research topic.

Before we contacted possible interviewees, a semi-structured interview guide was developed based on insights from the literature – *see appendix 1, 2 and 3.* The interview guide was divided into two parts, first we wanted to explore the current industry situation with regards to the environmental and digital status, in addition to how interviewees perceived the supply chain visibility – *see appendix 1*. Second, we wanted to study how BCT could enable CCSC by looking at the drivers, conditions and barriers for adopting this technology – *see appendix 1*. Within these two main areas; the current situation and BCT as an enabler, we had additional questions which could enlighten areas connected to the research topic – *see appendix 1*. However, it is important to avoid leading questions, and give the interviewee the possibility to interpret the question on their own. As the qualitative study with expert interviews tries to enlighten and improve the understanding of the research topic, we used the same interview guide for all interviewees, except for the experts within BCT and CE. For these interviews the questions were more focused on their respective expert areas in order to get a better understanding of the phenomena, and how they could be utilized in the construction industry – *see appendix 2 and 3*.

Due to the COVID-19 pandemic, interviews had to be conducted through online platforms, such as Zoom or Teams. To ensure that the interviewees' answers were captured as intended, we used digital audio-recording. Through the usage of online interview platforms, we could also record the interview as a video. Having online interviews was also beneficial because it was easier to both connect with the participants and interpret the meanings of answers in terms of whether a comment was meant humoristic or serious, compared to telephone interviews. In addition, to avoid misunderstandings, the interview guide and interview was conducted in Norwegian for the Norwegian interviewees, and in English for the two international interviewees – *see appendix 1, 2 and 3.* Furthermore, during all interviews we had one "active" and one "passive" interviewer as this is advantageous (Bell et al., 2019). The "passive" interviewer conducted notes and oversaw the process, and guided the interview back if the "active" interviewer forgot a topic.

2.3.3 Additional Data Collection

In order to further support our data collection through the expert interviews, we have collected data through attending one seminar, and collected material through published documents. This additional data has been connected to CE in the Norwegian construction industry because we believed that this would be important to enhance further understanding of the importance of implementing CE practices and business models in the construction industry. The seminar we attended was; "buildingSMART Norges faglige onsdag #14: *Åpne standarder som nøkkel til sirkulærøkonomi"* held April 28th, 2021. This was a webinar arranged in order to prepare for when the new national regulations for CE are introduced. Key actors from the industry wanted to discuss how digital solutions based on open standards could aid CE when the construction industry has to implement CE strategies and business models in their practices. In addition, we have looked at documents from Circular Norway and their annual circularity gap report. This rapport has provided an in-depth understanding of the current industry situation for Norwegian industries with regards to CE, in addition to an improved understanding of the need for CE initiatives in order to reduce waste and extraction of new materials.

In the theoretical background chapter, there are some references to the reports *Digitalt veikart (2017)* and *Digitalt veikart 2.0 (2020)*. These reports were utilized because of the focus towards how leading actors in the Norwegian construction industry can and should take action in order to become more digital. This data was believed to be relevant for us as this thesis is based in the Norwegian construction sector, and because the solutions could contribute to promote environmental and sustainable practices and CE values.

2.4 Data Analysis

In this section we will provide an explanation of how we used a *thematic analysis* in order to conduct our data analysis of the qualitative expert interviews. Furthermore, as described by our research strategy, our research approach follows the scientific approach of *systematic combining*. In the study we are therefore going back and forth between inputs from both previous literature and empirical findings. It is therefore beneficial to utilize thematic analysis, as this provides a reliable overview of the collected information (Dubois & Gadde, 2002).

When using systematic combining to generate theory, Dubois & Gadde (2002) argued that the researcher's objective is to discover new things, variables and relationships. First, we started with constructing a background for the theoretical background based on previous research on CE, BCT and supply chain visibility. However, throughout the process, the original theoretical background was revised several times due to new information gathered through expert interviews, reports and the seminar we attended, in addition to previous literature. An example of this was how our study originally emphasized that BCT could be utilized as information storage for construction processes, but our findings lead the thesis in the direction of utilizing BCT for digital assets and incentive systems. Changes where therefore made to the literature background in order to examine and analyse the research questions more thoroughly. Analysing the theoretical findings and the empirical data encouraged us to improve the scope of the research.

According to Yin (1994) and Dubois & Gadde (2002), it is important to use multiple sources of information in order to address a broader range of evidence, and thereby cross-reference. It was further argued by Dubois & Gadde (2002) that multiple sources may contribute to uncover new aspects and dimensions of the research question that might have been unknown to the researchers. Such dimensions may also change the direction of the study. In our research, we collected our main data through expert interviews and previous research, as well as attending one seminar focused on CE and looking at Circular Norway's gap report for CE. This was done in order to seek validation through contrasting sources of data. After attending the seminar, we wrote and structured our notes according to topic, and whether they were connected to any of our interview topics. This method was also used when reading through reports. This way it was efficient to connect the discovered and relevant topics to the themes and sub-themes from interviews, as explained below.

As mentioned, we have chosen to use the analytical method, thematic analysis, for this master thesis. Thematic analysis is described by Bell et al. (2019) as an approach for analysis that consists of identifiable heritage or distinctive cluster of techniques. It is one of the most common approaches to qualitative data analysis (Bell et al., 2019). When collecting our findings, the interviews were recorded, and transcribed shortly after they were conducted. The most relevant findings from the transcriptions were thereafter sorted into a spreadsheet in order to perform a thematic analysis of the content. The idea of performing a thematic analysis was to develop our research and find the main- and sub-themes from our findings, which could provide a foundation for the findings of this paper. This process involved utilizing the recommended themes provided by Bell et al. (2019). Some of these themes were for instance to search for repetition of topics, metaphors and analogies used, similarities and differences in the way interviewees discuss topics, linguistic connectors which can depict causal connections and missing data by analysing what the interviewees omit from their answers. As we had the same interview guide for almost all interviews, we started by deriving the themes from the prepared topics, thereafter we filled in with topics which were often repeated and believed to be of interest to the research question. The following table depicts the themes and sub-themes from our expert interviews, along with a selection of the most important quotes – *see table 2.*

Main Themes	Sub - Themes	Summary & Quotations
Current Industry Situation	Views on current situation with regards to CE practices	**Our findings indicates that environmental friendly practices fall short compared to prices and deadlines. In addition, interviewees states that there needs to be focus on political and economic incentives. However, improving supply chain visibility is pointed out as one of the main conditions.**
		"Circular economy and green practices are very hot in general, however it often comes down to something being delivered within a deadline, and then there are other considerations to take into account" - C3 *"I think this is a political aspect. I believe the circular economy is much more expensive (...) There must be political demands and guidelines for the construction industry to partake in it"* - D2.2 *"I do not believe that anyone will reuse materials in their fancy new building if it is not financially motivated. It's that cynical and that simple"* - D2.1 *"The information flow is essential for us to avoid wasting valuable resources. That is the most precarious and important thing here. In addition to avoiding losing information along the way"* - E1 *"We are completely dependent on digitalization in order to succeed with a circular economy"* - D4
	Views on current industry situation with regards to supply chain visibility	**Supply chain visibility was generally described as weak. The industry is fragmentated, and information is not exchanged if not demanded. The low levels of visibility is further connected to low levels of digitalization.**
		"The construction industry is still somewhat fragmented, depending on where it is. There are many silos" - C1 *"The documentation is only provided to the extent that something is requested"* - C4 *"There are some parts of the supply chain which neglect transparency and sharing data. Status quo is that we have insufficient transparency compared to other industries"* - D1 *"When it comes to product information today, it is not very digital. It is extremely analogue in many areas. There are lots of PDF files with little to none machine readability, and there is generally little focus on it"* - D4 *"It is not good at all. This is because we do not have a consistent digital value chain today"* - D4
	Views on current industry	**Our findings confirms that the industry has historically low levels of digitalization compared to other industries. There are a lot of available technologies, however, these are not standardized and does not cooperate well with each other.**

	situation with regards to digitalizatio n	*"The industry is known for being immature with regards to digitalization (...) the challenge is that the industry is very traditional in how they work"* - C3 *"We have everything; IFC for BIM, GSM standards - we have the tech (...) but it is not digitized"* - D4 *"The challenge revolves around standardization"* - C2 *"The challenge today is agreeing upon and standardizing the rules in order to follow them, and then digitizing them"* - D4 *"It is both good and bad. Some projects are very good, but in those instances, there is someone who demands it. (...) This is because all of it is an extra cost, and you do not do it if you do not have to"* - D4
Construction Supply Chains	**Actors view on BCT**	**All actors had knowledge of BCT, however, it became evident that they struggled to understand how the technology could be utilized.**
		"I've been working with blockchain for 3 years now, and only last year I started to see the decentralized way of working" - B2 *"(...) I don't think that either the industry or the technology is ready"* - D4 *"What can blockchain technologies contribute that other technologies cannot?"* - D2.3
	Views on BCT as a driver for enabling CCSC	**The main drivers for using BCT to enable CCSC are; improving supply chain transparency and traceability, using BCT as a support technology for other technologies, and using BCT as an incentive system through smart contracts.**
		"This is a technology being developed for multiple other industries which will function very well in our industry too, so we should really just start using it" - D1 *"Traceability (...) If implemented right it will reduce the resistance for sharing information"* - D2.3 *"The benefit with blockchain is the transparency because you get improved visibility and openness"* - D4 *"I will be very standard there, and say traceability and traceability"* - B1 *"The way that I would describe the power of blockchain for construction is that you have a baseline assumption that digital twins are the future. (...) How do we create the contracts, incentive structures that best fit this new environment? I think that blockchain fits this through smart contracts is the best way to do that"* - B2 *"Blockchain can streamline transactions from the supply chain, and this amongst other things means reduced wastage, and f.eks. automation and quick payment of invoices, which in hand could reduce the time for something to be delivered which could be good for other circular things in the later stages. (...) With waste in time and resources, the supply chain becomes longer, and the longer the supply chain is, the larger the carbon footprint is"* - B1 *"It does provide a great container storage and also the crypto economic incentives systems to pass back and create rewards for people that input the data in the first place" - B2*
	Views on conditions	**Our findings shows that the conditions which needs to be in place in order for utilizing BCT for CCSC are; issuing economic incentive**

Blockchain & Circular	needed for using BCT as an enabler	**systems, getting standardised processes, and showing the benefits with the technology through use-cases.** *"The incentives must be present. (...) Ultimately, economic incentives must be taken into account"* - D3 *"It has to start with the authorities making new regulations. (...) Much of the innovation in our field happens when governmental construction agencies order something new, with new regulations. Then the economic incentives in the industry will react"* - D1 *"The discussion has always been about what to share with whom, and when. We must focus on collecting and sharing data, but we have not yet put in place all the rules, accesses and exchange points"* - D2.3 *"It has to show that it has utility through solving real problems in use-cases. It has to turn out to be good for business - that it pays off"* - C1 *"It's like 'Show me the benefits'. And there are no business cases yet. (...) They want to see business cases with actual tangible benefits. And this is something we cannot offer them now"* - B1 *"The industry could not care less about which technology it utilizes. BIM, BCT or whatever. As long as it is economical and easy to use"* - C2 *"This is a very traditional industry, which requires some time to turn around. There is also a lot of focus on quality, time and economy. The biggest challenge at the moment is probably that everything is measured in economics"* - E1
	Views on barriers to overcome in order to use BCT as an enabler	**The barriers connected to using BCT for CCSC are; BCT might not function as a material bank, problems with ownership of data, premature technology, and long project timelines in terms of investments.** *"I think there will be problems with the large amounts of data, blockchain is not suitable for handling this"* - D3 *"So just as a holder of information I think you could use existing ERP systems, BIM models and data storages to just hold the information. (...) We should rather look into pointers, hashing and of-chain solutions for really large files. For me, blockchain is about transactions and incentives"* - B2 *"What you explain with blockchain being a digital general ledger for each project is cool, but I am not sure that blockchain is the technology which will give me this. I could get this from other solutions such as BIM"* - D2.1 *"There are too many problems connected to the ownership of the data"* - C4 *"Technological maturation (...) I don't think there will be any widespread implementation in the next 3 years, or 5, but within the decade, I think a lot of companies in the sector will be in the game"* - B1 *"A challenge regarding circularity, especially reuse, is what requirements must be set for old materials"* - C1 *"I can't defend a technology with a larger carbon footprint than other technologies. I think that this could be a barrier; how do we solve this problem in a technically and climate friendly way?"* - D4 *"A company can make investments in a project with a five year perspective, but not 60 years"* - D1

Table 2 - overview of themes and sub-themes with quotes

2.5 Ensuring Quality

In this section, we will present the quality criteria which have been used in order to ensure the quality of this study. When doing a qualitative study, Lincoln & Guba (1985) and Guba & Lincoln (1994) suggested that the quality criteria; internal and external validity, reliability and objectivity, should be changed with more suitable criteria. Therefore, to assess and ensure the quality of this qualitative research, we will evaluate the suggested criteria; trustworthiness and authenticity. First, we will present the trustworthiness, and then, we will go through the authenticity of the study.

2.5.1 Trustworthiness of Qualitative Research

Trustworthiness consists of four subcategories, namely; *credibility*, *transferability*, *dependability* and *confirmability* (Guba & Lincoln, 1985). The next subsections will therefore be divided into the different categories.

Ensuring *credibility* involves making sure that the collected data and findings are trustworthy (Bell et al., 2019). To ensure credibility, the study will ensure good practice, triangulation of data, and supporting findings with interview citation. This is an important aspect to consider when conducting a research as it will determine how acceptable the research is for others who read it (Bell et al., 2019). Triangulation of data refers to using multiple sources of data to support the findings in the study (Bell et al., 2019). When choosing the interviewees we used snowball sampling, where key actors connected us with other key actors from other areas within the industry. In addition, we have attended seminars to get more in-depth information about blockchain and how it could be utilized in the construction industry, and how the construction industry should work towards CE in Norway. This way our findings consist of a combination of previous research reviewed in the theoretical background, answers from 13 interviewees, and information collected from seminars regarding CE in construction in Norway. The collected data is therefore triangulated, and the probability for biased sources is reduced as the collected data came from a variety of approaches.

Furthermore, the data collection is following the General Data Protection Regulation (GDPR) where each participant is anonymous, and given a specific identification code. Before each interview, the participants also received the interview guide in order for them to be more prepared for the interview. This gave the participants the possibility to inform us about questions they would not answer, in addition to limiting our' possibility to influence the interviewees during the interview. When writing up the findings from interviewees, we have also emphasised using direct quotes from interviewees and giving further explanation to the context of the answers. This method ensures that when reading the findings one will get good insight into the answers and the interviewees mindset, and thereby compliment the trustworthiness of the study.

Transferability will be addressed as it is important that the results of the research can be utilized in another context (Bell et al., 2019). We have analysed the construction industry in general, and how increased visibility through utilizing BCT could enable CCSC by looking at the current situation with regards to CE, supply chain visibility and digitalization, and the drivers, conditions and barriers for using BCT as an enabler. As we have provided a thorough analysis of these themes and sub-themes, we believe that the findings could be utilized for the industry in total. In addition, the findings could also be relevant for similar industries in terms of supply chain structure and focus.

Dependability also contributes to making the study more trustworthy by making sure that complete records are stored and kept accessible through the whole research process (Guba & Lincoln, 1994, Bell et al., 2019). According to GDPR regulations, interviews recordings and transcripts have been stored safely and anonymously during the whole research process. To ensure anonymity, all interviewees were given a unique identification code before transcribing and writing up findings. Ex. in the identification code C1, C refers to an actor connected to the construction industry in general, and 1 refers to the time of the interview. In addition, as the findings provide quotes from the interviewees, others who might wish to further study this topic will have a good basis for starting. However, the full transcription will not be kept public as this goes against the GDPR regulations from the Norwegian centre for research data.

Lastly, it is important that the paper is *conformable*, which Bell et al. (2019, p. 365) described as whether the researchers have *"acted in good faith"* or not. This involves removing subjectivism and biased opinions by objectively weighting facts when writing up findings and interpreting them. Further, the researchers will try to act neutral with regards to interruptions of results and constantly validate and assess the collected data and the results that can be extracted from it. Thereby, subjective opinions and values should not be reflected in questions or interpretations of answers (Bell et al., 2019). However, Bell et al. (2019) states that it is nearly impossible to be completely objective. Therefore, to further ensure the conformability of the research, all interviews were transcribed before starting to write up the findings, and all findings were written before starting the discussion. In addition, both researchers were present during all interviews except one. This interview was then transcribed by the researcher which was not present.

2.5.2 Authenticity of Qualitative Research

In addition to ensure trustworthiness in the paper, Guba & Lincoln (1994) further suggested five more criteria to ensure authenticity. These are *fairness, ontological authenticity, educative authenticity, catalytic authenticity* and *tactical authenticity*. These criteria reflect upon a broader aspect, regarding the political impact of the research. In our thesis, fairness is provided through different points of views from a social group (Bell et al., 2019). For this research to be fair, it was important for us to interview a broad and varied group of actors from or connected to the construction industry, such as key industry actors, interest groups, material suppliers, digital support suppliers, and experts on BCT and CE in the industry. However, as the construction supply chain is very extensive and we had a limited timeframe, it was difficult to get hold of actors within all parts of the chain. On the other hand, because all interviewees could be considered to be experts within their field and having the required knowledge connected to the topic, the thesis is considered to uphold fairness. The educative authenticity concerns whether the interviewees will get an increased understanding of other viewpoints (Guba & Lincoln, 1994). We claim that through this research, we could help stakeholders in the construction industry to get a better understanding of the two phenomena, BCT and CE, and how BCT could be beneficial and help enable CCSC. Due to this, the thesis has the potential to receive ontological- and educative authenticity. With regards to catalytic- and tactical authenticity, we hope that this thesis could act as an inspiration, and that it will encourage industry actors and researchers withing the construction industry to consider necessary actions to become more environmentally friendly and partake in circular business models.

3.0 THEORETICAL BACKGROUND

The aim of this narrative theoretical background is to provide a foundation for the research topic; *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?* First, we will present CE and explain why CE values require companies and supply chains to change their business models to circular systems. Second, we will present CSCM, as a new management concept which tries to bridge the supply chain and CE practices. Third, we will use the circular business model, CCSC. In this section we will go through what the model is, characteristics of construction supply chains, the importance and challenges with implementing CCSC in the construction industry. Fourth, we will introduce supply chain visibility, as this is an important implication of being able to implement circular business models. In this section transparency and traceability will also be explained in terms of how they could contribute to more sustainable practices. Fifth, we will present what previous research says about digitalization, and how this could aid CE. Sixth, BCT is introduced as a possible technology which could enable the transition to CCSC. Lastly, we will provide a summary and the theoretical framework based on the theoretical background.

3.1 Circular Economy

In this section, we will provide an explanation for the phenomena CE as a new regenerative system and closed loop system, and its relevance and benefits. Second, we will go through the four R's and how these strategies demand a transition towards circular business models for supply chains.

During the last couple of decades, it has become evident that firms and their supply chains need to increase their sustainable and environmentally friendly focuses. This is due to the fact that we are seeing increased environmental problems, where current and traditional *extract-produce-use-dump* material flows and practises are leading to depletion of non-renewable energy sources and disorientation of the environment (Meadows, Randers & Meadows, 2004; Korhonen, Honaksalo, & Seppälä 2018a). The CE business model has therefore gained increased importance as a new business and supply chain concept, and both companies and individuals are realizing the broad variety of potential, opportunities and value in this practice (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Ellen Macarthur Foundation (EMF), 2019). The CE business model could be defined as *"a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling."* (Geissdoerfer et al., 2017, p. 759). This implies that in a CE, the value of the materials used is circling and utilized multiple times, contradictory to linear models. Thereby resources are captured at their highest possible value at all times in biological and technical cycles (Korhonen, 2004; Korhonen, et al., 2018a; EMF, 2014).

The EMF (2021) defines four main levels, referred to as the four R's, for the technical cycles to consider in industries when talking about CE – *see figure 1*. From the inner circle going outwards, the four R's are:

1. *Maintain/prolong & share:* prolonging the lifespan of materials by making them more durable, as well as repairing to reduce the need to create new products.
2. *Reuse/redistribute:* products being reused or redistributed to new owners in their original form or with small enhances. The marketplace, Finn, is an example of such a strategy.
3. *Refurbish/remanufacture:* restoring the value of a product or material. Refurbishing means repairing as much as possible, and remanufacturing means dissembling the product and rebuilding it.
4. *Recycling:* disassembled the product all the way down to its material level, and then reusing these materials to build new products. This process is very important in a CSC, however it is time consuming and costly, and it can be argued that reusing and remanufacturing are more efficient.

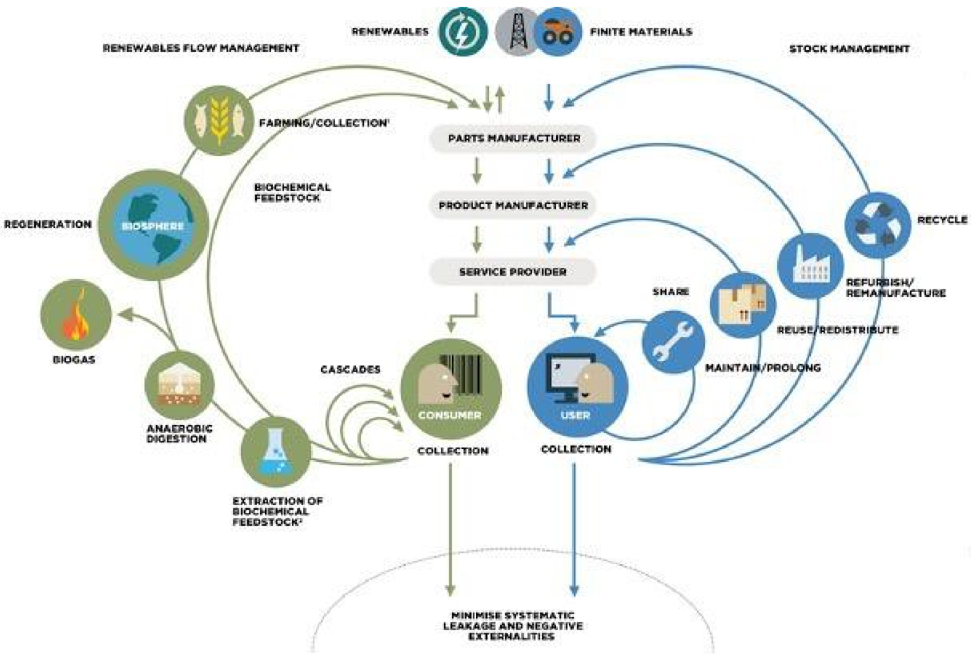

Figure 1- Circular Economy 'Butterfly Diagram', EMF, (2021)

Figure 1 shows a circular system diagram which is often referred to as the 'butterfly diagram' (EMF, 2021). The model builds on several schools of thought, and tries to capture material, nutrient, component and product flows, as well as the financial value for the four R's.

3.2 Implications for Circular Supply Chain Management

In this section, we will first provide an explanation of the supply chain concept. Second, we will introduce the new emerging concept CSCM as literature shows that this concept is more beneficial to use when talking about supply chains and circular economy as opposed to green supply chain management etc.

The supply chain is a concept which originally emerged within the manufacturing industry. Looking at the construction industry, the concept however is still relatively new (Chen, Hall, Adey & Haas, 2020). Christopher (2016, p. 13) defined the supply chain as a *"network of connected and interdependent organisations mutually and cooperatively working together to control, manage and improve the flow of materials and information from suppliers to end users"*. Within this definition it is possible to replace the word chain with network because the total system often consists of multiple suppliers and customers with their own suppliers and customers (Christopher, 2016). Cooper and Ellram (1993) points out that supply chain management aims to look at the whole supply chain, rather than just the next level to increase transparency and coordination.

Recently, there has been a growing interest in integrating CE and supply chain management because it has been proven that this could bring sustainable and environmental advantages (Genovese, Acquaye, Figueroa & Koh, 2017; Nasir, Genovese, Acquaye, Koh & Yamoah, 2017). In literature on sustainability and supply chain management, a number of concepts have been introduced, like for example green supply chains, environmental supply chains, sustainable supply chains, and closed-loop supply chains (Gurtu, Searcy & Jaber, 2015). However, it is only very recently that scholars have tried to systematically integrate CE thinking with SC and come up with a definition for CSCM. Farooque, Zhang, Thürer, Qu & Huisingh (2019, p. 884) suggest defining the concept as;

> *"Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users.*

Contrary to former definitions of the concept, this definition captures the two aspects of CSCM which makes this concept unique, namely; 1) the systems restorative and regenerative cycles based on CE thinking, and 2) the zero-waste economy vision adopted from CE thinking (Farooque et al., 2019). *Figure 2* illustrates the differences between a regular linear *extract-produce-use-dump* supply chain, and a closed loop CSC and how it facilitates a regenerative system and enables a zero-waste system.

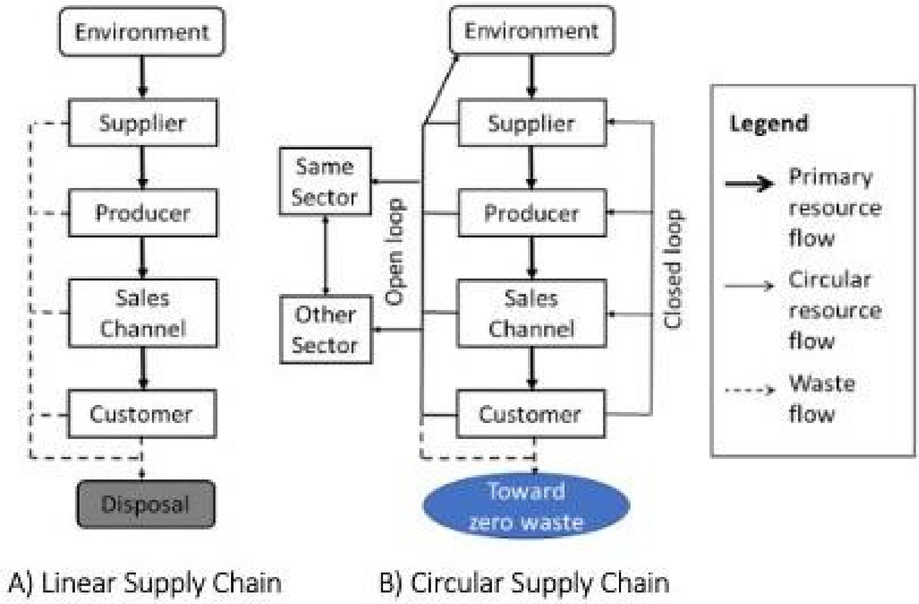

Figure 2 - Illustration of linear and circular supply chains, Farooque et al., (2019)

3.3 Circular Construction Supply Chains

In this section, we will first provide a definition of the construction supply chain based on the aforementioned supply chain definition. Then we will present the reasoning found in literature behind why the construction industry should transition to CCSC, and what this practice implies. Next we will go through some of the characteristics for the construction industry and supply chain visibility as one of the main conditions for establishing CCSC, as the industry characteristics could have a negative impact on the supply chain visibility.

3.3.1 Characteristics for Construction Supply Chain

Keeping the supply chain definition from section *3.2 Implications for Circular supply chain management* in mind, the construction supply chain has been defined by researchers as a *"network of stakeholders that are involved through upstream and downstream linkages in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer"* (Vrijhoef & Koskela, 2000, p. 3). Further, there are three characteristics that re-appear in literature, namely the supply chain structure, complexity and a competitive environment.

Structure

Cox and Ireland (2002) argue that it is difficult to characterize the construction supply chain due to the supply chain structure. Still, construction supply chains are often viewed as networks completing projects by multiple firms cooperating to supply professional services, materials, equipment and labour (Cox & Ireland, 2002; Chen et al., 2020) – *see figure 3.* Further, projects consist of multiple processes, such as design, procurement, production, logistics, inventory control, building operations and maintenance (Cox & Ireland, 2002; Chen et al, 2020) – *see figure 3.* The market demand is also unpredictable, and therefore, the industry is relying on temporary staffing and multiple smaller subcontractors. Due to the high number of actors in the construction supply chain network and the nature of the construction projects, the supply chains are often characterized as *"temporary and highly fragmented"* both vertically and horizontally (Briscoe & Dainty, 2005; Ribeirinho et al., 2020).

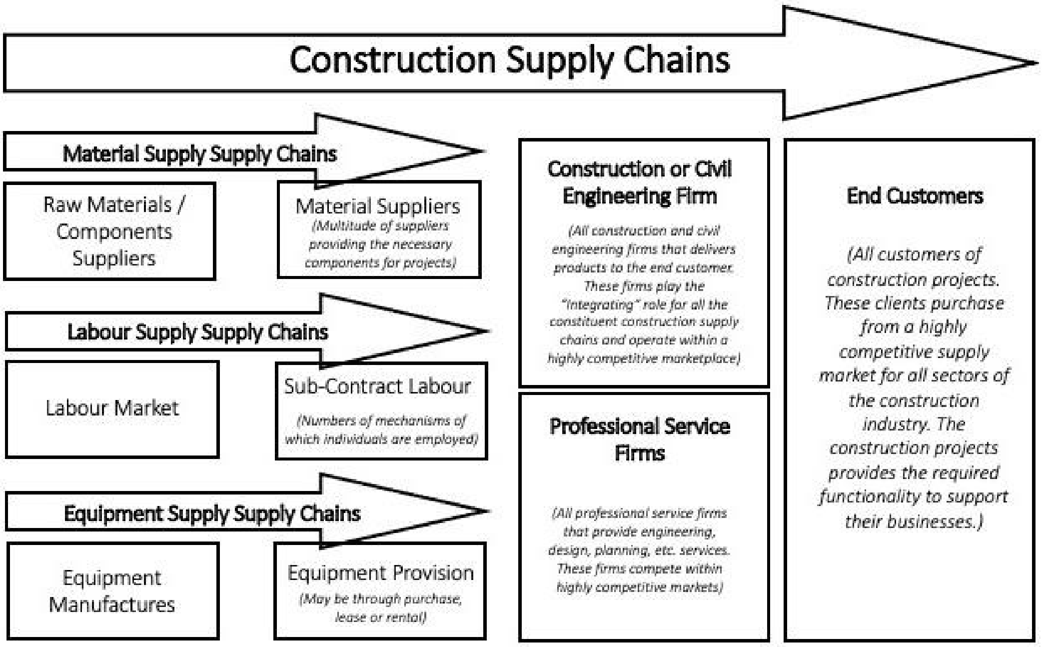

Figure 3 - Typical construction supply chain, Cox & Ireland, (2002)

Complexity

Another characteristic which is identified is the complexity of construction projects and their supply chains. Cox and Ireland (2002, p. 413) states that there is *"no single way of doing anything"*. This is due to the fact that the circumstances of the construction projects vary continuously, and there is an extensive number of unique one-off projects (Cox, A., Ireland, P. & Townsend, M. (2006); Hart, Adams, Giesekam, Tingley & Pomponia, 2019). This limits the ability to create standardization and repeatability (Ribeirinho et al., 2020). As mentioned, the projects consist of multiple different processes where the accountability is divided between the main actors performing these and their subcontracted workforce. This arguably contributes to the complexity of the supply chain network and hampers opportunities for development, as well as making coordination and traceability difficult (Briscoe & Dainty, 2005; Ribeirinho et al., 2020).

Competitive Environment

The construction supply chain is also characterized by being very competitive. Due to the high number of one-off projects and the lack of well established, long-term supply chains, actors in the industry are sometimes working together in projects and temporary supply chains, and sometimes competing for clients. This creates a lack of accountability and split incentives (Cox et al., 2006; Adams, Osmani, Thorpe & Thornback, 2017). Moreover, the competitiveness reduces the willingness to share information as others could then copy ideas (Cox et al., 2006). Briscoe and Dainty (2005) also found that there is a lack of confidence in the working relationship. The construction clients are usually distrusting the main contractor in a project, and the main contractor is in turn keeping the subcontractors and suppliers at an arm's length.

3.3.2 The Importance of Transitioning to CCSC

The purpose of CSCM is to lead companies and supply chains towards CSC where materials and products are circling, capturing value at the highest level by reducing unnecessary waste (Farooque et al., 2019; EMF, 2014). As the construction industry generates about 30 percent of the total waste stream across the globe (Olugbenga & Lukumon, 2019), it could be argued that the implementation of a CCSC is necessary. In Norway, the construction industry generates approximately 1,95 million ton waste each year, where deconstruction makes up for approximately 0,8 million ton equal to 40 percent of this waste (SSB, 2021). Nasir et al., (2017) found that, with regards to insulation products, utilizing the CCSC model considerably reduces the need for new resources and the amount of produced waste, compared to a linear supply chain. This is due to the fact that in a CCSC the four R's from the EMF model are included – *see figure 1*. These four R's have the potential to highly influence today's supply chains in the construction industry as they could facilitate for both reducing the need to acquire new resources for materials, as well as reducing the amount of generated waste.

While construction waste management tools do exist for the construction stage of buildings, there are few companies who implement such efforts into the design stages of the construction project (Olugbenga & Lukumon, 2019). Combining the concepts of CE and CSCM to the construction supply chain could therefore be beneficial as the construction process could both reuse materials, and implement solutions to ensure that the construction could be reused at the end of its lifecycle. To implement CCSC, the stakeholders in the construction supply chain must *"work in an integrated way to tackle waste and project inefficiencies"* (Olugbenga & Lukumon, 2019, p.864). This implies that stakeholders must engage in early CSCM and adapt solutions to reuse and recycle materials from the early stages of the construction process. However, stakeholders questioned the economic value of the model (Nasir et al, 2017). Even though CSCM seems to be very beneficial in terms of better resource management and utilization, the research on the topic is still premature, and there are challenges and limitations to overcome (Korhonen, et al., 2018a; Farooque et al., 2019).

3.3.3 Challenges with CCSC Transition

Looking at the construction industry and the transition to CCSC, researchers have identified some potential problems. This study aims to look into how increased visibility through utilizing BCT could enable CCSC, and literature supports that visibility is a considerable challenge to overcome for supply chains. Other challenges connected to the construction industry which could make it difficult to transition to CCSC are problems with choosing building materials, complexity of constructions, and making a clear business case.

Material selection & Complexity

A challenge which is pointed out in literature connected to implementing CCSC, is choosing the materials to use in a new project. This is regarded as challenging because the materials need to be analysed not only for their physical and technological properties, but also in terms of economic and social properties in order to determine their environmental impact (Samani, Mendes, Leal, Guedes & Correia, 2015; Gurgun & Arditi, 2017). Another challenge is the complexity of the buildings (Adams et al., 2017; Hart et al., 2019). Hart et al. (2019) points out that there are technical challenges connected to the material recovery in construction projects. It is difficult to recuse, remanufacture and recycle when it is uncertain what materials the building consists of and where they are used.

Business Case

In 2017, Adams et al. did a survey on what actors in the construction industry believed to be the challenges and enablers of CE in the industry. The most significant challenge was the lack of incentives to design an end-of-life issue for construction products as customers are often concerned with price and performance, rather than environmental credentials (Adams et al., 2017; Nasir et al., 2017). It is difficult to interpret the long-term need of users, and thus little incentives to design end-of-life considerations. It could therefore be argued that for construction supply chains to be able to transition into CCSC it is important with a clear business case. This is also supported by Mastos et al. (2021) as they stated that there is a lack of businesses and marketplaces for selling waste which have been collected from closed loop supply chains.

Supply Chain Visibility

Efficient information systems are of great importance for the supply chain to be able to succeed with transitioning to CE business models. This is due to the fact that the lack of information or uncertainty regarding the required information is pointed out as one of the obstacles for CE (Demestichas & Daskalakis, 2020). Korhonen, Nuur, Feldmann & Birkie (2018b) points out that when establishing material and energy loops it is paramount for the supply chain network to collaborate in the redesigned models to increase information sharing among others. Several other researchers have also identified limited collaboration and material information as challenges in the construction industry to establishing a CCSC (Singh & Ordonez, 2016; Ritzén & Sandström, 2017; Hart et al., 2019; Demestichas & Daskalakis, 2020). Mittal & Sangwan (2014) ranked the lack of information as one of the top-ranked barriers when trying to establish more green manufacturing. This is supported by Mastos et al. (2021), as the researchers did a study on how industry 4.0 solutions could enable

CSCM. In their three case studies they identified four different challenges for implementing CSCM in order to close the loop in supply chains;

1. Relationships are managed through traditional communication systems and there is suboptimal levels of automation
2. There is lack of visibility in certain phases of the CSC due to the lack of automated and trusted track and trace systems for waste management
3. A need to establish more marketspaces for collecting and selling produced waste
4. Complex collaboration, rules and IT systems differ considerably within different supply chains

It could be argued that three of these barriers are directly or indirectly connected to the supply chain visibility and information sharing, and thus support that low levels of visibility and information sharing systems are key barriers to transitioning to CCSC. Moreover, Mastos et al. (2021) states that some of the key findings of their study is that the proposed solution offered improved supply chain traceability and transparency through complete visibility and automation. The study demonstrates how industry 4.0 solutions enables CSCM because the proposed solution contributes to improve information transparency and aids companies in closed loop supply chains to oversee their processes and help their decision making (Mastos et al., 2021).

3.4 Supply Chain Visibility

As mentioned previously, improved supply chain visibility is one of the conditions which are needed in order to transition to closed looped CCSC in the construction industry. However, as described, the construction supply chain is characterized by aa being fragmented, complex and competitive, performing multiple one-off projects. Therefore, we will now present the supply chain visibility concept and the challenges with visibility perceived by researchers in the construction industry. Last, a definition of transparency and traceability, and their connection to sustainability.

3.4.1 Definition of the Concept

The term visibility could be explained as the ability to see or be seen. Looking at supply chain visibility, Francis (2008, p. 182) provides one of the most complete definitions, describing the concept as *"the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times of these events"*. Furthermore, supply chain visibility refers to the extent to which actors in the chain have access to vital and critical end-to-end information about entities and events, such as orders, inventory, transport, and distribution, at the right time (McCrea, 2005; Wei & Wang, 2010; Barratt & Barratt, 2011). Christopher (2016, p. 156) emphasizes that it is this sharing of information that enables firms in a supply chain to achieve cross-functional and horizontal management, and that the 'supply chain' in reality is a *"series of relationships between partners that is based upon the value-added exchange of information"*. In this paper, information sharing in the supply chain will be referred to as visibility.

With more complete information sharing, firms can improve their decision making to align decisions better with overall objectives (Christopher, 2016). In addition, information sharing provides the required transparency for coordinating inventory flows in the supply chain (Simatupang, Sandroto and Lubis, 2004). Juttner and Maklan (2011) also states that supply chain visibility and collaboration are intangible dynamic capabilities which can contain disruptions, but also competitive advantages. This is because improved visibility and information ensures well informed and effective decision making and appropriate response (Christopher and Lee, 2004).

3.4.2 Transparency and Traceability

Supply chain transparency and traceability are usually related concepts when discussing visibility, even though they have significantly different meanings. Researchers have come to the conclusion that improved transparency could be a factor which positively affects traceability. However, traceability does not necessarily improve transparency (Roth, Tsay, Pullman & Gray, 2008; Skilton & Robinson, 2009).

3.4.2.1 Supply Chain Transparency

Transparency refers to a situation where one is able to see clearly something that is behind something else. Supply chain transparency can be defined as the degree to which an actor in a supply chain has critical and relevant information about products, processes and flows of capital (Bastian & Zentes, 2013; Stohl, Stohl & Leonardi, 2016). To obtain transparency, Zhu, Song, Hazen, Lee & Cegielski (2018) states that it is crucial that the supply chain has the right information about products moving through the chain. The value of the information is further determined by how timely, accurate, consistent and complete it is (Hazen, Boone, Ezell & Jones Farmer, 2014; Morgan, Richey & Autry, 2015). In addition, the information needs to be structured in a way which makes it easy to utilize in the supply chain (Zhu et al., 2018). Researchers also argue that transparency is connected to supply chain trust, understanding and sharing of material information (Trienekens, Wognum, Beulens & van der Vorst, 2012; Schnackenberg & Tomlinson, 2016).

Through the usage of enterprise resource planning (ERP) systems, there has been considerable improvements in information sharing in supply chains. However, obtaining supply chain transparency is still a major challenge in large supply chains involving complex transactions (Vishal & Gaiha, 2020). An example of such a supply chain is the multinational manufacturing and engineering company, Emerson. Their supply chain is very complex, involving *"thousands of components across many suppliers, customers and locations"* (Vishal & Gaiha, 2020, p. 11). The president of the company states that such supply chains often struggle with *"long, unpredictable lead times and lack of visibility"* (Vishal & Gaiha, 2020, p. 11). Therefore, if the supply chain manages to obtain end-to-end visibility, this will greatly improve supply chain transparency, and the correct information would be available to the right actor at the time it is needed (Christopher & Lee, 2004).

Transparency and Sustainability

Supply chain stakeholders, such as consumers and government are becoming increasingly aware of stainable practises with regards to product, process and materials, and are therefore putting pressure on firms to improve their information sharing (Trienekens, 2011). By sharing information between relevant actors, the materials used can be made more accessible to the buyer - which increases the visibility and communication in the chain. Dingwerth & Eichinger (2010, p.74) state that supply chain transparency can *"empower information users to exert influence on the disclosure"* and *"become a tool for holding powerful actors accountable"*, empowering all actors within the chain to experience more reliable sources. Carter & Rogers (2008) argues that transparency is essential to obtaining sustainable supply chain management, and researchers have therefore focused on how increased transparency in the supply chain could improve sustainable practices, and reduce phenomena such as counterfeit products, suboptimal materials, child and slave labour, in addition to other problems which could occur due to low visibility (Bell, Mollenkopf, Meline & Brunette, 2016).

3.4.2.2 Supply Chain Traceability

Traceability could be explained as having a course of development which is possible to follow. Traceability is described as when a firm is able to identify and verify components chronologically as they move through the supply chain (Skilton & Robinson, 2009). Olsen and Borit (2013, p. 148) defined traceability as *"the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications."* This implies that the supply chain is able to track and trace their components, knowing what sources of raw materials are used, the elements which purchased components consist of, and tracking the environmental performance of a component throughout processes involved in production and along the supply chain, etc. (Dabbene, Gay & Tortia, 2014).

To be able to track any logistical components in the supply chain, it is important to have a well-structured traceability system. A traceable resource unit is what the traceability system is supposed to keep a trace on, and the this can be any type of traceable object in the supply chain. Typically, a traceable object is either a trade unit (case or box), a logistic unit (pallet or container) or production unit (batch) (Olsen & Borit, 2018). Furthermore, a traceable system needs to be able to; 1) Identify the traceable unit, 2) Document transformations, and 3) Record the attributes of the traceable unit, throughout its life cycle.

Traceability and Sustainability

Having a well-structured supply chain traceability system is essential for CSCM practices as the traceability system will require the firm to *"curbing illegal practices, improving sustainability performance, increasing operational efficiency, enhancing supply chain coordination, and sensing market trends"* (Pagell & Wu, 2009; Hastig & Sodhi, 2020, p. 1). This is due to the fact that being able to track materials as they move along the whole supply chain could enable the firm to identify and address the levels which are vulnerable to environmental risks (Cousins, Lawson, Petersen, & Fugate, 2019). When adopting CSCM, high levels of supply chain traceability could function as a strategic resource because traceability could enable the supply chain and its members to use asset information to achieve sustainable operations in complex systems throughout the product's lifecycle (Whyte, Stasis & Lindkvist, 2016; Cousins et al., 2019).

3.4.3 Challenges with Visibility and Information Sharing

Even though visibility in the supply chain could provide competitive advantages and improve environmental and sustainable practices through improved traceability and transparency (Bell et al., 2016; Hastig & Sodhi, 2020), it is also a critical challenge for businesses because of the restricted flow of information the firm possesses on its first, second and third-tier suppliers (Abeyratne & Monfared, 2016). With complexity and limited information flow, much of the product's history and composition can get lost. Limited visibility refers to a situation where some parts of the supply chain are unaware of the status of upstream and downstream operations and inventory flows as they are not receiving the proper information flows (Christopher, 2016). Wei and Wang (2010) states that information sharing is an activity which enables a supply chain to obtain transparency and traceability and thereby visibility. However, this could also create barriers to visibility, as not all firms are willing to share critical information due to the fact that this could potentially threaten their existence (Juttner & Maklan, 2011).

Although having an effective flow of information is viewed by most as a condition for obtaining an effective supply chain (Nooraie & Parast, 2015; Christopher, 2016), Briscoe and Dainty (2005) found that it was problematic to achieve in practise for construction supply chains. As mentioned, research shows that there are many different characteristics with the construction industry which could make it challenging to transfer information between the different actors in the supply chain network, thus making it difficult to trace material information and obtain supply chain visibility. Research shows that 25-30 percent of the construction cost derived from fragmented processes and hampered information flows (Digital veikart, 2017). It could be argued that the reason for this is largely connected to the current supply chain structure and collaboration, the complexity and competitive environment. The traditional structures for responsibilities and fragmented supply chains usually limit the amount of shared information, not only between different construction projects, but also within the same. In addition, information is often stored internally instead of across different sectors because to protect market shares and competitive advantages connect to unique information (Cox & Ireland, 2002; Cox et al., 2006; Briscoe & Dainty, 2005; Digitalt veikart, 2017). In addition, the industry is characterized by traditionally low levels of digitalization.

3.5 Digitalization

As mentioned, the construction industry has historically been one of the industries with the lowest levels of digitalization. However, improved digitalization could be used to increase the traceability which will improve the transparency, and thereby the supply chain visibility. Thus, digitalization and information technologies have been pointed out as key enablers for implementing CE business models in supply chains (Christopher, 2016; Kouhizadeh et al., 2019; Demestichas & Daskalakis, 2020; Mastos et al., 2021). We will therefore go through how digitalization could improve visibility and the potential challenges in the construction industry.

3.5.1 Improving Visibility

Leading firms and their network have accepted that the key to successful supply chain management is a well-functioning information system (Christopher, 2016). These firms recognise information technologies are key to improve responsiveness and efficiency, and understand that information systems are changing firm structures and reducing cost and risk in the supply chain (Nooraie & Parast, 2015; Christopher, 2016). As the digital transformation has gained considerable attention within the construction industry recently, there are now multiple options for how to capture information about the construction components. Computational devices enabled to collect information are now used in all aspects of a construction project. Therefore, there is a new focus on looking at the projects not only as deliverable physical products, they are also digital information platforms (Whyte, 2019).

In accordance with this research topic, several researchers highlight the emergence of new information technologies and the importance of improved information technologies as an enabler for CE (Whyte, 2019; Kouhizadeh et al. 2019; Demestichas & Daskalakis, 2020; Mastos et al., 2021). New technologies could help improve the supply chain traceability and thereby transparency which will lead to improved supply chain visibility. This way it could be possible to get improved and updated information about materials and products used, and use them in a circular system for reuse or recycling. Demestichas and Daskalakis (2020, p. 1) states that;

> *"Cutting-edge technologies, such as big data, cloud computing, cyber-physical systems, internet of things (IoT), virtual and augmented reality, and blockchain, can play an integral role in the embracing of CE concepts and the rollout of CE programs by governments, organizations, and society as a whole."*

Demestichas and Daskalakis (2020) did a review of different technologies which could function as enablers for CE, and some of the identified were smart tags, digital twins and IoT. Radio-frequency identification (RFID) and smart tags are some of the more widely used technologies. Smart tags gives each product a unique identification and improves tracing of the product itself, but also the environmental status. BIM is a digital twin technology which creates accurate virtual building models (Demestichas & Daskalakis, 2020). BIM has the potential to improve visualisation, identification, construction and operational issues. Swift, Ness, Kim, Gelder, Jenkins and Xing (2017) underlined that the combination of RFID and BIM could make construction products and materials more traceable, adaptable and reusable. Another major facilitator for CE which was identified in the study was IoT. This is a global network of interconnected objects with unique identifier codes and standard protocols for communication (Demestichas & Daskalakis, 2020). BCT has also raised attention among CE researchers recently due, among other, its traceability and transparency and security aspects (Kouhizadeh et al. 2019;

Demestichas & Daskalakis, 2020; Mastos et al., 2021). This we will come back to in section *3.6 Blockchain Technologies.*

3.5.2 Challenges with Digitalization

Even though there has been a considerable focus on digitalizing the construction projects recently, the industry is still in its infancy compared to other industries when looking at the level of digitalization (Alaloul, Liew, Zawawi & Mohammed, 2018). The low levels of technology in the industry could create problems with visibility as information is still heavily reliant on manual collection of data on resources. When crucial material and building information is collected manually, errors are inevitable (Young, Haas, Goodrum & Caldas, 2011). In addition, the industry has often utilized new digital tools to optimize one specific task, in a specific part of the supply chain, instead of looking at the whole picture (Digitalt Veikart 2.0, 2020). This implies that there is a need for a better way of transferring information, in order to improve visibility in terms of transparency and traceability.

Whyte (2019) states that as digitalization opens up for new and improved ways of collecting and storing information, and project information grows, it is important to establish common standards for which information platforms to use, and how to *"sorting, analysing, storing and retiring"* the information. This is in order to enable efficient information flow between the different supply chain actors within every new construction project (Whyte, 2019). Without information being sorted, analysed and stored in an orderly way, increased material information could potentially create more troubles with visibility in the supply chain. There have been substantial efforts in trying to standardize information data and reach a shared platform (Whyte, 2019; Digital Veikart 2.0; 2020), however, due to the previously mentioned problems connected to industry structure, complexity and the competitive environment it is difficult.

Furthermore, as there might be multiple different versions of digital information connected to one project, it is important to ensure that the latest version is always used, and that it is possible to trace decision making processes. Digital Veikart 2.0 (2020) concludes that to enable a seamless and digital flow of information in the construction industry, the industry needs to develop a shared platform for collaboration where the different parties *"talk the same language"*. The industry needs to agree upon how they are going to digitalize to avoid unoptimized solutions, where all companies utilize different technologies for information sharing.

3.6 Blockchain Technologies

In this section, we will discuss BCT as a possible enabler for aiding a transition to circular business models, such as CCSC. In order to do so, we will explain what BCT is and the structure of the technology. In addition, we will explain the characteristics; decentralization, open data, authenticity, and the difference between permissioned and permissionless blockchain. Lastly, we will go through some of the perceived challenges found in previous research.

BCT was developed and introduced as the technology behind the cryptocurrency Bitcoin in 2008 (Nakamoto, 2008). When Bitcoin was introduced, the source code for the BCT was open, meaning that no one can own the technology, and that everyone knowledgeable and skilled enough can utilize its core and develop or customize new applications to the technology. BCT can be described as a public and immutable ledger, and it is therefore often referred to as a distributed ledger technology where data is stored among all users in the network. All transactions that enter the system are stored in a chain of timestamped blocks, and this chain grows for each new transaction that is added to it (Carlozo, 2017). Furthermore, the blockchain ledger record is described as being "*rendered immutable, transparent, and auditable yet resistant to censorship and manipulation due to the technology's cryptographic and distributed foundations"* (Maull, Godsiff, Mulligan, Brown & Kewell, 2017, p 484). As the cryptographic foundations of the ledger are based on BCT, it is possible to keep track of each transaction, and offer informational accountability between the actors in the network. Risius and Spohrer (2017, p. 386) described the technology as;

> *"Blockchain technology refers to a fully distributed system for cryptographically capturing and storing a consistent, immutable, linear event log of transactions between networked actors. This is functionally similar to a distributed ledger that is consensually kept, updated, and validated by the parties involved in all the transactions within a network.In*

such a network, blockchain technology enforces transparency and guarantees eventual, system-wide consensus on the validity of an entire history of transactions".

3.6.1 Blockchain Structure

Before explaining the characteristics of BCT, we will go through the BCT structure structural, and its core technical order. As stated by Casino, Dasaklis and Patsakis (2018, p. 56), *"a blockchain should be considered as a distributed append-only time-stamped data structure"*. This is due to its function which allows a peer-to-peer (P2P) network where non trusting members can interact with each other through verified channels that are not regulated by any central authority safely. The network is created to be non- repudiable and to reduce the dependencies of third parties as its operation is based on consensus between the nodes, computers, in the network through its time stamped digital ledger (Niranjanamurthy, Nithya & Jagannatha, 2018). It is important here to understand that the blockchain is not copies of the transaction data, but thousands of copies of the transaction records. In simpler terms, this means that the original data is recorded with all changes that are made to it in a chronological time stamped manner which is checked against the other nodes, to ensure the immutable record.

As the system is based upon a decentralized structure, the blockchain works the following way when someone requests a transaction – *see figure 4* (Niranjanamurthy et al., 2018; Penzes, 2018);

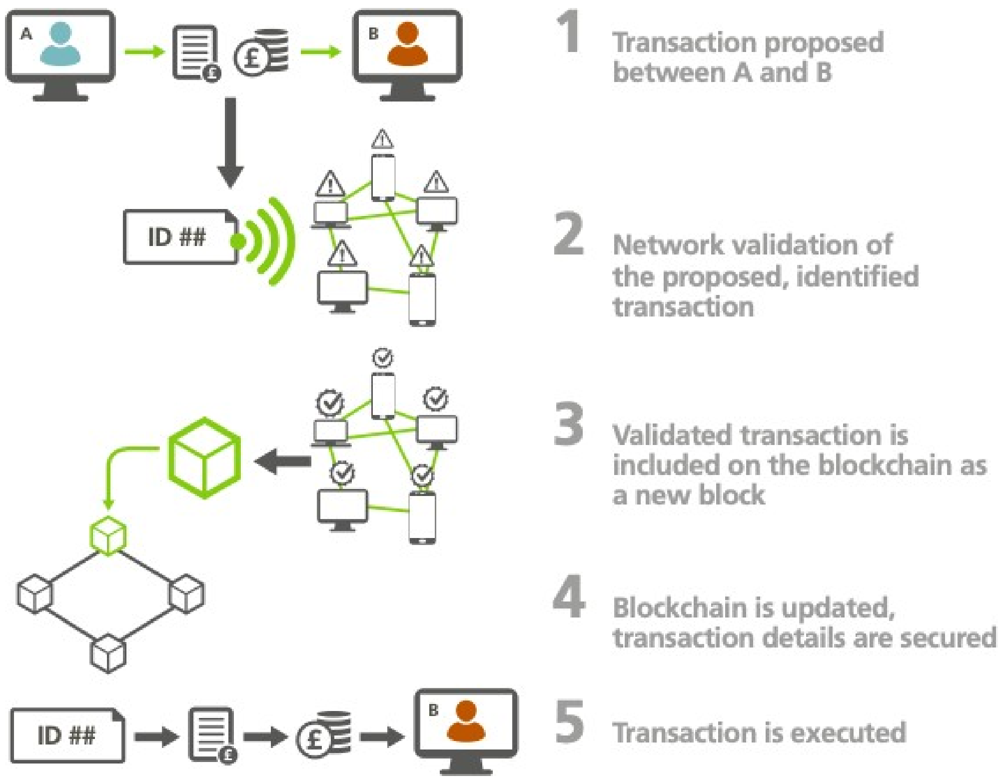

Figure 4 - Blockchain transactions, Penzes, (2018)

To further elaborate on this, Dasaklis, Casino & Patsakis (2019) split the basic mechanics of the blockchain into three layers, namely *blocks and transactions*, *consensus* and *compute interface*. Casino et al. (2018) regards these mechanics interconnected, whereas everyone provides a specific feature to the infrastructure.

3.6.1.1 Blocks and Transactions

The lowest layer of these mechanics is where *blocks* and *transactions* can be found. All blockchains contains a set of blocks which are connected to the previous block in the chain chronologically, thereby creating a continuous chain starting from the first block (Novo, 2018). To connect the blocks in a chronological order, each one contains a "hash", which is a mathematical function that takes an arbitrary input of numbers and letters and changes it into an encrypted fixed length output, of the previous block (Nakamoto, 2008). Due to this function, the blocks contain the transactional history of the entire chan. Transactions was therefore described by Novo (2018) as the transfers between entities, which are transmitted to the network where they are validated by nodes and then collected into the blocs. It was further described that contracts between two entities denotes transactions between peers in the network, to transfer digital assets from one part to the other in order to complete the task. In such transactions, any entity that is connected to the network as a node, will validate requested transactions that are broadcasted out to the P2P network (Casino et al., 2018). The validation of transactions leads to the next layer, consensus.

3.6.1.2 Consensus and Compute Interface

The goal of the middle layer, or the *consensus* layer, is to guarantee that there cannot be created corrupt branches, nor divergences in the chain, ensuring validity (Casino et al., 2018). Hunhevicz & Hall (2020) called the consensus mechanism the most important component of BCT. Today, there are different measures that can be undertaken in order to reach validity, but the two most utilized ones are *"Proof-of-work"* and *"Proof-of-stake"* (Zheng et al., 2017; Casino et al., 2018). The former was the original consensus method proposed by Nakamoto in 2008. It requires large amounts of resources, resulting in other consensus methods surfacing (Hunhevicz & Hall, 2020). The latter was created by King & Nadal (2012) to solve the energy consumption problem of *"proof-of-work"*. However, which method one utilizes is not important as long as it fits the use-case.

The *compute interface* is the upper level of the technology, and enables the technology to store complex digital assets, with dynamic states (Dasaklis et al., 2019). This is a layer that has evolved from the original Bitcoin technology (BlockChain 1.0) released in 2008. As the technology evolved to become more advanced, it embraced applications such as *smart contracts*, and the ability to transfer digital assets from one blockchain into another (Dhaliwal, 2018).

3.6.1.3 Smart Contracts

The term smart contracts were first introduced in the mid 1990s by Szabo who defined them as *"a set of promises, specified in digital form, including protocols within which the parties perform on these promises"* (Jani, 2020, p 12). In the paper, Szabo argued that a smart contract could be as analogized as vending machines, where a simple action, such as taking in coins, the vending machine could go through all processes it was pre-programmed to do, in order to serve the desired product. Through this analogy, Szabo explained, and expected, that in the future, such contractual actions could be implemented in a multitude of operations, ensured through digital means. Further, Wang et al. (2019, p. 1) define the term as *"the computer protocols that digitally facilitate, verify, and enforce the contracts made between two or more parties on blockchain"*. The application of Smart Contracts through BCT is argued to be one of the most transformative adaptations of BCT as it could potentially disrupt how work is organized today (Iansiti & Lakhani, 2017). Looking at CE, circular initiatives are dependent on lower incomes and more informal economies. Circular models could potentially rely on incentivising through smart contracts in blockchain. This was acknowledged by Kouhizadeh et al. (2019), arguing that smart contracts could enable incentives and *"incentivisation can support CE initiatives by offering rewards and tokens to consumers when they return and recycle their wastes"* (Kouhizadeh et al., 2019, p. 13).

3.6.1.4 Tokenization

Tokens are an abstract representation of any physical asset, and could be split into three types, namely payment tokens, such as cryptocurrencies, utility tokens, which provide digital access to an application or service and asset tokens which represent physical assets (Savelyev, 2018). Throughout this paper, all of these will be referred to as tokens. The term tokenization is usually used to describe how any information of value, digital or physical, can be converted into an encrypted digital token. This is arguably one of the most core components of the technology (Nakamoto, 2008; Li, Wu, Pei & Yao, 2019).

3.6.2 Blockchain Characteristics

BCT was created about a decade ago, and it has taken the technology several years to gain widespread recognition through academic research and in business cases for industries. The technology has nonetheless been explored in several academic studies since, and therefore several studies have looked into the characteristics of BCT. Puthal et al. (2018) conducted a review where he found the following characteristics depicted in the model below – *see figure 5.*

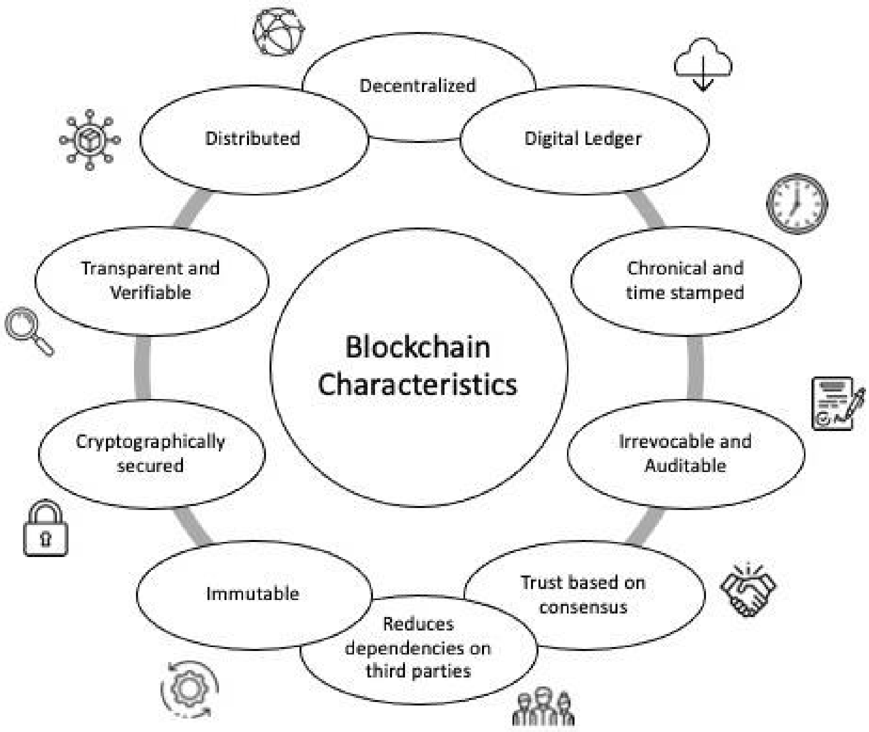

Figure 5 - Blockchain characteristics, Puthal et al., (2018)

However, Treiblemaier (2019, p. 3) stated that *"the shown characteristics might not apply equally well to all types of Blockchain manifestations"*. Further, Wang & Qu (2019) found three key characteristics that enable blockchain to be applied in shipping, transportation, logistics and supply chains. These were *open data, decentralization* and *authenticity of data*, which is in accordance with the characteristics found by Puthal et al. (2018). The following segments will take a further look into these segments.

3.6.2.1 Open Data - Transparency and Traceability

To ensure an effective and efficient supply chain, it is important that the entire supply chain is transparent. As described previously in *3.4.3.1 Supply chain transparency,* it empowers actors to make informed decisions, and it was defined by Francisco & Swanson (2018, p. 2) as *"the extent to which information is readily available to both counterparties in an exchange and also to outside observers"*. Further, as mentioned transparency and traceability are the two components that enable supply chain visibility. In a study conducted by Hofman (2020) it was argued that insight into data sources and whereabouts of goods is a measure towards visibility in the industry. BCT can take part in this process, however, it cannot support full visibility in supply chains alone. The technology can accompany and support other technologies such as BIM, IoT devices, RFID technology or other tracking devices and sensors (Francisco & Swanson, 2018), which can track and trace items, contracts, deliveries etc. BCT can therefore create immutable records that provide transparency to the users in the network.

Chang & Chen (2020) argues that as a distributed ledger technology, blockchain may help increase traceability and increase supply chain visibility due to the consensus mechanisms and its shared ledger. As discussed previously, the technology can provide the supply chain with the ability to turn assets into digital tokens (Francisco & Swanson, 2018; Li et al., 2019), which is a crucial milestone for traceability in the industry and for the supply chain to accomplish end-to-end visibility. In addition, supply chain traceability could leverage transparency through open data to provide information such as material origins, manufacturing process and environmental impact, which allows for real time traceability (Kouhizadeh et al., 2019). This is due to how every single node in the network works in unison to maintain and validate the transactions that occur in the shared ledger.

Further, Khan, Sarwat, Godil, Amin & Shujaat (2021) stated that supply chain practices are exposed to lack of transparency, and found that inclusion of BCT would be beneficial for green supply chain practices. By adopting the technology, the authors stated that one could ensure a transparent process of transactions which could help improve efficiency and reduce costs by regenerating resources. Such actions could result in long-run returns and increased sustainability practices.

3.6.2.2 Decentralization

Traditional databases and systems are often centralized, making transactions inherently trusted through a central governing body which can guarantee the validity of a transaction for a fee. However, the core of BCT is the decentralization of the centralized database control, which was considered as *“a revolutionary new computing paradigm”* by Hofmann, Wurster, Ron & Bohmecke-Schwafert (2017, p. 2). Hofmann et al. (2017) describes it as a structure that allows for a different approach and new levels of coordination and collaboration. The technology therefore exhibits a decentralized structure, where *“each transaction is verified by* *the participants via means of predefined validation and consensus mechanisms without affirmation or authentication by any central authority"* (Puthal et al., 2018, p. 19). Benefits therefore consist of cost reduction and it eliminates the risk of information loss as there is not just a single source, because the ledger is distributed and synchronised all over the network. Further, as the BCT is its own platform, laws and use regulations can be programmed directly into the BCT itself (Hofmann et al., 2017; Puthal et al., 2018).

3.6.2.3 Authenticity of Data

Trust is a key element of the technology that blockchain provides, however, it does not originate between the involved participants of the network, but through the integrity of the information which is contained and embedded in the BCT (Francisco & Swanson, 2018). The distributed nature of blockchain and the integrity provided by the technology enables participants who have no reason to trust one another, to interact with confidence due to the information they receive through the technology. Hofmann et al. (2017, p. 2) described the decentralization of trust as *"as shifting the 'trust boundary' from protecting a whole system against the outside by controlling access and centrally ensuring data validity, down to the individual participants in a blockchain network"*. This change in nature, where participants no longer need to trust one another, nor a third party, could become a stage for dynamic networks for people to share resources in a P2P network. In such an environment, records are time-stamped and secure and data manipulation attempts are detectable. These are the mechanisms that provide trust and reliability for the supply chain (Kouhizadeh & Sarkis, 2019). Further, Bai & Sarkis (2020) stated that in a trustless environment, supply chain costs could be lowered as one could remove middlemen auditors. The technology provides trust to the parties through immutable data records and through its distributed system and was said to have the potential for decreasing waste spoilage and defects through supply chains (Bai & Sarkis, 2020).

In modern construction supply chains, many companies store information in data silos. These systems, such as BIM are great assets to a specific firm, but are not transparent to the rest of the supply chain. According to Turk and Klinc (2017), the BCT has a role in the industry due to how the technology manages information on *who did what and when*, and therefore provides a sturdy basis for potential legal arguments that might occur in the supply chain. According to Tian (2017), the data silo gathering of information will eventually change from storing data locally, to storing data in blockchain networks. These networks will gather, and store, all the information of the products in a system all parties of the supply chain can take part of. Additionally, Tezel, Papadonikolaki, Yitmen & Hilletofth (2020) stated that with utilization of smart contracts to support procurement and supply chain activities due to *"automated payments, provenance tracking, contract administration, disintermediation, ownership and control of data"* (Tezel et al. 2020, p. 556) redefining trust.

Since the records are stored with all of the participants in the network, the transactions that are stored using BCT are immutable. This is also supported, as Zheng et al. (2017) argued, as the blockchain is distributed it can avoid a single point of failure. Further, it is near impossible to tamper with the registered transactions on the chain in a public blockchain as, *"once validated and added to the blockchain, the transactions can neither be deleted nor modified, which makes the blockchain immutable and irreversible"* (Puthal et al., 2018). It was also argued by Helo & Hao (2019) that any tampering with a transaction record would be notified by several computers in the network. Another security feature was brought to light by Puthal et al. (2018) who discussed that in order for hackers to alter the records, they would need to possess and control at least 51 percent of the nodes in the network.

3.6.3 Permissioned and Permissionless Blockchains

There are mainly two types of blockchains; permissioned and permissionless. These are often referred to as private and public blockchains due to the nature of how one can access them. The main distinction among these types of blockchain is how one shares the ledger and who's allowed to participate (Viriyasitavat & Hoonsopon, 2019). Examples of the different types of blockchains can be seen in *table 3.*

			Read	Write	Commit	Example
Blockchain types	Permissionless	Public Permissionless	Open to anyone	Anyone	Anyone	Bitcoin, Ethereum
		Public Permissioned	Open to anyone	Authorised participants	All or a subset of authorised participants	Sovrin
	Permissioned	Consortium	Restricted to an authorised set of participants	Authorised participants	All or subset of authorised participants	Hyperledger,Corda and multiple banks operating on a shared ledger
		Private permissioned *('enterprise')*	Fully private or restricted to a limited set of authorised nodes	Network operator only	Network operator only	Internal bank ledger shared between parent company and subsidiaries

Table 3 - Difference between permissioned and permissionless blockchain based on Hamma-Adama, Salman & Kouider, (2020)

To put the types into perspective, Nanayakkara, Perera & Senaratne (2019) argued that common applications with low confidential data would be suitable for the public blockchain, that the utilization of private blockchain would work great with enterprise-level secure applications and that consortium blockchain are best suited for group enterprise-level applications of common interest. Private and consortium blockchains could therefore suit the construction industry and construction supply chains quite well.

In a private blockchain, the ledger is only accessible and validated by a set group of nodes (Zheng et al., 2017; Mohan, 2019; Viriyasitavat & Hoonsopon, 2019). The system *"requires initiation or validation to nodes that want to be part of the system. Authorized nodes are responsible for maintaining consensus"* (Viriyasitavat & Hoonsopon, 2019, p. 5). With private blockchain, there will therefore be an owner or owners which both have control over who has access to the blockchain and which nodes that are to be authorized. It should be noted that in such a system as a permissioned blockchain, the technology could be tampered with. However, Viriyasitavat & Hoonsopon (2019, p. 5) argues that *"even though the system is not fully opened, the benefits of decentralization can be partially gained. For example, the system has some degree of false tolerance in the event of some nodes acting maliciously."* This means that participants are known, which results in both a reduction of risk from someone tampering with the technology, and the need of the energy inefficient and expensive *"proof-of-work"* consensus algorithm. Further, the performance and scalability of the system is superior to the slower public blockchains (Mohan, 2019). On the other hand, a public blockchain is accessible for anyone who wants to join, as long as they have the data equipment to take part in the network (Mohan, 2019). The consortium blockchain functions as a hybrid between the former two as it is a *"partly private blockchain solution without a single owner"* (Nanayakkara et al. 2019, p. 3). This combination is partially centralized, has a high efficiency, and can have a selected set of nodes that determine consensus.

It is nonetheless crucial to distinguish the two types of blockchain as the differences between the two types of blockchain have a different set of attributes. Zheng et al. (2017) divided the differences into a table consisting of six determining factors.

1. *Consensus determination* - The private blockchain has one organization which governs the blockchain, while the consensus in a public blockchain is determined by all miners in the network.
2. *Read permission* - In a private blockchain, read permission could be public or restricted, depending on the use-case. In a public blockchain, the transactions are open to the public, and anyone can join the network.
3. *Immutability* - A decentralized, public blockchain, is regarded as nearly impossible to tamper with, however, in a centralized, private blockchain, transactions could be tampered with due to the consensus determination of the central entity or entities.
4. *Efficiency* - The public blockchain is considered to have a low efficiency due to all miners having to come to a consensus for all transactions, while a private blockchain is regarded to have a high efficiency due to fewer validators.
5. *Centralized* - The two types of blockchain differ as a public blockchain is completely decentralized, while a private blockchain is centralized or centrally controlled by a group of actors.
6. *Consensus process* - The access to join the consensus process as a node in a public blockchain is open to all, while in a private blockchain, access to the become a node and take part in the consensus process is permissioned.

Choosing between the two types of blockchain is therefore a crucial aspect of implementation as the deciding factor can vary between projects in regard to what is deemed necessary and what types of activities that are to operate on the blockchain.

3.6.4 Challenges with Blockchain

Within the construction industry of today, there are several challenges to overcome in order to reach a state where BCT can actively be utilized and in order to improve the effectiveness of the supply chain visibility (Behnke & Janssen, 2020; Tezel et al. 2020). The technology is still in its early phases, and the findings from Behnke & Janssen (2020) suggest that the reason for why BCT is still at a pilot-level is because a well-organized and standardized supply chain between all involved parties are needed before it is possible to utilize BCT. Due to this, there are still few use-cases and companies in the logistics and supply chain management sector who have implemented the technology. In his study, Tezel et al. (2020) identified the following challenges with BCT for the industry:

> *"Authentication of data input in the immutable blockchain structure, legal gaps, (...), human errors in coding of smart contracts, (...), significant energy consumption requirements by the nodes, exchange rate volatility in the cryptocurrencies, lack of organizational readiness, resistance to change, and insufficient skilled human resources for blockchain"* (Tezel et al., 2020, p. 550).

These challenges are severe for the technology to overcome in order to be evaluated as a viable option for the construction industry today. Currently, the construction supply chain is regarded as fragmented and there is a lack of reliable data. In a research conducted by Demestichas & Daskalakis (2020) it was argued that the establishing of trust and sharing of data between competitors was a major challenge for digitalization as a whole. This is due to the notion that companies are averse to risk regarding property rights and privacy, which corresponds with Tezel et al. (2020) second challenge of legality regarding ownership of decentralized data.

Another challenge that has been proposed earlier in this paper is the significant energy consumption requirements by the nodes in the network. This challenge has been proposed by researchers due to the tremendous amount of transactions needed to process the back-and-forth communication that consensus algorithms utilize. Niranjanamurthy et al. (2018) discussed that these transactions far outnumber those needed by a traditional database, which in turn can lead to high levels of energy consumption and costs. Contradictory, the technology has been introduced as a technology that leverages sustainability practices, yet, with a practice of operation that requires an intensive energy output, which in itself can cause environmental burdens (Kouhizadeh et al., 2019).

Moreover, BCT suffers from challenges regarding its maturity as the technology first emerged 13 years ago, in 2008. Therefore, the knowledge regarding the possibilities and limitations with this technology is still limited among researchers and practitioners, for example the construction industry. In a study conducted by Kouhizadeh et al. (2019) it was found that blockchain based systems suffer from its infrastructure. For instance, the technology can still experience failure with interoperability, technological security and stability. Further, Mastos et al. (2021) recognised that there is a limited connection between theory and practice when it comes to 4.0 applications such as blockchain. As studies focus on theoretical and conceptual frameworks, the real-world applications are not validated by the industry. Due to the industry's lack of blockchain knowledge and the technology's immaturity, researchers argue that *"the barriers to adoption, forces of resistance, would be a new relatively untested technology that may be quite expensive and risky"* (Kouhizadeh et al., 2019, p.12). Additionally, Niranjanamurthy et al. (2018) also argued that there might be a barrier with cultural adoption of the technology, as it represents expensive start-up costs in the direction of a decentralized network, which requires all users to partake to function properly.

Lastly, Behnke and Janssen (2020) found that a significant number of the conditions for implementing BCT are related to regulatory requirements and organizational changes, among others, in order to support the possible benefits of improved traceability and transparency from BCT (Behnke & Janssen, 2020). One of the important findings was that BCT requires an architecture which is suitable for more than one supply chain process. This is because suppliers do not want to be approached with different BCT architectures from different customers. It is therefore important to address questions such as *"what type of data is shared and who has access to which data"*. Without having a standardised way of retrieving, organizing and storing the data, the level of automation and visibility will be lost (Behnke & Janssen, 2020). Having a variety of individual BCT architects would lead to fragmentation and complexity, and as the construction industry is already characterized by this (Briscoe & Dainty, 2005) it is important to organize the supply chains within the construction industry and establish a standardized BCT platform before implementing the technology (Behnke & Janssen, 2020).

3.7 Summary of Theoretical Background and Framework

In the theoretical background we have presented previous literature and research which are relevant for our research topic; *blockchain enabling circular construction supply chains through increased supply chain visibility.* As there are limited previous studies looking into this topic or combining the two phenomena BCT and CE, several research areas have been presented in order to cover all aspects of this topic. The theoretical background presented for this research will therefore be used as the foundation for the development of a theoretical framework. This framework will then guide the rest of this research in terms of findings and discussion.

In summary, there has been an increasing focus on making supply chains more environmentally friendly by moving away from the traditional *extract-produce-use-dump* material flows (Meadows et al., 2004; Korhonen, et al., 2018a). CE has therefore gained increased attention as a regenerative system where products are utilized at their highest value (EMF, 2014; Nasir et al., 2017; Geissdoerfer et al., 2017; Farooque et al., 2019). Literature reveals that the construction industry demands about 40-50 percent of the new yearly extracted resources, and contributes to approximately 40 percent of the produced waste (Digitalt veikart, 2017; Material Economics, 2020; SSB, 2021). The industry contributes to a considerable amount of CO2 emissions and could therefore benefit from implementing circular business model (Nasir et al., 2017).

Looking at the construction supply chain, it is often described as fragmented with complex structures due to the number of actors and operations (Cox & Ireland, 2002; Briscoe & Dainty, 2005; Chen et al., 2020). As CE is a relatively new concept there are still multiple challenges to overcome (Korhonen, et al., 2018; Farooque et al., 2019). One of the most important challenges were connected to supply chain visibility as a premise for transitioning to CE business models (Mittal & Sangwan, 2014; Hart et al., 2019; Mastos et al., 2021). Furthermore, although having an effective information flow is viewed by most as a condition for obtaining an effective supply chain (Christopher, 2016), Briscoe and Dainty (2005) found that it was problematic to achieve in practise due to the supply chain characteristics.

The literature also revealed that the construction industry has traditionally low levels of digitalization compared to other industries (Whyte, 2019; Digitalt veikart 2.0, 2020). However, several researchers highlight the emergence of new information technologies (Whyte, 2019) and the importance of improved information technologies as an enabler for CE (Kouhizadeh et al., 2019; Demestichas & Daskalakis, 2020; Mastos et al., 2021). This is due to the fact that technologies could help improve traceability and transparency, and thereby material information for the circular system (Swift et al., 2017; Demestichas & Daskalakis, 2020).

Blockchain has been pointed out as a possible technology which could contribute to enable a transition to CE models (Kouhizadeh et al., 2019; Demestichas & Daskalakis, 2020; Mastos et al., 2021). Previous research describes the technology could provide the supply chain with real-time traceability (Kouhizadeh et al., 2019), due to the ability to transform physical assets into digital tokens (Li et al., 2019; Francisco & Swanson, 2018), which could be traced through the supply chain. Further, BCT could create smart contracts capable of atomization (Tezel et al., 2020), and thereby create incentives for CE practices (Kouhizadeh et al., 2019; Khan et al., 2021). However, as the technology is relatively new there are still challenges to overcome (Kouhizadeh et al., 2019). Some of these challenges are; limited connection between theory and practice (Mastos et al., 2021), struggles with interoperability issues (Kouhizadeh et al., 2019), need for requirements and common standards (Behnke & Janssen, 2020), and ownership of decentralized data (Tezel et al., 2020).

As mentioned, both BCT and CE are relatively new concepts and therefore there is still limited research on how BCT could facilitate a transition to CE models. However, we believe that the theoretical background reveals some of the most important aspects to consider, such as improved supply chain visibility and digitalization. In order to answer how BCT could enable CCSC, we have chosen to focus on the drives, conditions and barriers of this topic as especially benefits and challenges have been re-occurring throughout the literature review. Therefore, a conceptual framework was created based on the theoretical background.

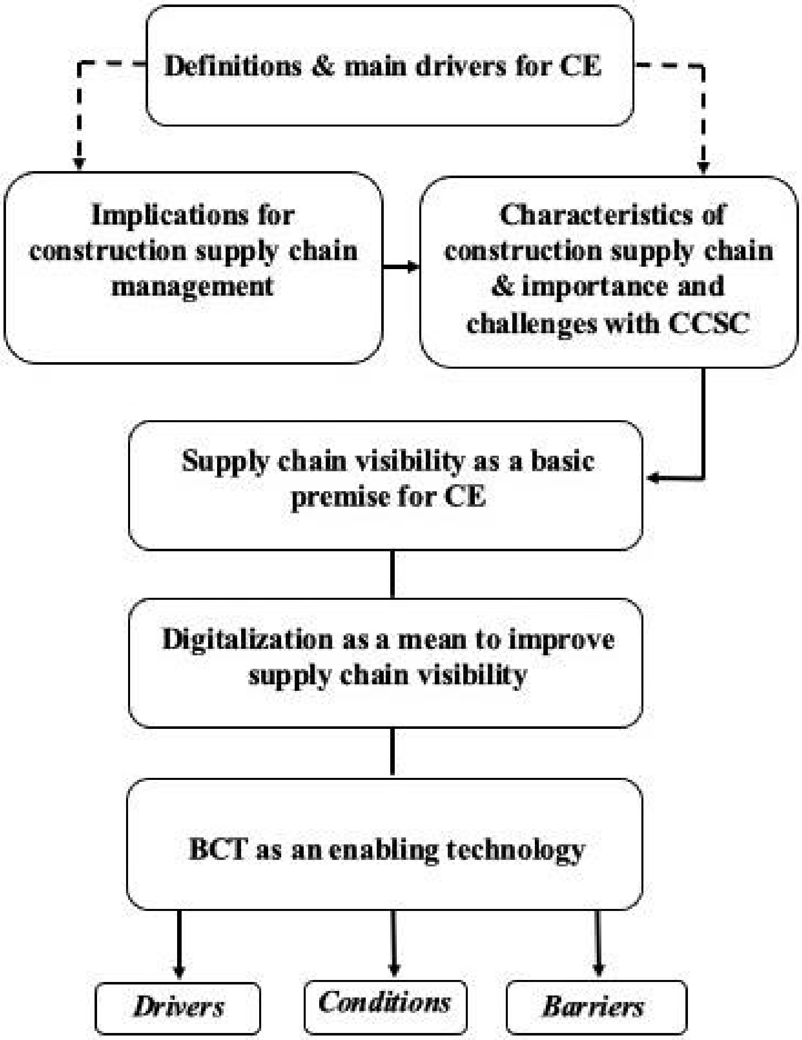

Figure 6 - Conceptual framework for conducting research

The theoretical framework highlights several aspects which were considered to be important to study in order to answer the research question; *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?* In order to answer this research question, we developed two sub-questions regarding the industry situation in terms of CE practices, supply chain visibility and digitalization, and the protentional drivers, conditions and barriers for BCT to aid circular practices.

We have reviewed previous research which provides a solid background for studying this topic, and the framework based on this research will guide research findings and discussion. First, literature on CE as a phenomenon was presented and why it is important in terms of becoming more environmentally friendly. Second, we presented CSCM as a means to bridge supply chain management and CE practises, CE practises are closely linked to the supply chain. Third, we introduced the CE business model CCSC - where the goal is to incorporate CSCM practices in the construction supply chain. In this chapter, the construction supply chain characteristics were also described, as well as the need and barriers for transitioning into CCSC. Fourth, we introduced the supply chain visibility concept as this was highlighted as one of the main barriers with transitioning into CE business models. Here, transparency and traceability were also presented, as well as a more in-depth description of why supply chain visibility is challenging in construction supply chains. Fifth, digitization was introduced as a means for how to improve the supply chain visibility, however, there were also challenges with this as the construction industry is known for having historically low levels of digitalization compared to other industries. Sixth, BCT was introduced as a technology which could enable CE practices in the construction industry due to the characteristics of the technology. However, there were also challenges, namely; ownership of data, resource consumption, maturity and standardized structure.

Throughout the theoretical background, we have gone through why the different aspects might improve practices and aid the transition to CCSC, however, there have also been multiple challenges to overcome with regards to CE, visibility, digitalization and BCT. This is the reason for why we want to look into the three areas; drivers, conditions and barriers in the framework for BCT as an enabler for CCSC. Drivers refers to what previous research and our findings shows to be beneficial with using BCT to enable CCSC. In previous research, conditions and barriers are often referred to as challenges, however, we believe it is beneficial to divide the two. This is due to the fact that conditions refer to prerequisites or circumstances that needs to be in place before companies would want to invest in the technology. Barriers, on the other hand, refers to reasons for why companies to unable to overcome negative conditions or gain from positive drivers.

4.0 EMPIRICAL FINDINGS

In the following chapter, we will present the findings from our research. Our thesis aims to look at how increased visibility through utilizing BCT could enable a transition to CCSC in the construction industry. As this is an experimental and proactive research focused on how something could potentially be improved for the future, we have focused on finding the views on the drivers, conditions and barriers to adapting BCT to aid transition to CCSC in the construction industry. We have chosen a qualitative study with expert interviews in order to enhance the understanding of the studied phenomena through semi-structured interviews with key actors in the industry. This will enable us to enlighten the current industry situation, and whether introducing BCT could enable the needed visibility for materials to circulate in the supply chain. The first section will provide an empirical setting of the current situation in the construction industry, focusing on the supply chain visibility. The second section will provide the current views on drivers, conditions and barriers to utilising BCT to become a part of the CE.

As we have chosen a thematic data analysis inspired by the literature research and theoretical framework from the previous chapter to structure our conducted interviews, we will present the findings connected to different main themes and sub-themes together with explanations supporting quotes. The identification code C stands for general construction actors, D is for digitalization in construction, B is for blockchain experts and E is for CE in construction. In the case of interviewees with codes C, D and E, quotes are translated from Norwegian to English which means that the phrasing could be somewhat different.

4.1 Current Industry Situation

Both BCT and CE are relatively new phenomena and therefore it is important to look at how the industry regards their own visibility, digital and environmental status. As the study is looking at BCT as the means for achieving improved supply chain visibility in the construction industry and the transition to CE as the outcome, the findings will focus on providing an in-depth understanding of the industry situation with regards to digitalization and visibility. Firstly, views on CE will be provided, and secondly, we will go through views on digitalization and the supply chain visibility.

4.1.1 Views Regarding Circular Economy

Our findings shows that the Norwegian construction industry is moving in the right direction in terms of circularity as there is emphasis on using environmentally friendly products such as timber and steel (Circular Norway, 2020). In addition, Norway is a pioneer with regards to energy-efficient buildings (Circular Norway, 2020). The importance of starting to consider improved CE strategies was also portrayed in the webinar held by buildingSMART on April 28th, 2021, where key actors from the industry and government representatives had gathered to discuss how they could prepare for the new circular regulations. However, the report from Circular Norway (2020) shows that the construction industry has the highest consummation of raw materials, accounting for 58,3 billion tons. Moreover, the report states that the industry accounts for 20 percent of all waste, and that only 28,8 percent of the produced waste is recovered. A considerable amount of valuable demolition and waste which could be reused and recycled is therefore not entering the circulatory system. This is also due to the fact that a lot of the materials are locked into stock in buildings. Combining both construction and operation of buildings, the industry accounts for 15 percent of the greenhouse gas emissions in Norway (Circular Norway, 2020). Thus, the report states that it is imperative that the construction industry reduce material consumption by entering a circular system.

When asking about how the current situation is with regards to CE practices in the construction industry, most of the interviewees aligned with findings from the buildingSMART webinar and the Circular Norway report. They commonly held that the industry is aware that CE is important and that environmentally friendly practices are necessary to get in place. However, the interviewees tended to focus more on the perceived problems with transitioning into CE than to talk about how the industry standards were today with regards to environmental standards. Even though interviewees expressed concern with environmentally friendly practices, the interviews revealed that such practises are down-prioritised for other considerations, such as cost or deadlines, if the project managers have to make priorities. This was explained by one of the interviewees arguing that; *"Circular economy and green practices are very hot in general, however it often comes down to something being delivered within a deadline, and then there are other considerations to take into account"* - C3. As we have set out to investigate whether improved supply chain visibility could enable CCSC, we asked the interviewees specifically what they believed to be challenging with regards to implementing CE practises.

4.1.1.1 Regulations

Most of the interviewees agreed that regulations are necessary in order to become more environmentally friendly and truly incorporate CE practices. As stated clearly by one interviewee; *"I think this is a political aspect. I believe the circular economy is much more expensive (...) There must be political demands and guidelines for the construction industry to partake in it"* - D2.2. When asking what political guidelines, the interviewees saw as probable, it was stated by the same interviewee that; *"I think that requirements are coming. Regulations for sharing product information must be established"*- D2.2. The need for regulations with regards to CE was also shown by another interviewee stating; *"Regulations! There will be regulations for establishing common parameters for reuse"* - E1. Another interesting finding was connected to the fact that the industry is very capital intensive, and that this is problematic because buying new materials is far too lucrative due to the low prices. This is shown in the following argument; *"This is a capital strong industry, and it is demanding. The materials today are far too cheap, and it is lucrative to buy new - This is why you need the regulations"* - D4.

4.1.1.2 Incentives and Business Models

Another barrier that was pointed out by interviewees was the lack of incentives and established business models with CE practices. *"You have to have some incentives. (...) How can you motivate change? With a bit of a carrot and stick mindset"* - C1. Some of the incentives which were discussed involved getting tax releases if companies could document the usage of circulated materials, or "green loans" that provide better interest if the project complies with CE values. However, most incentives were connected to price and favourable business models. This was best stated by one interviewee bluntly saying; *"Everybody wants to make money. This is the number one rule. Everything is money"* - D2.1.

The interviewees argued that the business models of today are fully functioning, and that the most important factor for implementing new models is that the change is economically favourable. This is illustrated in the following statement; *"First and foremost, it's about the financial perspective. If it's not much more expensive, it is easier to reach. If it is a little more expensive, we can still reach it. It just cannot be much more expensive"* - D1. The common view among interviewees was that they would not consider implementing CE practices if it was shown to be more expensive. However, if it could be done with increasing costs by much it could be considered as it would be good for the company's reputation. Further elaborating on this, one participant answered; *"I believe that economic incentives are the key factor. It's what gets people moving in one direction"* - C3. The argument continues by another expert; *"I do not believe that anyone will reuse materials in their fancy new building if it is not financially motivated. It's that cynical and that simple"* - D2.1. In addition, interviewees argued that sustainable materials usually are more expensive than the materials used today, and that this could make companies less likely to invest in these types of materials. This was illustrated in the following statement; *"When it comes to CE, used or recycled materials must become cheaper than buying new ones"* - C3.

4.1.1.3 The Need for Visibility and Digitalization

Even though interviewees argued that getting regulations and incentives in place was important, improving the information flow with regards to materials and their environmental status was argued to be essential in order to transition to CE business models such as CCSC. One of the interviewees also argued that improving material information was the most important part for enabling the transition. This was clearly illustrated in the following argument; *"The information flow is essential for us to avoid wasting valuable resources. That is the most precarious and important thing here. In addition to avoiding losing information along the way"* - E1. This was further elaborated on as interviewees argued that in order to have a circular usage of materials it is important with good material information and visibility in the supply chain and through the product life cycle. This was also confirmed in our findings from viewing the Circular Norway (2020) rapport. In the rapport it was stated that being able to track used resources, and strengthen the connections between the supply chain actors through digital platforms and technologies was one of the prerequisites for bridging the circularity gap. However, as of now the industry is somewhat unaware of the origin of their products, as explained by the following answer; *"We know that multiple of the products we use in our constructions we don't know the origin of or their social and environmental footprint"* - D4. At the buildingSMART webinar, several speakers also discussed the problems connected to finding the right information and documentation for materials, which are needed in order to reuse or recycle these materials in a circular system. This argument supports the theory connected to problems with transitioning to CCSC for the construction industry, as sufficient supply chain visibility is needed.

When asked about the current situation regarding CE in the construction industry, several interviewees stated that it is crucial that the industry becomes more digitized in order to improve the information flows with regards to used materials. Becoming more digitized was also pointed out as a condition for partaking in a CE business model, because improved digitalization could facilitate improved supply chain visibility. This view is illustrated by the following statement; *"We are completely dependent on digitalization in order to succeed with a circular economy"* - D4. The attended webinar held by buildingSMART discussed how technologies such as BIM, RFID, artificial intelligence (AI), and 3D etc. could be used when establishing strategies for becoming more circular, and the importance of getting a more technological and digitized construction industry was highlighted by several speakers.

4.1.2 Views Regarding Supply Chain Visibility

In the theoretical background of this thesis, the term supply chain visibility was introduced, as it is a key point within the scope of the research question. As a means to explore and understand the visibility in the industry today, the interviewees were asked several questions with regards to this topic. As mentioned, improving transparency and traceability is of great importance in order to improve the overall supply chain visibility. Therefore, the following section will focus on findings regarding supply chain transparency and traceability.

4.1.2.1 Transparency in the Construction Industry

There are several views of supply chain transparency within the construction industry as it is today. The majority of the interviewees held a common view with regards to the supply chain transparency in the industry. They stated that it is very limited, and too low compared to other industries. One of the reasons the interviewees often came back to when explaining why the industry suffered from low transparency was that the industry structure is characterised by one of the projects and a very fragmented structure. As described previously in the theoretical background, the construction supply chains often consist of numerous stand-alone entities instead of working together as a network. This view is illustrated by the following statements; *"The construction industry is still somewhat fragmented, depending on where it is. There are many silos"* - C1. *"It is very disconnected and it is limited"* - D2.1. The participants' answers emphasize that the industry could benefit from more transparency and openness in regard to sharing of information. The problem regarding the industry structure and transparency was best described by this following argument;

> *"Terrible. It's like, the worst. We have no understanding of the supply chain. Because we organize on a project-by-project basis, we create new supply chains for every project. This means that we don't invest in systematic processes to create continuity in the supply chain. Everything is on an ad-hoc basis. So, the supply chain has adapted in kind and we have very low visibility in particular with sustainability. (...) It is a big problem"* - B2.

Furthermore, another topic that derived from the interviews was that information sharing between the contractor and the client is limited to the set specifications of the contract that was negotiated. This means that if the client does not specify what sort of detailed information it wants from the contractor it will not receive any. This was perfectly summed up by one interviewee claiming that;

> *"The documentation is only provided to the extent that something is requested. If there is a client who is not aware of this, they will get*

documentation accordingly. Documentation is only considered as a hassle in the value chain. It is not anything they make money on" - C4.

Even though most interview participants agreed that improving supply chain transparency in the construction industry is important, it was pointed out that the industry actors have limited incentives to share information. Some of the reasons for this were explained to be due to the current payment structure, like this view emphasizes; *"The data exists, but there are no incentives to share due to the way the payment structure is structured today"* - D1. In addition, there were some who questioned whether increased transparency could be harmful. These actors were mainly private actors, and argued that an increase of transparency could increase the risk of sensitive information being shared, such as pricing strategies, labour costs and contractual details. This is illustrated in the following answers; *"There are some parts of the supply chain which neglect transparency and sharing data. Status quo is that we have insufficient transparency compared to other industries"* - D1.

"We think you could share a lot more. We're on the same wavelength as you; it is not prices and timekeeping, but the product parts. This should be open access in the parts of the project that are open. In the parts where one has trade secrets you should not have to share" - D2.1.

To summarize the participants' view of the industry's supply chain transparency, we can use this quote from one of the industry's largest actors; *"It is not good at all. This is because we do not have a consistent digital value chain today"* - D4.

When asked about how the supply chain visibility could be improved in the industry, several participants answered that the most important factor was to digitalize the industry. We will come back to the link between a more digitized industry and CE practices later in the findings. To become more open and transparent, the industry must first embrace more digital solutions, which in turn can enable data to be more shareable. Two of the interviewees discussed the importance of digital transparency. They mentioned how a digital and transparent system would have reduced the problems caused by building with asbestos as one would have known where renovations were needed as soon as the materials properties were known. However, most of the participants were quick to mention that in order to become more transparent, there would have to be some regulations set by either the client or the government as the current standard was well functioning and that changes would be considered to be costly. The following argument supports this; *"Demands. I believe that demands would have driven it forward in the first place"* - E1.

4.1.2.2 Traceability in the Construction Industry

During the interviews the participants were asked several questions related to the traceability in order to further explore the construction industry's supply chain visibility. Even though some declared that the Norwegian construction sector is miles ahead of other European countries, there was, as mentioned before, a consensus around the notion that the industry could benefit from more digitalization. One of the interviewees accurately described how easily tracing of materials could be lost through this statement.

> *"The challenge is that they are not very digitally mature, and when someone «buys something with cash at a department store and brings it to a construction site» there is no digital trace for the purchase. Then you have lost all connections to the models etc. This is a challenge for the industry today"* - D2.2.

Another view supported by all of the interviewees was that BIM is a key element to the industry and that the technology serves many functions in regards to planning, documenting and collision controls. However, two of the participants argued that although there have been great advances within the Building and Modelling aspects of the technology, the Information has been neglected and is poorly structured. The most direct statement was by one of the industry experts who reported that; *"What one has managed to achieve with BIM-ifying is that one can improve your planning (...) However, one still does not connect the I, or, the product information"* - C2. In turn, this makes it harder to trace materials through the supply chain. This point will be further discussed in regards to the standardization of product information as seen in paragraph *4.1.3.1 - The Importance of Establishing Common Standards*.

Further, another actor reported that there is virtually no focus towards documentation in projects as they have reached completion nor in the final phase of the construction. The actor states that the models used in construction seldom are *"as built"* but that the models represent the planned project, with the corresponding documentation and information. This means that changes that are made during the construction seldom are registered and updated on the original model, which renders the model outdated. Another participant argued that in order to be able to reuse or recycle materials when the building is demolished, one would need the material information of the core components. However, one interviewee described the knowledge of what materials that were used in a building as; *"We have no awareness of this, as information only flows between the contractor and the manufacturer"* - D4.

Some of the interviewee's report that most of the documentation is secured by contractors as there is a good flow of information between the manufacturers and the suppliers. However, it was argued by one interviewee that; *"there is often a breach of information when the contractor buys and resells the product in a project"* - C1. This view was one that most interviewees agreed upon, making material traceability particularly challenging. This was especially if the building were to be sold during its lifetime.

> *"The contractors that constructed the building have great control over what the building consists of in terms of fire classification, materials, products etc. There are quite a few details they have an overview of. Then, it slips when they hand it over to the client. It is a huge job and considered a hassle to collect* FDV - *documentation"* - C3.

One last point which was made with regards to the supply chain traceability in the industry, was that interviewees agreed that much of product information in the industry today is under digitalized, and in many instances relatively analogue. This is illustrated in the following two statements; *"When it comes to product information today, it is not very digital. It is extremely analogue in many areas. There are lots of PDF files with little to none machine readability, and there is generally little focus on it"* - D4. *"Best case scenario the information is available on PDF-files, and probably, in most cases, there is nothing"* - C2. Further, the interviewees argued that the usage of analogue tools would reduce the ability of the companies to trace product information. Thereby, the supply chain visibility is obstructed.

4.1.3 Views Regarding the Digital Status

As the study is looking at whether BCT could be applied to enable CCSC, it is interesting to investigate how the current technological standards in the industry are. Traditionally, the construction industry is perceived as very traditional, with low levels of digitalization as mentioned in the previous literature review chapter. This was also stated by almost all interviewees; *"Today, the industry is perceived as very under digitalized"* - E1. Among the interview participants there was also a strong consensus about the industry being immature with regards to digitalization. One of the interviewees argued that this could be connected to the fact that the industry is very traditional in both their line of work and how they work; *"The industry is known for being immature with regards to digitalization (...) the challenge is that the industry is very traditional in how they work"* - C3. This argument was also supported by the fact that there is still a considerable amount of PDF documents being exchanged manually. Exchanging information is pointed out as one of the important areas of improvements with regards to the industry becoming more digitizing. Exchanging information and documents by mail or print is likely to contribute to substantially increased time and resources connected to collecting and finding the right information at the right time. The following two statements illustrate this view; *"It is still very premature as we use an extensive amount of time and resources on finding and collecting PDF's"* - C2. *"(...) we are working with making information digitally available, preferably not in PDF formats"* - C4.

However, interviewees agree upon the fact that the construction industry has improved vastly during the last couple of years with regards to digital solutions and new technologies to improve work efficiency. Saying that the construction industry is under-digitized is therefore somewhat misleading because of the number of new technologies that are being used in different construction projects and companies. *"It is a jungle of offers, services and software"* - E1. Interviewees agree that there are multiple different options to choose from within new technologies, but that the problem is that these are not digitalized or connecting well enough with each other. This argument was best explained through the following statement; *"We have everything; Industry Foundation Classes, or IFC, for BIM, GSM standards - we have the tech (...) but it is not digitized"* - D4.

4.1.3.1 The Importance of Establishing Common Standards

When asked about how the digital status was today in the industry, it became evident that finding new and improved technologies which could contribute to increasing the supply chain visibility is not a major problem. As mentioned in the previous section, the industry already has an extensive amount of newly developed technologies ready to use. However, the problem is that these technologies are not digitized in a way so that information flow would be improved between different levels, projects and actors in the industry. When asked about how this could be achieved there was consensus among the interviewees that the industry needs to develop common standards for how to collect and store information retrieved from different technologies in a common platform. *"The challenge today is agreeing upon and standardizing the rules in order to follow them, and then digitizing them"* - D4. This was further elaborated on by another interviewee stating that; *"A considerable amount of software companies are only making their own proprietary solutions - so they don't talk with other ecosystems. Then we fall short. We need to have some common components which enable us to communicate!"* - C1.

Another finding that was pointed out, is how important it is to have common standards with regards to structuring the data being collected and shared among parties about materials and products. This was best explained by one of the interviewees saying *"Shit in, shit out"* - C1. In addition, the interviewees pointed out that having common standards for structuring data would be very important if the industry was going to improve supply chain visibility and material information both in terms of future projects and to retrieve similar information about past projects. As one of the interviewees explained; *"This is a challenge because they receive a lot of documentation in different formats throughout the life cycle, in addition to challenges with reading and collecting past information"* - C2. Another interviewee elaborated on this argument, saying that; *"Those who have worked with this for a long time are concerned with standardizing and classifying, but also how* *this was done previously in order to find and sort data now"* - D1. This is supported by findings from the Circular Norway (2020) report, which states that even though the data on the used materials are robust, the data connected to the entire life-cycle usage is very limited and thereby making it challenging to follow material flows. Thus, the rapport highlights the importance of improving consistency in data connected to used materials if they are to be reused or recycled.

4.1.3.2 Data Structure and Product Information in the Construction Industry

Through the interviews it became clear that the construction industry has limited visibility due to a number of reasons. Firstly, the interviewees held a common standpoint with regards to the industry being very traditional, which has made information sharing with regards to products insufficient in construction projects and during the project lifetime. Even though there has been substantial focus on new technologies, the industry is still one of the least digitized, as illustrated by the following statement; *"When it comes to product information today, it is not very digital. It is extremely analogue in many areas. There are lots of PDF files with little to none machine readability, and there is generally little focus on it"* - D4. Another point which contributes to low levels of product information being exchanged is the fact that there are no systems in place which demand this exchange after the building is finished. The buyer has to ask otherwise, information traders are rare as they are perceived as costly and unnecessary. *"It is both good and bad. Some projects are very good, but in those instances, there is someone who demands it. (...) This is because all of it is an extra cost, and you do not do it if you do not have to"* - D3.

Moreover, interviewees have pointed out the importance of establishing common standards as the focus on digitalization increases. As of today, there is no common consensus about which standards or technologies should be used. *"The challenge revolves around standardization. (...) There is so much talk about maturation and the extent to which one is able to use digital tools at a basic level"* - C2. Interviewees argue that establishing one common standard could increase the product information being exchanged between parties because common standards could facilitate improved traceability. One blockchain expert also argued that improving the supply chain traceability could also enable us to understand how these could be recycled. This is illustrated in the following statement; *"The second is through traceability. Then we can see where the materials came from, understand their properties better so we can know how we should recycle them correctly"* - B1.

4.2 Blockchain and Circular Construction Supply Chains

In this part of the chapter, we will look into the industry actors and the blockchain experts' view on BCT and how it could contribute to enable the transition to CCSC. We will present the perceived benefits found for using BCT in the construction industry. After this, we will go through the results on what is viewed as the conditions for utilizing the technology, in addition to what the interviews show to be the perceived barriers. However, first we will introduce the industry actors and experts' general view on BCT, because the interviewees also have somewhat limited knowledge and understanding as the technology is still premature.

4.2.1 Construction Actors' View on BCT

BCT is a relatively new and complex technology. All participants have heard about the technology and most of the participants with code C and D have also tried to understand it or looked more into the technology. Only participants with code B have in-depth knowledge. A common statement among interviewees was that they had tried to understand the technology, but that they failed to see the area of contribution in the construction industry. *"(...) I read up on it and tried to understand, however, I didn't quite understand how it could be used"* - C1. The C and D actors also seemed generally more sceptical towards introducing the technology, and these participants questioned what this technology could contribute with, which existing technologies do not. *"What can blockchain technologies contribute with, that other technologies cannot?"* - D2.3. An interesting statement was therefore that one of the blockchain experts stated that he had started looking into blockchain three years ago, but only this year had he started to understand how the technology actually could be used. This is illustrated in the following answer; *"I've been working with blockchain for 3 years now, and only last year I started to see the decentralized way of working"* - B2.

As mentioned previously, the interviewees were concerned with establishing common standards for digitization in the industry. BCT was then pointed out as a technology that could be used as a common standard for storing material information in the industry, as BCT is dependent on standards for information in order to function properly. This was illustrated by the following statement; *"We need to have a common understanding of requirements, and a core competence of standards and formats needs to be in place in order to utilize blockchain to retrieve information"* - C1. Another interviewee further argued that using BCT as an open standard for the industry is the only reasonable usage of the technology in the following statement; *"(...) this is what we are talking about with open standards for communication of data and information. This is the only reasonable usage of blockchain outside of being a new technology - it could be an open standard"* - D2.1.

On the other hand, one participant also expressed concern about BCT being very time and resource consuming if introduced as a standard in the construction industry due to the nature of the industry structure as complex and fragmented, arguing;

> *"Blockchain demands an extreme amount of resources as all information from all nodes in the whole network is going in. This will be an enormous data structuring process and will demand process capacity from another world - as I interpret it. Especially as a regular construction supply chain is as complex and fragmented. Yes, we have looked into it, but I don't think that either the industry or the technology is ready"* - D4.

4.2.2 Drivers for Using Blockchain

During the interviews, the interviewees commonly held that BCT would be beneficial for the industry if implemented to support the right operations. Most interviewees also recognize that this is a technology that other industries are starting to utilize. As described in the theoretical background, the construction industry is characterized as being highly fragmented due to the extensive number of actors in a typical construction supply chain working together in temporary networks to complete projects for clients (Cox & Ireland, 2002; Briscoe & Dainty, 2005). As a result, one of the interviewees stated that *"This is a technology being developed for* *multiple other industries which will function very well in our industry too, so we should really just start using it"* - D1.

4.2.2.1 Improved Traceability and Transparency

The interviewees mentioned several aspects of BCT which they believed could be potential drivers for using the technology in the construction industry. However, most actors focused on the fact that BCT could improve the traceability and transparency of materials and products. By increasing the traceability and transparency, interviewees also argued that this would improve the information sharing and visibility in the supply chain. *"Traceability (...) If implemented right it will reduce the resistance for sharing information"* - D2.3. *"The benefit with blockchain is the transparency because you get improved visibility and openness"* - D4. One of the blockchain experts provided a more in-depth understanding of how BCT could provide end-to-end pipeline traceability of materials because the BCT would provide a complete history of all the different steps and processes the material has been through from extracting the raw material to being used in a construction to deconstruction. This was also argued in Circular Norway (2020) as tracking and optimizing of resource use through digital, online platforms can strengthen connections between supply chain actors. Circular Norway (2020) also provides a clear example of how BCT is currently used for ensuring both transparency and traceability along the value chain of container-deposits of plastic bottles. Utilizing the same principles, the industry could then increase the transparency in the construction supply chain because all actors connected through the building's lifetime could receive complete information. The following statement illustrates this argument:

> *"I will be very standard there, and say traceability and traceability. (...) We will first see the traceability through where exactly it came from, when it came and what are the entities/ actors that participated in the whole process from raw material to construction or to deconstruction. This also goes hand in hand with transparency because we know why, how and from where, so we can see if something happened along the way or if something shady that should have been taken care of is there" - B1.*

The blockchain experts also mentioned the benefits of using BCT based on material passports to increase the traceability. The interviewee argued that this was because material passports could potentially increase the horizontal information flow in otherwise vertical supply chains, which classifies the industry. Circular Norway (2020) also argues that the incorporation of digital technologies and material passports could effectively relay key material information about the materials sustainable design, past use and its future potential. This is because the information provided can be generated for both new and existing buildings through techniques such as 3D scanning. This is shown in the following argument:

> *"So, tracking physical things, we're seeing material passports, blockchain based material passports (...) I think that this is a perfect use-case for blockchain because blockchain can provide horizontal integration in a world of vertical set-ups. So, it can provide horizontal information. It can trace across these different silos all the way to the building"* - B2.

4.2.2.2 BCT Combined with Established Technologies

As it became apparent that there had been considerable focus on digitalization within the construction industry during recent years, it was interesting to hear actors' views on combining BCT with already established technologies. As BIM is one of the most promising technologies being used today, this was especially interesting with regards to the possibility of storing this model on a BC. Therefore, the interviewees were asked about the possibility of storing and distributing the whole digital twin to the involved parties in a construction supply chain. The received answers from the interviewees were aligned and pointed to that this would be very inefficient as the model would become too extensive and would contain necessary amounts of information. *"I don't think we should put BIM on blockchain either way, I think they are too big"* - B2. *"Storing BIM on a blockchain is like saying that you need the whole grocery store at your home because you need an orange"* - D1. As the aim is to increase visibility, this idea was therefore quickly set aside.

On the other hand, interviewees argued that connecting blockchain only to certain parts of the BIM could potentially be beneficial. This way it could be possible to have updated, transparent and secure information about the parts which are beneficial to reuse or recycle when the building is decomposed at the end of its lifetime.

> *"A way that I think this could work is that you could stick up layers in a BIM file so if you can particularize the layers that you want to transact through blockchain to other people, then you can take this layer from the blockchain, download it to a central model and that could actually work. (...) When you have BIM there are different setups. One is that you have a model and you have timestamps where the engineers (construction, architecture etc.) make their models and then they upload it at certain timestamps and then the model tries to bring them together. The other type is like google docs where it is automatically updated and uploaded at the time you do it. With blockchain it would probably work best with the first model where we have specific timestamps where we upload parts of the model, and no automatic uploading. This could drive around the problem. Then we have parts of the model and not the huge model itself. And then these levels are cryptographically stored in models and can be downloaded in certain timestamps and then uploaded to the central BIM"* - B1.

Moreover, during its lifetime, the building is likely to be sold and have multiple different owners, and therefore important information is often lost if it is not acquired to follow the sale. Interviewees pointed out that using blockchain together with a BIM could potentially ensure the needed continuity of the most essential parts. *"If a building is sold, which usually happens, we often lose continuity. This is where blockchain could become useful with regards to the data connected to the property also following in a sale"* - C3. One of the blockchain experts mentioned that there is a company specializing in making blockchain for BIM called BIMChian. Their vision is to achieve improved communication and data interconnection through leveraging decentralized technologies, and that this will ultimately increase the buildings lifecycle management in the construction industry (BIMChain, 2020).

Some interviewees still raised concern that the combination of blockchain being connected to certain parts of the BIM. They argue that this usage would be an un-optimal way to use the technology, as it would be very important to define the right components of the BIM which should be connected in order to still gain visibility. *"If you connect blockchain to everything, all materials and products which are used in a building connected to a program which is made to visualise, it's not gonna be an efficient usage of the technology"* - D1. One of the blockchain experts also discussed that it is important to focus on finding the incentives that work best for promoting environmentally friendly actions, and that using blockchain in smart contracts would be more beneficial for this usage, than improving visibility by connecting BIM and BC. This is supported by the following argument:

> *"The way that I would describe the power of blockchain for construction is that you have a baseline assumption that digital twins are the future. (...) How do we create the contracts, incentive structures that best fit this new environment? I think that blockchain fits this through smart contracts is the best way to do that"* - B2.

4.2.3 Benefits with BCT towards CCSC

4.2.3.1 Buildings as Material Banks

When asked about what the interviewees perceived as the benefits of using BCT to aid the transition to CCSC, multiple interviewees stated that it is becoming more popular to look at the buildings as material banks. *"It has now become popular to look at the building as a material bank"* - C1. In order to fulfil this view, interviewees also specified that it is important with good supply chain management, where it is possible to obtain correct information efficiently when needed about which materials are being used in the building, where these materials are being used and whether they still fulfil the requirements for using them in a circular system. *"The construction is a material bank, and then we need to know which materials are used"* - D3. The argument was best explained by on interviewee;

> *"What I perceive as most important to enable a circular economy is that we have good supply chain structures, where it is possible to trace everything. A digital supply chain. (...) With good supply chain management we will be able to track materials and products to the construction, in terms of transport, economy and environmental status. Then it is also possible to document which products exist in a particular building."* - D2.1

Furthermore, interviewees discussed that they believed that BCT could provide this information not only because it could provide improved visibility by enabling improved transparency and traceability of the used materials and products, but also because of the immutability and security of the technology. *"If we have used blockchain as the basis, then what is written there is true"* - D3. *"In a system where information about a product can be securely stored on the internet over the building's lifetime, we can be sure that this information is polite"* - C4.

4.2.3.2 Streamlining Processes to Reduce Time and Resource Waste

Another point which was enlightened through the interviews was the challenge with wastage in the construction supply chain connected to inefficient time management and resources. One of the interviewees pointed out that one of the problems with transitioning into CCSC is connected to the logistics of material management after deconstruction of a building and before the materials and products are reused in another building. The interviewee argued that BCT could potentially function as a platform for material information about the collected components to enable easier accessibility for other potential users. *"Logistics and storage time from deconstruction to reuse makes up for a considerable part of the challenges connected to CE. Blockchain will be able to function as a common platform for information"* - D4. One of the blockchain experts also highlighted the fact that blockchain could potentially streamline processes within the supply chain, in other words make the supply chain leaner, through automating processes and operations. This could then make it more efficient to retrieve products at a later stage in a CSC as there would be less waste of time and resources. This is illustrated by the following argument;

> *"Blockchain can streamline transactions from the supply chain, and this amongst other things means reduced wastage, and f.ex. automation and quick payment of invoices, which in hand could reduce the time for something to be delivered which could be good for other circular things in the later stages. (...) With waste in time and resources, the supply chain becomes longer, and the longer the supply chain is, the larger the carbon footprint is"* - B1.

4.2.3.3 Blockchain as an Incentive System

An interesting finding connected to the benefits of using blockchain in the supply chain, was that it has the potential to function as an incentive system. The blockchain experts highlighted that blockchain can be used as an incentive system by for example either compel actors in a supply chain network to work together or by creating rewards which are released when a job is registered as done. This is illustrated by the following two quotes; *"It does provide a great container storage and also the crypto economic incentives systems to pass back and create rewards for people that input the data in the first place" - B2. "Blockchain, even private blockchains, can force, (hehe) that's a strong word, I mean incentivise people in the network to reach a consensus on problems"* - B1. One blockchain expert also argued that the real power in blockchain is not to improve the visibility in the supply chain, but rather the benefits with using this technology is to create new processes based on incentive systems which the blockchain can trigger when the conditions for a task are met. This argument is best presented in the following quote;

> *"Blockchain allows you to both create the incentive system and carry that data simultaneously. It is quite powerful in that perception. I think that this is really the key here. (...) Blockchain does have some power for automation, but the real power is in its distribution, immutability and the sense of trust and transactions. And therefore, it's not about tackling existing processes, but to create new processes based on blockchain"* - B2.

4.2.4 Conditions for Implementing CCSC Through BCT

The questions the participants answered were split into the categories of BCT and CE. Therefore, this section will be explored in the same manner. The findings from interviews with the blockchain experts and construction industry actors were clear in terms of the need for a clear business case, regulations and use-cases in order to implement the technology and transition to CCSC.

4.2.4.1 Incentives for BCT

When the interviewees were asked about what they thought would be the catalyst for implementing BCT into the construction industry the interviewees had a few different opinions. However, there was one theme that most seemed to agree upon. This theme was one of economic incentives. Every interviewee mentioned the subject in one way or another. One of the most detailed summaries was stated as such;

> *"It has to start with the authorities making new regulations. (...) Much of the innovation in our field happens when governmental construction agencies order something new, with new regulations. Then the economic incentives in the industry will react"* - D1.

The notion was continued through the other interviews as well with slight variations such as two other interviewees who answered more directly; *"The client has to say that they will put, let's say, 100 thousand extra in the contract if the entrepreneurs utilize or do that"* - C2. Further, one of the interviewees argued bluntly that, *"The incentives must be present. (...) Ultimately, economic incentives must be taken into account"* - D3.

Another view was the view that the technology must be evolved from its current consensus algorithms, such as *"proof-of-work"*, due to its high electricity usage and high transaction costs. This was argued by one of the blockchain experts and put in such a way; *"we need a secure and low transaction cost blockchain and a much more developed layer of Smart Contracts on top of that layer too"* - B2. This view was shared with another interviewee who also stated that BCT is energy intensive, an attribute which is in need of advancement.

4.2.4.2 Requirements and Regulations for BCT

When the interviewees were asked about which actions that would be necessary in order for the BCT to be utilized there were some who argued that the most likely way it would find its way into the industry was through requirements or regulations. The reason for this was explained by one of the interviewees to be that; *"A prerequisite for blockchain to create value is that we have control over the process*

(...) We must have a set of rules and requirements - it is not so much about the technology, but the process" - D4. This was started because everybody in the supply chain with access would have insight into the processes the technology would process and everyone with access could behold the information the technology stores. This was further elaborated upon by another interviewee who mentioned that; *"The discussion has always been about what to share with whom, and when. We must focus on collecting and sharing data, but we have not yet put in place all the rules, accesses and exchange points"* - D2.3. Further, it was explained that one of the most basic conditions for blockchain is that the entities in a supply chain have to share information, and today, no one wants to share too much. As information about hourly wages, mark-ups and contracts are secret, companies will not give up this information freely. *"It is shared across companies who are in business. What do you want to share, and what do you ensure that you share little enough so you don't reveal trade secrets"* D2.2. Through the same logic, another interviewee stated that there *"must be an amendment to the law that says we have to do this.(...) or it must be a requirement from the client"* - D3.

4.2.4.3 Use-Cases and Business Models for BTC and CE

When discussing how one could implement BCT in order to reach a CE in the construction industry, there were two arguments in which all of the actors were in consensus. First, for the technology to be effective, digitalizing the supply chain is important. This was best described by one of the participants who argued that *"a digital baseline is the starting point, and then you need a community of people that are invested in the systems to do it"* - B2. Second, in order for the industry to embrace the technology, there must be conducted use-cases that can provide information to which extent the technology can be utilized and how economical it is. As one of the participants mentioned; *"It has to show that it has utility through solving real problems in use-cases. It has to turn out to be good for business - that it pays off"* - C1.

Further, the interviewees argued that the construction industry is a traditional industry and that their practices currently *"get the job done"*. However, even though there is a reluctance in changing a winning formula, the entities are willing to find new solutions in order to increase profits. The interviewees therefore argued that business cases must be conducted. As stated by one of the blockchain experts; *"It's like 'Show me the benefits'. And there are no business cases yet. (...) They want to see business cases with actual tangible benefits. And this is something we cannot offer them now"* - B1. Another interviewee further expanded on this notion with the argument that; *"We must also be able to create the business models that enable us to achieve economic growth and a reduction in the greenhouse gas accounts"* - D4. Another interviewee also followed this train of thought, and argued that the largest barrier that the phenomena would have to overcome were to be inducted into business models as there is a difference in knowledge of the topics. Further, interviewees also argued that there *"is a big gap between the theoretics and commercial entities who are to make money"* - D1.

Another view was also shared across a number of the participants. The technology could not just be added onto the systems that are being used today, it has to be integrated into business models as stated by one of the blockchain experts; *"the most important prerequisite is that blockchain is contextualized within the sector, and not only within the sector, but in certain business models"* - B1. Further, it is also argued that the technology must be embedded into solutions where no one notices that it is there. *"It must be added in the form of a technology or standard that functions as a foundation that very few people should worry about"* - C2.

There was also a view that was stated by one of the participants which should be considered. *"The industry could not care less about which technology it utilizes. BIM, BCT or whatever. As long as it is economical and easy to use"* - C2. This was further strengthened by another interviewee who argued that; *"This is a very traditional industry, which requires some time to turn around. There is also a lot of focus on quality, time and economy. The biggest challenge at the moment is probably that everything is measured in economics"* - E1.

Another interviewee also shared this view through the notion that every contractor has won the tender due to its low price, as this is a criteria which is valued greatly. The entrepreneur will therefore also deliver within the budget, hiring the lowest priced workers, in order to ensure a profit. As stated by one interviewee when arguing about profits when taking part in CE; *"no one is interested in taking risks or using something they are not familiar with as that will increase the risk"* - C2.

Further, when asked about the information about material properties, one interviewee answered;

> *"It is of the utmost importance. In terms of what kind of properties, we want from our supply chain (...) properties do not appear through thin air. They must be facilitated by incentives for construction, political socialism as mentioned earlier and also the conscious choice of the actors doing the SC"* - B1.

4.2.5 Barriers and Reflections with Blockchain as an Enabler for CCSC

The last sub-theme which was highlighted during the interviews was the potential barriers for implementing BCT in the construction industry. When asked about what the interviewees perceived as the most eminent barriers for this technology the revived answers concerned whether BCT would really be the most beneficial technology, who should own this data, and the maturity of the technology. Furthermore, interviewees commonly held that the benefits for using BCT to aid CCSC had a long-term perspective and they questioned the environmental aspect of using BCT.

4.2.5.1 Reflections on BCT as a Possible Enabler

During the interviewees it became evident that multiple interviewees thought that using BCT to aid a transition to CCSC in the construction industry sounded interesting, and that they saw much potential in BCT for the industry. On the other hand, several interviewees questioned whether this would be the most beneficial usage of BCT. One of the interviewees questioned whether a blockchain would be able to store the amount of data needed because of the size of the construction project and information gathered throughout the building's lifetime. *"I think there will be problems with the large amounts of data, blockchain is not suitable for handling this"* - D3. Moreover, the interviewees argued that the general ledger aspect of a blockchain was very interesting, however, the information storage aspect could be provided through other existing technologies as well. *"What you explain with blockchain being a digital general ledger for each project is cool, but I am not sure that blockchain is the technology which will give me this. I could get this from* *other solutions such as BIM"* - D2.1. One of the BCT experts expressed that blockchain is more connected to transactions and incentive systems, as mentioned previously in 4.2.1.2. In this experts' opinion, using BCT for information storage seemed to be of little use, as illustrated in the following argument;

> *"So just as a holder of information I think you could use existing ERP systems, BIM models and data storages to just hold the information. (...) We should rather look into pointers, hashing and of-chain solutions for really large files. For me, blockchain is about transactions and incentives"* - B2.

In addition, one of the interviewees expressed concern with regards to introducing BCT as the means for how the construction industry could transition to CCSC. This was due to the fact that BCT is still a relatively new technology and there are few that understand its potential yet. Therefore, using this technology could potentially slow down the progress of CE in the industry, as shown in the following argument;

> *"We are completely dependent on digitalization in order to succeed with a circular economy. As I see it, this can be done with current technologies, we don't need blockchain technology. It might have made it easier, but I think the barriers are extensive. I am afraid that if we introduce blockchain as the solution, it will slow down the development of the circular economy because many will fall off"* - D4.

Ownership of Data

Another challenge which was discovered during the interviews was the problem connected to ownership of data. Owning the data connected to building materials and products throughout the building's lifetime would be essential when using BCT as someone would have to be responsible for the access to the information. *"Who do you think should own this blockchain? Who should distribute it and give the permissions?"* - D2.1. For this reason, multiple actors questioned who should be responsible for this information. It was also discussed that owning the data connected to a blockchain could potentially be very valuable for companies, and therefore the interviewees also questioned whether this information should be privately or publicly owned. *"There are also problems of legal nature (...) for example, when you use decentralization using BC, who actually owns the data?"* -

B1. This problem was also expressed precisely by one interviewee saying; *"There are too many problems connected to the ownership of the data"* - C4.

4.2.5.2 The Maturity of BCT

During the interview, both of the blockchain experts commonly held that a barrier to implementing BCT was the problem with the maturity of the technology. One of the experts argued that BCT has been around for about 13 years now, and only discussed thoroughly for about six years. The technology is therefore still relatively new, and as mentioned previously in 4.1.3.3 the BCT experts themself had just recently begun to understand the technology and its potential. Because of this one of the experts argued that the industry is not mentally prepared for this technology, but also that the technology itself is not ready for such usage yet. There is still research needed to explore the possibilities and prepare, as shown in the following statement; *"Today we're not ready. We're not even near ready. At the research level it's starting to come but I don't think that we are mature enough to really do this. I also think that blockchain is not mature enough to do it. (...) I would say that in addition, cognitively, we are not ready"* - B2. However, the experts argue that in time BCT could be a game changer. This whole argument is best demonstrated in the following argument;

> *"The problem with industry actors being suspicious of blockchain is that they don't understand the technology. (...) BIM has been around for 30 years (...) we cannot expect the same from a technology that is 13 years old, and has not been discussed within the industry for more than 6 years. (...) Technological maturation (...) I don't think there will be any widespread implementation in the next 3 years, or 5, but within the decade, I think a lot of companies in the sector will be in the game"* - B1.

4.2.5.3 Requirements for Environmentally Friendly Solutions

One of the interviewees highlighted the fact that reusing products and materials from old buildings might be difficult as the quality of the product or material is likely to be lower than initially. During the lifetime of the building several unexpected problems might occur and repair jobs might have been done, as exemplified in the following statement; *"Firstly, it's been repainted seven times,* *and there is probably fungus in it. It's a lot of shit in general. What I am thinking about is; wouldn't it be easier to just melt it and make something new?"* - D1. A challenge with regards to reusing products and materials is therefore that there needs to be specific requirements for the quality of the materials which are accepted to reuse in another building. This was stated by an interviewee; *"A challenge regarding circularity, especially reuse, is what requirements must be set for old materials"* - C1. Interviewees argued that using BCT the problem might be avoided as changes could be stored on the blockchain end-to-end form construction, during the building's lifetime, and to deconstruction. However, another point which was made then was the importance of keeping the information updated; *"Someone needs to be responsible for updating this information, otherwise it's not happening"* - C4.

On the other hand, even though some interviewees argue that BCT could potentially provide a complete information history with regards to the products and materials used in a building to enable CCSC, several interviewees questioned the environmental aspects of the technology. One interviewee argued that BCT was very energy intensive, and supporting a technology which is energy intensive in order to become more environmentally friendly was not an option. *"I can't defend a technology with a larger carbon footprint than other technologies. I think that this could be a barrier; how do we solve this problem in a technically and climate friendly way?"* - D4. Another interviewee also questioned whether it was possible to calculate the carbon footprint of BCT, as illustrated in the following quote; *"We have started to look at blockchain as very energy intensive. Is this something that we can calculate?"* - E1. Nevertheless, one of the blockchain experts also addressed this issue calmly and expressed that the BC´s carbon footprint was a problem which is likely to be solved in the future. *"You are probably going to get people asking about the carbon footprint of blockchain, which I think are all problems that can and will be solved"* - B2.

4.2.5.4 Project Timeline and Long-Term Perspectives on Profits

The last barrier to implementing BCT to enable CCSC that was discovered during the interviews is connected to the project timeline. Transitioning into a CCSC could potentially become difficult due to the fact that the profits of reusing the materials enter at the end of a building's lifetime, *"50-100 years"* - D2.1. Interviewees expressed that working with collecting and updating information for such an extensive amount of time, and making investments with a long-term perspective on profits is problematic. *"A company can make investments in a project with a five-year perspective, but not 60 years"* - D1. Interviewees argued that projects usually held a short-term perspective and that the focus usually involved delivering on time and collecting the profits as the margins are usually small. This is demonstrated in the following arguments;

> *"The inherent project timeline is a challenge (...) The dilemma in the industry, called a barrier, is that few are concerned with the long-term perspective. A contractor building a building is concerned with delivering within the deadline, earning the money and ensuring that the building holds throughout the compliant period (2-5 years)"* - C2.

> *"It is quite well established in research in multiple contexts, including the ones in Scandinavian countries, that the companies' margins are small, that there is a backlog of projects in the best-case scenario and that this profit margin is calculated with a profit ahead"* - B1.

From the expert interviews, we have been able to increase the understanding of the current situation with regards to environmental practices and its importance and challenges, as well as the current situation regarding supply chain visibility and how digitalization could contribute to improve traceability and transparency. However, it is crucial that more standards are established and common technologies are being utilized in order to improve the information flow. The interviews have also enhanced the understanding of the drivers, conditions and barriers for utilising BCT to enable CCSC. BCT has potential ability to increase traceability and transparency in the supply chain, it could be combined with other established technologies as a common platform, and it could function as an incentive system through using smart contracts. On the other hand, economic incentive systems, new regulations and more use cases most lay the foundation for using the technology. In addition, there are barriers connected to the maturity and capabilities of BCT as an enabler among others. Finding solutions which could contribute to reduce the amount of consumption in Norway is both imperative and possible. The Circular Norway report (2020) even states that Norway has the possibility to become a regenerative power-house.

5.0 DISCUSSION

In the following chapter, we will discuss and elaborate on the research findings, and how it relates to previous literature presented in the theoretical background. In this chapter, we have made a detailed comparison where we will combine and discuss the current issues discovered in literature with the drivers, conditions and barriers from our findings. Lastly, we will present and discuss an evolved model based on the theoretical framework.

Our findings and the theoretical background address several interesting aspects of how improved visibility through BCT could facilitate for CCSC, however, we have chosen to concentrate on the most relevant and interesting findings which could contribute to answer our research question; *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?* Our discussion will follow the structure of the theoretical framework, in addition to covering the main- and sub-themes from our interviews in order to answer both sub-questions and the main research question. We will first conduct a discussion on the current situation with regards to supply chain visibility and digitalization as it has been established that visibility is a main condition for CE. Following this, we will have an in-depth discussion of the main *drivers, conditions* and *barriers* for using BCT to aid CCSC. As described in the research methodology, we wish to increase the understanding of the research topic. Therefore, we have chosen to enlighten the drivers and barriers of the combination of the phenomena BCT and CCSC, but also the conditions that need to be in place for the implementation of the two. Based on this discussion we believe that it is possible to answer whether BCT is a possible enabler CCSC.

5.1 The Role of Visibility in Enabling CCSC

In the following section we will first discuss the importance of implementing CCSC in the construction industry as the industry is responsible for a considerable part of the extracted resources and the produced waste. Following this discussion, we will discuss why visibility and digitalization are important for this transition. Factors which could hamper the visibility is that the construction industry suffers from fragmented supply chain structures, reluctance for sharing critical information, different opinions on the level of digitalization, and problems with standardization.

5.1.1 The Importance of CE Practices

Our findings show that obtaining more environmentally friendly practices within the construction industry is of great importance as the industry is contributing to a considerable amount of CO2 emissions and waste (Circular Norway, 2020; BuildingSMART, April 28th 2021). In addition, the industry actors which were interviewed expressed that implementing more environmentally friendly practices values was on the agenda. These findings are in accordance with previous research which shows that material production in itself contributes greatly to increasing the CO2 emissions during the building's life cycle, and that on a global scale, the construction industry demands 40-50 percent of the yearly extracted resources to use in production of new building material (de Wit, 2018; Material Economics, 2020). Moreover, the industry also contributes to approximately 40 percent of the waste (Digitalt veikart, 2017; SSB, 2021) which implies that the industry disposes of approximately the same amount of resources each year as they demand new ones. Therefore, we would argue that implementing new environmentally friendly solutions for the construction industry could arguably contribute to reducing the produced greenhouse gas emissions and waste.

Previous research shows that CE is a phenomenon which has received a great amount of attention due to its potential for reducing companies' environmental footprint because it is possible to utilize resources at their highest possible value (EMF, 2014; Geissdoerfer et al., 2017; Korhonen, et al., 2018a; EMF, 2019). Therefore, our findings supports that implementing CE values in the construction supply chain and transitioning into CCSC is an environmental strategy which should be considered in order to reduce the environmental footprint for the industry. Furthermore, based on the aforementioned problem connected to resource extraction and waste contribution, our findings also supports that implementing CE business models in the construction industry would contribute to reducing theneed to extract new materials, and thereby also reduce the waste generated from the industry.

5.1.2 The Importance of Supply Chain Visibility and Digitalization

Looking at CE business models it is possible to argue that following supply chain management strategies, such as obtaining visibility, are of great importance as CE in its essence could be argued to be closely connected to supply chain practices. Previous research on CE and the supply chain have established the important role of supply chain visibility (Demestichas & Daskalakis, 2020; Mastos et al., 2021) in order to be able to implement CE business models, such as the CCSC. The importance of having the appropriate information about products and materials used in a building when deconstruction was also confirmed in our findings. There are undoubtedly other important aspects which are important challenges to overcome, however, this study has focused on the supply chain visibility and information sharing. This is due to the fact that it is possible to argue that the construction industry is struggling with regards to their supply chain visibility due to the supply chains being fragmented with complex structures (Cox & Ireland, 2002; Briscoe & Dainty, 2005; Cox et al., 2006; Digitalt veikart, 2017; Digitalt veikart, 2020). This was also confirmed in our research findings. On the other hand, several interviewees focused more on the competitive environment as a contributing factor to the limited information flow. This was because of the fear of sharing potential crucial information and their competitive advantages. Combining the fragmented and complex structures of the supply chain and the competitive environment, it is therefore possible to argue that the construction industry needs to improve its supply chain visibility and information sharing. Otherwise, it will be very difficult to attain the right information about the materials used in the buildings and their quality. Without the right knowledge about the materials and products, using them in a circular closed loop system will be very difficult as it is crucial to have all the right information in order to utilize these products in a new building.

Furthermore, the review of literature regarding visibility in the construction industry uncovers the fact that the industry has historically low levels of digitalization. Even though there has been an increased focus on technologies in the industry lately, the industry is still far behind compared to other similar industries

(Alaloul et al., 2018; Whyte 2019). Furthermore, from both our findings and previous literature it was discovered that there is still manual information collection happening in the construction supply chains. With the complexity and the fragmented structure on top of this, it is possible to argue that mistakes are bound to happen, and that this will ultimately contribute to reducing the visibility due to incorrect information being captured or not captured at all (Young et al., 2011). The low levels of digitalization could therefore represent a great challenge for construction supply chains to partake in circular systems. On the other hand, from previous research it is stated that there are now multiple technologies which could be utilized to facilitate improved supply chain visibility, such as RFID, BIM, IoT etc. (Whyte, 2019; Demestichas & Daskalakis, 2020; Mastos et al., 2021). Our findings also support this view as some interview participants expressed disagreement on the level of digitalization and pointed out that there are multiple different technologies which are utilized and support information sharing and information storage, such as BIM. However, others point out that even though there are new technologies which could now be used, these technologies do not necessarily contribute to digitalizing the industry as they are not cooperating. This was also pointed out by Digitalt Veikart 2.0 (2020) as one of the challenges with digitizing the industry as the different technologies need to "speak the same language" in order to improve the information flow. Based on this, we would argue that there is strong disagreement within the industry with regards to the digital status, as some actors from the industry state that it is difficult and time consuming to find the required information, while others state that it is easily found.

With regards to the previous argument, the research findings and previous literature on digitalization in the construction industry comply with the fact that finding common standards for information collection and storage is important. From research findings the actors in the construction industry express concern with the fact that there needs to be common standards. This is because it can be argued that if the collected information regarding products and materials are nonoptimal, limited or incorrect, the construction supply chains are unable to successfully implement closed loop systems like in the CCSC. Whyte (2019) supports this and highlights that as more technologies are being utilized in the industry, it is highly important to establish shared standards for "sorting, analysing, storing and retiring" information. With regards to establishing CCSC one could argue that it is extremely important to have clear and standardised ways for retrieving information (Behnke & Janssen, 2020) in order to be able to sort efficiently out which products are going to be reused or recycled in material loops. Thus, an important aspect for the industry to take into consideration when establishing new digital solutions is to have technologies which are able to function together and exchange the proper information. In addition, the industry needs to store material and product information similarly in order for others to be able to access the information in the future when the buildings are deconstructed and materials retrieved in order to be reused or recycled.

In summary, it is important that the industry incorporates CE values such as implementing the CCSC model as the industry arguably extracts and wastes approximately 40 percent of the yearly extracted resources. However, both previous research and our findings states that this could be difficult due to the limited supply chain visibility it could be argued that the industry suffers from. In addition, there is conflicting views on the level of digitalization, and the need for new technologies as there are already multiple technologies to choose from. However, these do not necessary exchange information easily between each other as there are different standards. Therefore, in order to transition to CCSC, we wanted to explore the usefulness of BCT as the enabling technology to increase the supply chain visibility. There are multiple reasons why this technology could benefit the construction industry in terms of becoming more environmentally friendly. On the other hand, there are also conditions and barriers to overcome. These drivers, conditions and barriers will be discussed in the next section.

5.2 BCT to enable CCSC through Improved Supply Chain Visibility

We will now discuss the most important drivers, conditions and barriers based on our research findings and supported by previous research. We would argue that the most important drivers for utilizing BCT to enable CCSC are improved supply chain visibility and incentives through smart contracts. In terms of the conditions, it is important to establish a clear business case and promote incentives with utilizing this technology and CE practices. The maturity of the technology is, however, a challenging barrier to overcome as it is arguably the root cause for most of the other identified challenges.

5.2.1 Drivers for Blockchain as an Enabler

In this section, we will discuss the different drivers that were found for BCT as an enabler of CCSC looking at the literature research and our findings. Previous studies have shown that there are several options for how BCT could contribute in the construction industry (Francisco & Swanson, 2018; Li et al., 2019; Chang & Chen, 2020), which our findings can confirm. In the following sections, we will discuss the drivers that were shown to be promising by both the literature and through our research. The first two subsections will discuss how tokenization of assets and interoperability with other technologies can influence the supply chain visibility. The following sections will discuss smart contracts and how BCT can be used as an incentive system to facilitate the change towards a CCSC.

From previous literature, it was established by Li et al. (2019) and Francisco & Swanson (2018) that tokenization is an abstract representation of a physical object, which in turn can be utilized as a digital marker for a specific product. These tokens can thereafter be tracked through a blockchain network, providing the supply chain with the ability to trace products, components, shipments or other activities live, from end to end. In our findings we also found that the same thought was discussed by the blockchain experts. The experts argued that this function in a supply chain could increase the supply chain visibility. Further, the experts described an advanced method for utilizing the technology as to create material passports for products. By adding a material passport to a product, the constructor can trace the products utilized in a building throughout the supply chain up till its origin. Applying such information to a product could increase the traceability of the product along the supply chain, providing information to entities with regards to the quality of the product and the transaction. It could therefore be argued that implementing material passports through applying BCT could result in a horizontal information flow in a vertical supply chain. Additionally, we would argue that an application like this could have the potential to ensure information regarding the product quality throughout the materials lifetime. Moreover, we would argue that this would enable the owner of the materials to gain increased knowledge about the building if something were to happen with the materials. An example of why this would be beneficial was pointed out through the interviews as multiple actors mentioned the problem with finding out which houses could have problems with asbestos. We would argue that if companies had used BCT and material passports, finding and mapping these houses could have become a quick and efficient process.

In previous literature, it was also stated that BCT could facilitate interoperability with other technologies such as BIM, RFID and other IoT devices (Francisco & Swanson, 2018). Such interoperability might benefit the entities in the supply chain by providing live information about material whereabouts, transactions and conditions the products were exposed to. Furthermore, some of the interviewees argued that connecting BCT to specific parts of the BIM model could facilitate for improved supply chain visibility, and that there are already examples of companies trying out this method. Not only could this increase the supply chain visibility as described by Chang & Chen (2020), we would also argue based on our findings that connecting BCT to other technologies could reduce the resistance for sharing information with all participants in the supply chain due to the immutability and security of BCT. However, multiple interviewees were clear on the matter that BCT cannot be utilized as a material database, and this was also supported by Hofmann (2020). Considering this, we would say that it is possible to utilize current technology systems such as BIM as a database, with different strands of blockchains connected, in order to connect the immutable transactional history of materials, but not in terms of storing information for buildings as material banks.

Research demonstrates that lack of information is regarded as major obstacles for CE (Mittal & Sangwan, 2014; Korhonen et al., 2018b; Demestichas & Daskalakis, 2020; Mastos et al., 2021). Our research findings also show that the transition is sought by industry actors, who agreed that the industry could reach improved circular practices through digitalization of data and practices. Based on our previous literature, we would argue that such practices could be implemented in the supply chain through the implementation of smart contracts on blockchains. Tezel et al. (2020) argued that smart contracts could automate and support procurement - and supply chain activities. However, one of the blockchain experts stated that using BCT in supply chains could only be done if everyone agreed that digital twins and material passports are baseline assumption for the future. Utilizing BCT in the construction industry could therefore be connected with material passports and other currently utilized technology, and from this we would argue that one could see how BCT could increase traceability in the supply chain as the technology has the ability to bridge several elements of transactions and information exchange together. From an automated supply chain, one might create smart contracts that facilitate procurement, transaction costs, and live feed of material flow into the supply chain, as well as material information that is passed along each transaction. Such a supply chain could benefit from automation of procurement, payments and information as the smart contracts can be programmed to activate processes as soon as the required action has been performed. Such an action could for instance be a delivery of materials to a construction site, where the algorithm registers the delivery truck's goods through RFID, and automatically proceeds to pay the products invoice. From our research findings it was stated by some interviewees that the technology could also be used to efficiently retrieve materials and products in a later stage of a construction process, to ensure that the materials are relocated into CE business models such as the CCSC. This way BCT could be used and aid the construction industry in terms of reducing waste of resources and time. Based on this, we would say that it is reasonable to assume that such actions could increase the effectiveness of marketplaces that deal in reused and recycled materials.

Today, blockchain practices are mainly focused towards the finance sector as decentralized cryptocurrencies, with few applications yet in other sectors. As discussed above, the supply chain visibility in the construction industry is limited, and this makes it challenging to transition to CCSC. However, our research suggests that BCT and its applications could be a possible enabler for CE (Kouhizadeh et al., 2019; Demestichas & Daskalakis, 2020; Mastos et al., 2020). On the other hand, in our findings it is suggested that BCT is not suitable for bulk storage of information as the blocks in the blockchain have a finite storage capacity. Therefore, rather than using BCT as an technology for material information storage, we would argue based on our findings that BCT should be connected to transactions and incentives. This way one could utilize BCT as an incentive system for information sharing, transaction tracing, open data and for enabling CE business models, such as CCSC. As described in our research findings, the smart contract applications could be programmed to reward actions that are of interest to the constructor or the client. This way, the client could reward the usage of recycled or reused materials, or if it is facilitated for being easy to extract materials for reuse and recycling at the end of a buildings life time. If the contractors fulfil such clauses, the smart contract has authority to activate a reward automatically. This incentive system could potentially also reduce material waste within the supply chain as it could be easier to incentives for less wastage of time and resources. Moreover, it is possible that entities will provide more of their data, as the supply chain actors can be incentivised to share more information than previously without revealing their competitive advantages and price mechanics. With increased traceability and transparency, it is possible to argue that the supply chain visibility will be increased simultaneously. Thereby, by applying smart contracts and incentive systems, we would argue that not only will the supply chain visibility increase, but the industry could also implement a system which promotes and rewards circular practices.

The drivers for utilising BCT as an enabler for CCSC and other closed loop supply chains, are connected to the technology's applications for converting physical assets to digital assets, which could increase supply chain visibility, and to create incentive systems through smart contracts which could promote circular practices to the supply chain. We discussed how BCT can utilize digital assets in order to track and trace materials throughout the supply chain, as the technology can be programmed with great interoperability with other currently utilized technology. This could increase traceability in the supply chain and promote efficient solutions for material processes. Further, the technology's smart contract applications can be combined with incentive systems, where the supply chain therefore could promote circular practices in the supply chain as well as automating transactions. This could reduce lead times, increase supply chain transparency through an increase in information sharing and it could potentially reduce material waste at the end of the building's life-cycle.

5.2.2 Condition for Blockchain as an Enabler

As this thesis addresses the need for improving visibility in the construction supply chain because improved visibility has been proven to be critical for transitioning to a CCSC (Korhonen et al., 2018b; Demestichas & Daskalakis, 2020; Mastos et al., 2021), we believed that it was important to focus on conditions and challenges which were directly connected to this topic. Because of this and the fact that both

BCT and CE are still considered to be new phenomena, the literature research is somewhat limited on research regarding the conditions that need to be in place in order to use BCT to aid CCSC. However, through the research findings it is possible to argue that most of the conditions for utilizing BCT in the construction industry are connected to introducing and improving incentives. Our findings focus on the importance of establishing incentives and showing a clear economic business case, regulations and more use-cases. The same conditions apply for CE in the industry.

In literature, it was established that implementing BCT in the construction industry could become difficult as the technology requires an extensive amount of start-up capital (Niranjanamurthy et al., 2018). In the research findings it was also confirmed that the actors within the construction industry believe the technology to be expensive. Therefore, multiple actors argued that in order to utilize the technology it is crucial that the client or the government increase the economic incentives in order for the industry to be rewarded for using a technology which is more expensive than other technologies. On the other hand, both the theoretical background and the research findings shows that it would also be beneficial if it was possible to make it less expensive to operate the blockchains. "Proof-of-work" is a consensus method which is expensive due to requiring large amounts of resources to process transactions (Viriyasitavat & Hoonsopon, 2019). From our findings it is possible to conclude that for the construction industry it could be beneficial to operate with permissioned blockchains, where all participants are known as it can be argued that only permissioned actors can join the network. Further, as the actors are known, the risk of misbehaving nodes is reduced, which would make the complex and expensive "proof-of-work" method unnecessary. The cost connected to BCT would then be reduced as it would be possible to use consensus methods which are less expensive and resource demanding, while still obtaining transparency and traceability to increase the supply chain visibility. This is because it could be argued that the permissioned BCT would remain at a comprehensive level as the number of actors would be restricted to only the ones connected to a construction project. This was also supported by Nanayakkara et. al. (2019) stating that the permissioned blockchain is more suitable for enterprises.

As mentioned previously in this discussion, the findings show that the industry actors are very concerned with establishing common standards for technologies and which platforms to utilize. This is due to the fact that even though the industry historically has low levels of digitalization, there has been a lot of new technologies emerging recently. Therefore, the findings highlight that in order to start utilizing BCT as an enabling technology for CCSC it is of great importance that common practises for the application of the technology are first established. There is a need for a pre-decided set of rules for what information should be shared and who should have access (Behnke & Janssen, 2020). This is supported by the findings, where actors argue that it is crucial that critical business information which companies utilize to obtain competitive advantages are kept secret. However, due to the nature of the technology, it is programmed which information should be shared and when shared in a permissioned blockchain it is still a slight to non-probability for the information to be leaked or obtained by hackers. Nonetheless, Behnke and Janssen (2020) supports the fact that one of the conditions for establishing BCT is to establish a standardised and common architecture for how to use the technology. Otherwise, their study showed that the technology could lead to increased complexity and fragmentation in the supply chain. As the construction industry is already struggling with fragmented and complex supply chains (Cox et al., 2002; Briscoe & Danity; 2005; Cox et al., 2006), this is an important factor to consider. Moreover, the construction supply chains are very traditional in their way of working, which implies that the supply chain structure would have to be reorganized in a more structured manner, which is likely to be both time consuming and costly. In addition, it would be important to get everyone on board with the same solution in order for it to work (Kouhizadeh et al., 2019).

Even though CE practices and business models are becoming more important and established within the different industries (Geissdoerfer et al., 2017; EMF, 2019), our findings shows that the construction actors are less concerned with environmentally friendly practises if these turn out to be more expensive than the current practises. As the construction industry is one of the industries which contributes to most of the generated waste, it is arguably highly important for this industry to enter into circular closed loop supply chains. On the other hand, from our findings it was shown that there are multiple new organizations operating with how to make the industry more environmentally friendly and concerned with circular practices. However, literature argues that establishing businesses concerned with such end-of-life practices is an issue in the construction industry due to the fact that both actors and customers are often more concerned with cost than environmentally friendly solutions (Adams et al., 2017; Nasir, et al., 2017). Because the emphasis on economic incentives is as important as it is in the construction industry, establishing regulations for CE practises was also pointed out as a solution. This way constructors and their supply chains would have no choice other than to implement the most beneficial CSCM practices. Even though the findings point to the industry as being a capital-intensive industry, there are multiple smaller firms operating in the supply chains with low margins (Cox et al., 2006), and therefore enforcing more environmentally friendly solutions through regulations might be beneficial.

Both BCT and CE are relatively new phenomena, and through our research demonstrates that there are relatively few researchers who have studied the combination of the two. Thus, a very important condition which was uncovered in our study with regards to both BCT and CE was the need for more use-cases. The findings show that uncovering the business model and incentives for how these two phenomena could contribute to create economical value for companies are crucial in order for investments to be made. As mentioned, there are an increasing number of newly established businesses which focus on CE practises, thus showing the potential of such practises in the construction industry is possible. However, the technology is still premature compared to other technologies such as EPR, RFID and BIM, which we will come back to below. Thus, there are few use-cases to look at, and the real-life application is still limited (Kouhizadeh et al., 2019; Mastos et al., 2021). In addition, the project timeline for using BCT to increase visibility in order to transition into CCSC is relatively long compared to regular construction projects. Therefore, conducting use-cases of how this would work as a business model and the economic incentives which potentially lies here is a long process, which can be difficult to succeed with.

To be able to utilize BCT as an enabler, our findings show that the most important conditions are not directly linked to the combination of BCT and CE, but rather the two phenomena separately. Furthermore, regulations, standards, use-cases and incentives were pointed out as being the most important enablers for both phenomena. However, it could be argued that out of the four, focusing on improving the incentives are the most important. It is highly important to show the business model in combining BCT and CCSC and prove that there are economic incentives in implementing more green practices, even though investments in technology are more expensive. This was best said by one of the actors, who stated; *"Everything is money."*

5.2.3 Barriers for Blockchain as an Enabler

In this subsection we will discuss the inherent challenges BCT faces for becoming an enabler for circular practices and what barriers that might lie ahead. In this section we have focused on the barriers and challenges that were found in previous literature and from our findings. Both research and findings were quite clear on the subject, and it was therefore possible to find clear arguments regarding the subject. We will therefore discuss the different aspects of BCT maturity, ownership of data and lastly, the technology's energy requirements based on our findings and previous literature.

As of today, BCT's greatest challenge derives from its level of maturity. As mentioned above, it has only been 13 years since BCT was launched by Nakamoto in 2008, and therefore the knowledge with regards to this technology is still relatively limited compared to widely used BIM systems, which were introduced approximately 30 years ago. Further, as mentioned above, BCT is mostly used in cryptocurrencies today. As earlier research provides insight towards cryptocurrencies, insight into how the technology could be utilized in the construction industry has just recently gained traction. However, as it has not been a priority, our findings show that even for BCT experts, it can take years to fully comprehend the potential of a decentralized structure in the industry. Further, as the technology is rather new, there is, as mentioned, a lack of use-cases as most research provides theoretical assumptions for the technology. However, Mastos et al. (2019) recognized that there is a limited connection between theory and practical solutions. This lack of transferability could reduce acceptance for testing for companies. Looking at the practical implementations of the technology today, Kouhizadeh et al. (2019) also found that the technology currently suffers from its infrastructure whereas the system still might experience failure with interoperability, technological security and stability. Additionally, Behnke & Janssen (2020) found that BCT requires an architecture that is suitable across multiple practices. Further, Kouhizadeh et al. (2019) argues that companies in the construction industry are slow to adapt to new technologies as they rather utilize those who are tested and proved to be economical, rather than untested technologies that might be expensive and risky. As the technology is relatively new, it lacks tangible results proven by use-cases. Due to this it is likely that neither industry nor the technology itself is ready for widespread implementation of BCT. Further, it is reasonable to assume that industry actors are averse towards the technology as it is not yet fully understood. As we set out to explore how BCT and increased supply chain visibility could enable CCSC, our findings actually shows that it could slow down the progress towards CE in the industry because the technology could be intimidating for industry actors with limited knowledge, time and resources.

Another factor which we would argue that could be a difficult barrier for the technology is connected to the ownership of data. As our findings suggest, there is a scepticism towards the technology as there are currently no regulations regarding ownership of data which is decentralized. In line with our research findings, we would argue that it is difficult to decide who should own decentralized data. This could become especially difficult when looking at BCT as an enabler for circular practices, as the retrieved data could then prove to be important and a source of income. Moreover, Tezel et al. (2020) described companies as risk averse regarding property rights and privacy, which makes it reasonable to assume that regulations must be set in place before the technology can be implemented. Further, our research illustrates that one of the basic prerequisites for blockchain is that supply chain entities share information with each other. However, companies are averse to sharing information as open data could result in revealing of trade secrets and competitive advantages. Presumably, companies are reluctant to provide competitors with too much information as it could hurt business in the long run. This way, we would argue that the question regarding the ownership of data becomes even more important, because the company which owns the data could potentially gain both competitive advantages and increased income, and therefore deciding who should possess this data becomes more difficult.

The final barrier we will discuss in this section is how blockchains would fit in a CCSC. Niranjanamurthy et. al. (2018) argued that the technology's main function is to process transactions. As found in our findings, constantly updating information is important in order for the information to be relevant. On the other hand, Niranjanamurthy et al. (2018) reports that the amount of transactions that are performed by a blockchain system far outnumber the transactions that are needed in a traditional centralized database. This is due to consensus algorithms where all nodes in the network are to process and approve the transaction. In turn, it is possible to argue that this could lead to high levels of energy consumption. Additionally, in our research, it was found that several industry actors did not support a technology that provides a higher carbon footprint than other currently utilized technologies. Argued by Kouhizadeh et al. (2019), it is contradicting that a technology that leverages CE-practices in itself is less energy efficient than current technologies. This can in turn cause problems for environmental practices, and our findings shows that it raises questions about how capable BCT is to enable CSC. However, through our research, it was discussed that some solutions have already surfaced, such as the consensus method of "Proof-of-stake", created by King & Nadal (2012). Further, in our findings it was also argued by BCT experts that all problems related to energy consumption can, and will, be solved. However, this could also be an indication that the technology is not yet ready for practical implementation in the industry.

In summary, for BCT to be utilized as an enabler for CCSC, there are several barriers the technology must overcome. Through our research and findings, we have shown which barriers are believed to be most important to address, and how they affect the construction supply chain. In this chapter we have discussed BCT maturity as the technology is arguably not ready for implementation in the construction supply chain today. Further, the technology has a barrier regarding regulatory actions as there are no set or rules regarding ownership of decentralized data. This means that companies could be reluctant to share information as property rights and privacy cannot be guaranteed. The final barrier discussed above explores the contradictory state of BCT as an enabler of circular practices, when the technology itself is resource inefficient. Even though researchers explore options for energy reduction, the technology is currently utilizing more than traditional databases. In short, the recurring factor in all of these points is that neither the current state of BCT, nor the construction industry is mature enough for widespread implementation of BCT.

5.2.4 Reflections on BCT as an enabler for CCSC

Based on the discussion of our findings and previous literature on the research topic, we will now present a new model derived from this discussion and the theoretical framework presented at the end of the theoretical background – *see figure 7.* This model evolved from the end of the framework, and shows the perceived connection between BCT and CCSC through the drivers, conditions and barriers. The lines represents that there is a direct linkage between BCT and CCSC, while the stippled lines represent challenges with BCT – *see figure 7.*

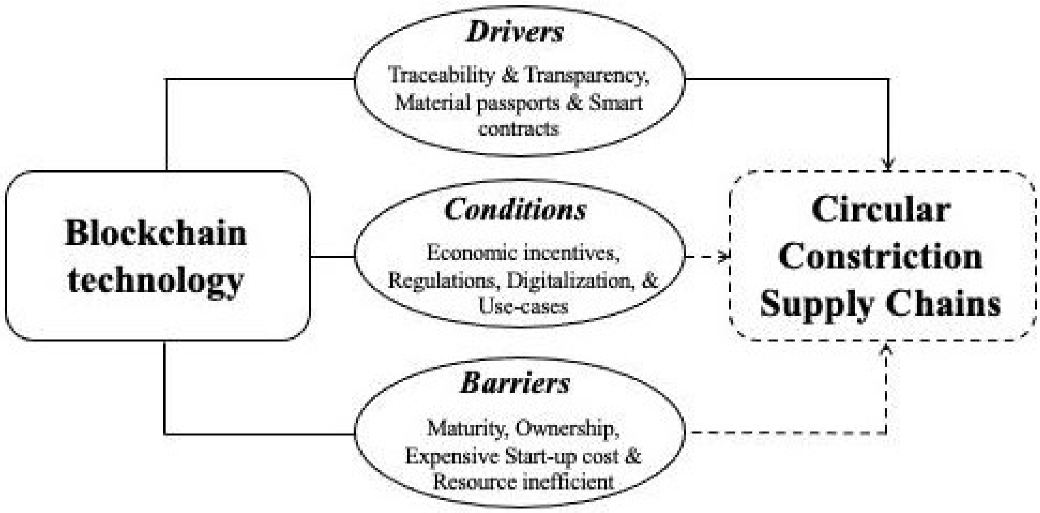

Figure 7 - Context for drivers, conditions and barriers for BCT to enable CCSC

From our findings and discussion, we would argue that BCT could directly aid the construction industry in becoming more in line with circular practices and the CCSC model – *see figure 7.* This is due to the fact that BCT could improve the traceability and transparency through digital tokens and smart contracts, and thereby improve the supply chain visibility which is an important factor for incorporating CE practices. Furthermore, our discussion of the drivers showed that blockchain enabled smart contracts also could provide incentive systems for implementing CE practices in the supply chain through issuing rewards when contract clauses are fulfilled. On the other hand, our findings and discussion also show that there are several conditions to be met and barriers to overcome for the technology to find its place in the industry. For companies to be willing to invest in this new and expensive technology that blockchain is, there must be clear economic incentives and regulations, in addition to more research conducting real-life use-cases. Further, the maturity of the technology makes it difficult to know how BCT could best contribute to enable CCSC, due to the limited amount of prior research conducted on the matter. As shown in *figure 7*, there are stippled lines extending from conditions and barriers towards CCSC representing how these points are not contributing towards CCSC. The line surrounding CCSC is therefore also stippled as the current state of BCT cannot fully support CCSC. We would argue that BCT could definitely aid CCSC, however the technology might not yet be ready for implementation today.

6.0 SUMMARY AND CONCLUSION

In this chapter, we will present a summary and conclusion to our qualitative master thesis based on the research question. First, we will provide our study's theoretical implications. In this part we will also answer the two sub-questions. Second, we will provide the practical implications for the construction industry. Lastly, we will discuss the perceived limitations, and possibilities for further research.

Our aim with this master thesis was to investigate the following research question; *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?* In order to do so, we developed two sub-questions regarding how the current situation is in the construction industry regarding CE practices, supply chain visibility and digitalization, and the potential drivers, conditions and barriers for BCT to aid CCSC. The thesis is based on a qualitative study with expert interviews in order to investigate and increase the understanding of the research topic. It was beneficial to conduct qualitative expert interviews due to the fact that the studied phenomena are not yet implemented in the construction industry. Overall, we have interviewed 13 key actors from the industry, as it was important to understand how they perceived problems the industry is facing and how BCT could be used. After completing and analysing the interviews, the collected findings were discussed and compared with previous literature reviewed in the theoretical background.

6.1 Theoretical Implications

Our first sub-question is; *How is the current industry situation regarding circular economy practices, visibility, and digitalization?* Our findings and theoretical background reveal that it is crucial to implement CE strategies in the construction industry as the industry is responsible for a major part of virgin material extraction, as well as being responsible for a considerable amount of the yearly produced waste (Digitalt veikart, 2017; Circular Norway, 2020; SSB, 2021; Klima- og miljødepartementet, 2021). This implies that the level of circulating materials in the industry is too low. Our empirical findings are aligned with previous literature which states that transitioning into circular business models will reduce the amount of extracted resources, and this in turn will reduce emissions (Circular Norway, 2020; Mastos et al., 2021). The importance of this empirical finding was further supported as Klima- og miljødepartementet (2021) published their new CE strategy plan for Norwegian industry sectors in June 2021.

However, previous literature argues that an important condition for transitioning to CE business models is good supply chain visibility (Mittal & Sangwan, 2014; Korhonen et al., 2018b Demestichas & Daskalakis, 2020; Mastos et al., 2021). However, from theory and our research findings it is possible to conclude that this is difficult in construction supply chains due to the fragmented and complex structure (Cox & Ireland, 2002; Briscoe & Dainty, 2005). Further, from our findings, interviewees confirmed that the industry was struggling with obtaining optimal supply chain visibility, and that this was due to struggles with digitalization. Despite this, the interviewees had conflicting answers with regards to the level of digitalization. Some believed that the level of digitalization was sufficient as there are many new technologies available that could increase supply chain visibility. On the other hand, some interviewees found it problematic to transfer information due to the lack of standardization with regards to which data to collect, how to store, and which technologies to utilize. Some are still using manual collection, while others have adapted to more advanced systems. Even though the importance of standardization is emphasised in previous literature (Whyte, 2019; Digital Veikart 2.0; 2020; Behnke & Janssen, 2020), the conflicting answers from interviewees confirms that there is a problem with digitalization and standardization, which makes it more difficult to transfer information.

When we started this master thesis, we wanted to look into how BCT could be utilized due to the transparency and traceability the technology offers, as well as the cryptographical security that ensures immutability (Maull et al., 2017; Carlozo, 2017; Mastos et al., 2021). Because of these technological capabilities, we believed that BCT could be utilized as a standard technology in order to increase supply chain visibility and improve the information flow throughout the materials lifecycle. However, through our review of previous literature and expert interviews, it became evident that using BCT to store information, was not an optimal usage of the technology. We will now go through our main theoretical implications connected to the second sub-research question; *What are the potential drivers, conditions, and barriers for blockchain technologies to aid circular construction supply chains?*

Our findings implies that the perceived drivers for utilizing BCT in the construction industry could be split into three main parts, namely tokenization, transparency and traceability, and smart contracts. These abilities are recognized in the literature as some of the main characteristics of the technology. BCT has the ability to transform physical objects into digital assets which allows for digital twins of products and materials (Nakamoto, 2008; Francisco & Swanson, 2018; Li et al., 2019) that can provide additional information about a product and follow it throughout its life cycle. Therefore, this study implies that BCT could aid circular practices through using material passports to obtain end-to-end life-cycle information.

Further, as previous literature states, the BCT functions as an immutable ledger, where transactions that are made can provide trustworthy data for every participant in the network (Maull et al., 2017; Carlozo, 2017; Turk & Klinc, 2017). When combining this immutability with the technologies interoperability with other systems such as RFID, IoT solutions, BIM etc., BCT can provide real-time supply chain visibility (Kouhizadeh et al., 2019). Our empirical findings imply that this could therefore reduce wastage in the construction supply chain as materials are known and excess material can be circulated of correctly. Lastly, by applying BCT it could be possible to program smart contracts that activate when certain conditions are met (Tezel et al., 2020). As the technology can have authority over payments, this can provide the industry with automated processes from procurement to material tracking. Due to this, our study implies that smart contracts could be programmed to incentivise CE practices in order to reward supply chain actors when they comply with stipulated circular conditions.

Previous literature, usually discuss challenges with implementation of BCT, however, in this study we wanted to improve the understanding of the phenomena, and therefore chose to divide challenges into conditions and barriers for BCT adaption. Therefore, conditions are mainly derived from our research findings, and this study therefor contributes with improving the understanding of aspects which must be in place before trying to implement the technology. In this study, we found that some of the conditions that must be in place in order to implement BCT for CCSC are economic incentives, regulations and more use-cases. This is because this thesis is one of the first studies addressing how BCT could aid CE practices and business models in the construction industry. There are some examples of how BCT could be used in food or retail supply chains, but this study has looked closely as how it could aid CCSC in construction.

From reviewing literature and our empirical findings, there are some barriers to overcome. Our study implies that the main barrier for applying BCT is the fact that the technology is still relatively new. There is limited knowledge of how to use and implement the technology outside of cryptocurrencies. Because of this, our study implies that BCT might not be the right technology to use in order to enable CE strategies. There are also problems connected to the ownership of the decentralized data stored on the blockchain (Tezel et al., 2020), and the fact that operating a blockchain is very resource demanding which goes against the CE principles (Kouhizadeh et al., 2019; Viriyasitavat & Hoonsopon, 2019; Niranjanamurthy et al., 2018). However, as the technology is relatively new, our research findings suggests that it is likely that these barriers will be able to be solved in the future.

We have now presented our main implications summarised from our findings and contributions to the literature, in order to be able to conclude our main research question; *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?* Our conclusion is that BCT could contribute to increasing the supply chain visibility in the construction industry through its traceability, transparency, immutability and decentralized characteristics. Firstly, this could be done through the utilization of material passports and interoperability with other technologies. This could contribute to making the construction industry less fragmented and complex, as everyone in a specific supply chain would have the same information, reducing time and resource waste in supply chains. Secondly, we propose the application of blockchain enabled smart contracts with incentive systems. These contracts could have the potential to enable CCSC by incentivising construction companies to favour CE-practices in the construction process. However, as of 2021, the technology is still premature, and there is need for further research and development to facilitate for conditions and overcome barriers for BCT to enable CCSC.

6.2 Practical Implications

Our study also provides some practical implications for actors in the construction industry and their supply chains to consider when trying to use BCT to enable CCSC in the construction industry. In order to utilize a technology to improve the information flow in the chain, it is crucial that everyone has a common understanding and standard of how to collect, sort and store the information. Thus, BCT could be utilized across multiple systems for the industry. This way the architecture could be similar for projects and information exchange could improve. However, through the interviews that were conducted for this research, it became evident that in order to reach the required standardization it is important that everyone in the industry is aligned and willing to utilize either the same technology or technologies that are able to cooperate more efficiently.

In order to implement BCT to enable CCSC, our findings further show that there are some conditions that need to be in place. First and foremost, the conditions for implementing the technology in the construction industry regards establishing clear economic business cases, which can incentivise companies and their supply chains to partake in the utilization of this technology for reaching circular practices. Environmentally friendly practices are often regarded as being more expensive, and therefore it is important for the client to incentivise contractors through improved economic conditions. Another action for change could be for the government to issue new regulations, as this would motivate the whole industry to find new improved solutions of implementing CE strategies in their businesses. Focusing on conducting more use-cases could also motivate the industry to utilize the technology as industry actors find tangible results more appealing than theoretical promises. Starting out with small use-cases of how BCT could aid CCSC would be beneficial and could contribute to enlighten others of the potential and economic incentives which lies in this solution for CCSC.

However, our study shows that BCT might not be the most efficient technology to use as an enabler for CCSC in the construction industry. As the industry is traditional and has just recently familiarised itself with technologies such as BIM, new, unproven technologies could be repelled. This could potentially hamper the circular transition, due to difficulties with understanding the technology and the limited amount of use-cases. On the other hand, as our empirical findings suggest, BCT and smart contracts could be used as an incentive system to aid CE practices. Therefore, our last practical implication suggests that instead of using BCT to store material information regarding a construction during its lifetime as the study set out to investigate, actors in the construction industry should use BCT to issue rewards when partners fulfil circular contract demands.

6.3 Limitations

When starting to work on this thesis, we were aware that there would be some limitations regarding the research area and the combination of the two phenomena we sought out to explore. This is due to the fact that both phenomena are relatively new, there is limited previous research, few use-cases, and our knowledge of the research topic was somewhat narrow.

The main limitation was that there was a lack of previous literature conducted on our research topic. As both phenomena are relatively new, there have been conducted research for each of the phenomena separately, however, there are limited studies connecting the two phenomena with the construction industry as an empirical setting. For BCT, research has generally been conducted in regards to cryptocurrencies and smart contracts. Even though researchers have started to explore BCT in the construction industry, most of the research is theoretical. Additionally, the phenomenon CE is also relatively new, resulting in some of the same limitations. More research has been conducted on this subject than on BCT, however, it is still limited within the construction industry. Due to the limited amount of research that has been conducted on the two phenomena, there is also a lack of research conducted on the two of them combined. Regardless, as we have explored the drivers, conditions and barriers of the two, it has been possible to compare and contrast. The amount of overlapping research from each phenomenon is therefore considered sufficient for this thesis.

A result of the limited research conducted on the two phenomena is that industry actors are reluctant to partake in use-cases as researchers cannot predict cost reductions, efficiency increase or reliability issues in advance of a project. Contradictory, the answers industry actors require in order to partake in use-cases, is the same information the researcher will have to explore through use-cases in order to provide. This has limited the opportunity to compare tangible and quantifiable costs and benefits in the industry, and has compelled us to seek information from theoretical studies. The limited number of use-cases provides this thesis with the limitation that most theories are untested, and not validated by the construction industry. However, we sought to increase the understanding of the topic in order for the industry to view BCT as a possible technology which could aid the transition to CCSC, and this we have been able to do.

Another challenge is the fact that we have limited prior knowledge of both BCT and CE. As the comprehensive technical aspects of the technology are outside our prior area of expertise, our knowledge of the technological implementation of BCT is limited. Furthermore, we also possess a limited prior knowledge of the intricacies of CE as this is a broad research area with a multitude of subject areas. As both of these phenomena are relatively new, we had to explore different research in order to increase our knowledge enough to be able to create a model to bridge the two phenomena. Reviewing previous literature therefore took more time than first expected, however, we believe that we have made a thorough theoretical background which will aid those who read this thesis with the understanding of the phenomena.

As this is qualitative research with semi-structured interviews for data collection, we have been dependent on prior research, answers from actors within the construction industry, and blockchain experts. An inherent limitation with this is that all interviewees, to an extent, will answer our questions subjectively. This is regarded as a limitation, however, at the same time, it could provide some insight into the construction industry's current affairs. Furthermore, with regards to the blockchain experts, it might provide biased answers due to the experts favouring their area of research over other aspects of the technology. This was noted as the blockchain experts contradicted each other by recommending the type of blockchain that they themselves favoured and utilized in their research.

When conducting interviews, we tried to contact several contractors, however, we were unable to get hold of some of these companies, and others replied that they did not have the relevant expertise to contribute with. This may have led to the thesis missing out on essential findings, as these actors might for example have in-depth knowledge about the conditions that need to be in place in order to efficiently construct a building and preserve parts for circular usage. This limitation was a result of the limited time of the master thesis and the ongoing COVID-19 pandemic. For this thesis there were eleven interviews in total. The interviewees consisted of general experts from the construction industry, industry actors with more specific digital expertise, blockchain experts connected to the construction industry, and an expert within circular practices in the construction industry. As this thesis suffers from the limitations of a master thesis, with limitations related to time and resources, it was challenging to generalize our conclusions. However, as this study was conducted with multiple different actors from the industry, all with both digital competences, and most with sufficient circular competence, this thesis was conducted in regards to provide generalizable conclusions for the industry as a whole, not specific roles nor businesses.

This thesis has examined a combination of two phenomena and their interoperability that has not been previously explored in the construction industry. To explore a section of such magnitude in the construction industry has led to limitations towards what areas we have found to be of interest. Therefore, we were compelled to explore the drivers, conditions and barriers these phenomena could provide and face for the industry. These subject areas were explicitly selected to provide the groundwork and that could benefit others to further explore the research topic. Despite the aforementioned limitations, this research and its findings are still relevant as shown in *6.2 Practical Implications*.

6.4 Recommendations for Future Research

With regards to the conducted study in this thesis and the limitations that were discussed in the previous section, we believe our thesis topic could accentuate interesting subjects for future research. We therefore recommend future researchers to further investigate the studies regarding BCTs ability to enable CCSC. For future research our utmost recommendation is to conduct quantitative studies in order to collect and analyse how BCT can enable circular practices in construction companies. As mentioned, there is limited research conducted with regards to BCT ability to encourage CE-practices, and from our findings it is possible we see that this could make companies reluctant to take part in use-cases. Therefore, it is important that future research conducts research with explicit costs and benefits from the technology.

Further, comprehensive use-cases studies should be conducted in partnership with companies within the industry in order to find the most optimal use of BCT. As shown in our research, the technology possesses great potential for interoperability with other technologies that are currently utilized. Therefore, it would be interesting for researchers to explore to what extent blockchain interoperability can provide other systems with information and how this could be utilized for CE business models.

In this thesis we have explored the drivers, conditions and barriers for utilizing BCT to enable CE in the construction industry. As we have identified the most pressing matters for each section in this paper, it would be interesting for researchers to dive deeper and quantifiable explore the themes this paper provides. However, there are also still several interesting themes that are relevant for future research that we did not have time to explore in depth through this thesis. For instance, researchers could explore how implementation of the technology would vary between larger and more capital-intensive contractors compared to smaller and less well financed construction companies. Researchers exploring such matter could provide knowledge concerning how systems function in relation to one another and how much it would be utilized in smaller firms where digitalization might not be as well developed in the everyday work.

Another compelling subject for future research could be to explore how, or if, blockchain incentive systems could be integrated vertically in the construction supply chain through smart contracts. This is one of our main findings for BCT as an enabler for CCSC in is defined in this study as a driver. Looking more into how this could work would therefore be interesting. This type of research could be conducted in order for the researchers to enlighten how, or if, these systems could encourage circular practises for reusing and recycling of materials at end-of-life cycle in the construction industry. In addition, if researchers conducts use-cases it could be possible to quantifiably capture if there is a positive or negative correlation between implementation and reduction in costs. Such findings could further support the findings from this thesis.

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8.0 APPENDIX

8.1 Appendix 1: Interview guide – Actors from Construction Industry

Interview Guide **Research Question:** *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?*
<u>Introduction to the Master Thesis and the Interview</u> We are two MSc students at BI Norwegian Business School in Oslo studying 'Logistics, operations and supply chain management'. In our thesis, we are writing about how blockchain technologies could enable the transition to circular usage of materials in the construction industry. This is because we would like to explore how the relationship between improved visibility in the supply chain and improved material information could enable the transition to circular supply chains. As environmentally friendly productions and reduction of carbon emission is becoming increasingly important, being able to partake in a circular economy could enable the construction industry to reduce material usage and minimise extraction of new materials. Therefore, we wish to examine whether improved material visibility and information could enable circular usage of materials. In this interview we will mainly focus on, 1) The current situation in the construction industry with regards to visibility and digitalisation, and 2) drivers, conditions and barriers with implementing blockchain.

Tema	Spørsmål
Industri	**Vi ser på hvordan BCT kan muliggjøre sirkulær bruk av materialer - Hvordan ser byggebransjen ut i dag, mtp. digitalisering og miljøstandarder i forhold til produktinformasjon og synlighet i verdikjeden?** - *Oppfølging: Hvor ligger utfordringene og potensialet?*

	- *Oppfølging: Har BCT vært på deres agenda nå/tidligere?* Hvordan kan man benytte markedsplasser for brukte materialer? Hvordan er SC visibiliteten mellom aktører i byggebransjen i dag? - *Oppfølging: Hva kan gjøres for å forbedre disse punktene mellom partene?*
1) Muligheter / Fordeler	**Hva ser du som de største *fordelene* ved å implementere BCT mot å muliggjøre sirkulær økonomi?** Hva tenker du om muligheten for å lagre dagens systemer som BIM eller andre systemer på BCT?
2) Forutsetninger	**Hva ser du som de viktigste *forutsetningene* ved implementering av BCT for å muliggjøre sirkulær økonomi i byggebransjen i dag?** - *Oppfølging: hvilke forutsetninger er knyttet til CE og gjenbruk av materialer?*
3) Barrierer	**Hva tenker du kan være potensielle *barrierer* for å implementere BCT i bransjen, for å muliggjøre sirkulær økonomi, mtp. gjenbruk av materialer?** - *Oppfølging: barrierer knyttet til implementering av sirkulær bruk av materialer og SC visibilitet?*

8.2 Appendix 2: Interview guide - Blockchain Experts, Construction Industry

Interview Guide **Research Question:** *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?*
 <u>Introduction to the Master Thesis and the Interview</u>

We are two MSc students at BI Norwegian Business School in Oslo studying 'Logistics, operations and supply chain management'. In our thesis, we are writing about how blockchain technologies could enable the transition to circular usage of materials in the construction industry. This is because we would like to explore how the relationship between improved visibility in the supply chain and improved material information could enable the transition to circular supply chains. As environmentally friendly productions and reduction of carbon emission is becoming increasingly important, being able to partake in a circular economy could enable the construction industry to reduce material usage and minimise extraction of new materials. Therefore, we wish to examine whether improved material visibility and information could enable circular usage of materials.

In this interview we will mainly focus on, 1) The current situation in the construction industry with regards to visibility and digitalisation, and 2) drivers, conditions and barriers with implementing blockchain.

Theme	Questions
Industry	**We are looking at how BCT could enable circular use of materials - How does the construction industry look today, in the terms of digitalization and environmental standards in relation to product information and visibility in the value chain?** Can you briefly explain what BCT is? What is the difference between private and public BCT? - *Follow-up: Which of the two do you have the most faith in within a construction supply chain?* How can BCT be implemented together with current IT- and ERP solutions? - *Follow- up: Could BCT be utilized in addition (or as a supporting system) to modern ERP systems?* - *Follow-up: how can industries construct standards which can allow systems to communicate across platforms?*
1) Drivers	What do you value as the greatest benefits of implementing BCT to enable a circular economy in the construction industry?

	- *Follow-up: What does BCT bring to the table that current ERP-systems and BIM does not?* How can BCT improve supply chain visibility? How can BCT prevent wastage in the construction industry?
2) Conditions	What do you see as the most important prerequisites for implementing BCT to enable a circular economy in the construction industry? In what parts of the construction supply chain would BCT be most useful to enable circular economy? What other technological solutions must be implemented in order to achieve the benefits BCT can bring - regarding transparency and traceability?
3) Barriers	What are the greatest barriers for the implementation of BCT in the construction industry today? Can BCT handle the enormous amounts of data the industry requires to be stored?

8.3 Appendix 3: Interview guide - Circular Economy Expert, Construction Industry

Interview Guide **Research Question:** *How can blockchain technology enable circular construction supply chains through increased supply chain visibility?*
<u>**Introduction to the Master Thesis and the Interview**</u> We are two MSc students at BI Norwegian Business School in Oslo studying 'Logistics, operations and supply chain management'. In our thesis, we are writing about how blockchain technologies could enable the transition to circular usage of materials in the construction industry. This is because we would like to explore how the relationship between improved visibility in the supply chain and

improved material information could enable the transition to circular supply chains. As environmentally friendly productions and reduction of carbon emission is becoming increasingly important, being able to partake in a circular economy could enable the construction industry to reduce material usage and minimise extraction of new materials. Therefore, we wish to examine whether improved material visibility and information could enable circular usage of materials. In this interview we will mainly focus on, 1) The current situation in the construction industry with regards to visibility and digitalisation, and 2) drivers, conditions and barriers with implementing blockchain.

Tema	**Spørsmål**
Industri	Kan du komme med en rask forklaring av hva CE og CSC? Hvem eier materialene når byggene er revet? Vi ser på hvordan BCT kan muliggjøre sirkulær bruk av materialer - Hvordan ser byggebransjen ut i dag, mtp. miljøstandarder i forhold til produktinformasjon og synlighet i verdikjeden? - *Oppfølging: Hvordan vil dette være lagret i byggets levetid på 60-100 år?* - *Oppfølging: Hvem skal eie dataen?* Kan du forklare kort hvordan byggebransjen ser ut i dag, mtp. digitalisering i forhold til produktinformasjon og synlighet i verdikjeden? - *Oppfølging: Har BCT vært på deres agenda nå/tidligere?* Hvordan er SC visibiliteten mellom aktører i byggebransjen i dag? - *Oppfølging: Hva kan gjøres for å forbedre informasjonsoverføring og synlighet mellom partene?* - *Oppfølging: Kan du utdype litt om viktigheten av visibilitet (traceability og transparency) og CSC?*
1) Muligheter / Fordeler	**Hva ser du som de største *fordelene* ved å muliggjøre sirkulær økonomi i byggebransjen?**

	- *Oppfølging: Mange er skeptiske, hvor er businessen i CE?* Tror du BCT kan bidra med løsninger som dagens teknologi ikke gjør mtp.. synlighet og CSC?
2) Forutsetninger	**Hva ser du som de viktigste *forutsetningene* for å implementere CSC i byggebransjen i dag?** - *Oppfølging: hvilket nivå av sporbarhet/ synlighet vil du si at det er i bransjen i dag?* - *Oppfølging: digitale løsninger og sirkulær økonomi?* Hvilke materialer og produkter er brukt, dagens løsninger?
3) Barrierer	**Hva tenker du kan være potensielle *barrierer* for å implementere sirkulær økonomi, mtp. gjenbruk av materialer?** - *Oppfølging: barrierer knyttet til implementering av sirkulær bruk av materialer og SC visibilitet?* - *Oppfølging: Hvor villig er bransjen for å ta i bruk digitale løsninger (som f.eks. BCT) for å nå CSC?*