Master's degree thesis

LOG950 Logistics

Blockchain in construction industry for improved material information

Markus Hammerstad

Number of pages including this page: 101

Molde, 25 May 2021

Molde University College
Specialized University in Logistics

Mandatory statement

Each student is responsible for complying with rules and regulations that relate to examinations and to academic work in general. The purpose of the mandatory statement is to make students aware of their responsibility and the consequences of cheating. Failure to complete the statement does not excuse students from their responsibility.

*Please complete the mandatory statement by placing a mark **in each box** for statements 1-6 below.*		
1.	**I/we hereby declare that my/our paper/assignment is my/our own work, and that I/we have not used other sources or received other help than mentioned in the paper/assignment.**	☒
2.	**I/we hereby declare that this paper** 1. Has not been used in any other exam at another department/university/university college 2. Is not referring to the work of others without acknowledgement 3. Is not referring to my/our previous work without acknowledgement 4. Has acknowledged all sources of literature in the text and in the list of references 5. Is not a copy, duplicate or transcript of other work	Mark each box: 1. ☒ 2. ☒ 3. ☒ 4. ☒ 5. ☒
3.	**I am/we are aware that any breach of the above will be considered as cheating, and may result in annulment of the examination and exclusion from all universities and university colleges in Norway for up to one year, according to the Act relating to Norwegian Universities and University Colleges, section 4-7 and 4-8 and Examination regulations section 14 and 15.**	☒
4.	**I am/we are aware that all papers/assignments may be checked for plagiarism by a software assisted plagiarism check**	☒
5.	**I am/we are aware that Molde University College will handle all cases of suspected cheating according to prevailing guidelines.**	☒
6.	**I/we are aware of the University College's rules and regulation for using sources**	☒

Personal protection

Personal Data Act

Research projects that processes personal data according to Personal Data Act, should be notified to Data Protection Services (NSD) for consideration.

Have the research project been considered by NSD? ☐**yes** ☒**no**

- If yes:

Reference number:

- If no:

I/we hereby declare that the thesis does not contain personal data according to Personal Data Act.: ☒

Act on Medical and Health Research

If the research project is effected by the regulations decided in Act on Medical and Health Research (the Health Research Act), it must be approved in advance by the Regional Committee for Medical and Health Research Ethic (REK) in your region.

Has the research project been considered by REK? ☐**yes** ☒**no**

- If yes:

Reference number:

Publication agreement

ECTS credits: 30

Supervisor: Bjørn Jæger

Agreement on electronic publication of master thesis

Author(s) have copyright to the thesis, including the exclusive right to publish the document (The Copyright Act §2).

All theses fulfilling the requirements will be registered and published in Brage HiM, with the approval of the author(s).

Theses with a confidentiality agreement will not be published.

I/we hereby give Molde University College the right to, free of charge, make the thesis available for electronic publication: ☒**yes** ☐**no**

Is there an agreement of confidentiality? ☐**yes** ☒**no**

(A supplementary confidentiality agreement must be filled in)

- If yes:

Can the thesis be online published when the period of confidentiality is expired? ☐**yes** ☐**no**

Date: 25.05.2021

Table of Contents

Acknowledgment

I would like to start by thanking my supervisor, Bjørn Jæger, for your support and guidance. Your involvement in this study has been vital in both the theoretical aspect and setting up meetings with other individuals that have contributed to the research.

Secondly, I would like to send a special thanks to Stephan Nilson and Torje Vingen Sunde from Unisot, who participated in discussion sessions hosted by Bjørn. Here I got the opportunity to discuss my ideas and question in regard to blockchain.

I also wish to thank Contech for inviting me to one of their webinars, where I got my first meeting with the Norwegian construction industry. This gave me some insight into the current problem of the industry, which was very helpful.

And not to be forgotten, I would like to express my gratitude towards the interviews' participants. Their contribution to this research is significant, and without it would not be possible to finalize this study.

Abstract

The construction industry is the second biggest sector in Norway but one of the least digitalized. It is estimated that only 40 to 60 percent of the potential labor is used, and when it comes to materials, there is at least a 10 percent waste. It is stated that the industry's efficiency can be increased by 50-60 percent if measures are taken in specific areas. Some of these areas are improving the procurement process, increase transparency and take advantage of new digital technology and automation.

These logistical challenges all depended on a well-managed information flow among the supply chain actors. Traditionally, no well-established tool or system exists for managing business-to-business information flows. The recent blockchain technology seems promising.

Based on this, the author decided to explore how blockchain can improve the information flow of materials in the construction supply chain.
I developed the research problem by using a general exploratory research approach. To support the investigation of the research problem, three research questions were developed and answered through a general case study on the material information flow in the construction industry. The case study was conducted through exploratory research with the use of semi-structured expert interviews. The theoretical part will consist of literature on the general construction industry, supply chain, blockchain technology, and literature on blockchain in the construction industry. The result is divided into two parts, where the author first answers the given research questions concerning the current situation, barriers for implementation, and important supporting technologies for blockchain. The second part consists of using the result from the previous part to answer this thesis research problem.

The main conclusion of this research is that there are some great opportunities for implementing blockchain in the construction industry. The blockchain can improve the information flow by enhancing transparency and traceability and automating information sharing with IoT devices.

List of figures

1.0 Introduction

In a world where there is ongoing urbanization, affordable housing, and other essential constructions are vital. The construction industry is playing a crucial role as a solution provider to many of the urbanization challenges (Tafazzoli, Nochian, & Karji, 2019). The construction industry also has a vital role in environmental challenges. To put this statement into context, the construction industry emits over one-third of all greenhouse gasses and consumes 25 percent of all water (Müller, Krick, & Blohmke, 2020).

Materials used in construction are one major contributor to emissions, and as of now, 10 percent of materials are wasted. The materials cost stands for 50-60 percent or more of the total incurred cost in a construction project (Gulghane & Khandve, 2015) (Kong et al., 2004). On top of that, it will be increasingly important to know what materials are used in the complete construction and the origin of these materials. The material information about previous projects is minimal if not nonexistent, which makes the process of handling material waste challenging (Garas, Anis, & El Gammal, 2001).

It is safe to say that material management is a vital part of the construction industry and needs improvement. To enhance material management, it is necessary to improve the flow of information on the materials.

A characteristic of the construction industry is that it is segregated with many different actors working on the same projects, and they must follow strict rules and regulations (Dainty, Millett, & Briscoe, 2001). Therefore, there is a need for joint planning and coordination across the actors requiring high visibility and transparency.

The challenge for this industry is to share the information that the different systems and technologies generate in an accessible and digital way. Leite et al. (2016) mention that rapid technological advances and sensing technology have increased information and data created during a construction project.

The current IT systems used in the construction industry are disparate. Each actor has several IT systems of various kinds, making it challenging to integrate internally, especially externally.

Through the interviews done as a part of the research, I can confirm that the industry generates extensive data and information but lacks a digital infrastructure to benefit fully

from it. The information flow between the different actors is poor due to using systems that are not integrated.

There is a need for systems that can exchange information more accurately and quickly, where organizations are open, which is critical to maintaining relationships in complex supply chains. The new and disruptive technology called blockchain has been highlighted as a possible solution to improve visibility in supply chains. The blockchain offers transparency, and the technology may be the following digital framework for managing these relationships. This study will focus on the applicability of blockchain to keep track of materials information across the supply chain, from raw materials until it is replaced. As part of the study, this paper will also map the current supply chain and how blockchain can be implemented using the current technologies.

1.2 Problem statement

The aim of this master's thesis will be to investigate how blockchain technology has the potential to impact knowledge flow in the Norwegian construction industry. To concentrate on the field of investigation, the scope of this paper would be to explore how blockchain can enhance the information flow related to materials. The main research problem of this thesis is, therefore:

RP: *How can blockchain improve the flow of information in relation to materials throughout the construction supply chain?*

An exploratory literature study was conducted to investigate the research problem, followed by a case study on the general supply chain of the construction industry. This involves mapping the current state and exploring opportunities and barriers for implementing blockchain in the construction industry. To guide the research, three research questions were defined:

RQ1: *What is the current state when it comes to information flow in the construction supply chain?*

Mapping the industry as it is today was essential to get a better understanding of what kind of challenges it has, as well as what causes them. Only by doing this was I able to find applicable areas of the supply chain where blockchain could have a positive effect. This also leads the way to the next RQ:

RQ2: *What are the barriers to the implementation of blockchain in the construction industry?*

Since this paper is exploratory, it can be used by others who wish to research the same topic. Therefore, it was essential to identify the opportunities and identify the barriers to implementing blockchain in the construction industry. This can help future research to point their work in the right direction.

During the research, it became apparent that blockchain needs to be implemented with supplementing technologies. Therefore, it was viewed as essential to research and explain these technologies. As a result, the third research question became:

RQ3: *What type of supplementary technologies can blockchain benefit from?*

1.3 Background for the thesis

According to SSB (2019), the total revenue of the Norwegian construction industry was 560 billion NOK divided across 58 000 establishments and 256 000 employers. This makes the construction industry the second biggest sector in Norway.

Today, the construction industry has a reputation of being a rather resource-demanding industry with low levels of efficiency (Meland, 2000). SSB (2018) states that the productivity in the sector has been reduced by 10% since the year 2000. In comparison, the productivity in Mainland-Norway has increased by 30% in the same timeframe. Thunes (2015) points at the lack of interaction and innovation can take a fair share of the blame for the reduced productivity. By attending webinars where the construction industry's challenges were discussed, the lack of communication and information sharing between the different actors came up as a big problem. They struggle with information silos and information asymmetry. Information asymmetry is a problem because the various actors tend to use this to their advantage. They withhold some of the key information they have in order to take less responsibility and keep their cost at a minimum.

Blockchain has been viewed as a possible solution for this problem in supply chains in general.

(Chang, Katehakis, Melamed, & Shi, 2018) states that disintermediation, smart contracts, and as a solution to information asymmetries are three compelling elements of blockchain

technology that could be included in SCM. They then describe blockchain with the following characteristics: transparency, security, efficiency, and immutability. With these characteristics, blockchain can be a technology that can provide transparency in the way that all actors can access this information. It can also prevent the information from being tampered with. This could be a giant leap towards a supply chain with no information asymmetry.

1.4 The structure of the thesis

This first chapter provided a short introduction to the topic and a motivation leading to the research problem and research questions to be investigated. The second chapter consists of an overview of the research methodology used in this paper.

Chapter three consists of a theoretical background where previous work on the subject has been collected and reviewed. In chapter four, findings from interviews with the construction industry professionals, suppliers, and blockchain experts are presented. Chapter five discusses the findings and compares them to the literature. This is followed by listing the limitation of the research and future research opportunities, followed by the conclusion of this paper. Chapter six consists of a conclusion followed by limitations and future research.

2.0 Research Methodology

This chapter will elaborate on the methods used, why they are used, and how they were performed. I will describe the type of research done, including research strategy and research design. I will also include the methods that have been used regarding collecting the necessary data, as well as how the data have been analyzed.

2.1 Research strategy

For this master thesis, the author chose an approach to collect the viewpoint of well-established actors in the industry and experts on the topic. The qualitative research approach is concerned with the qualitative phenomenon, which relates either to quality or kind (Kothari, 2004). Or put in other words, qualitative research is appropriate to answer

why and how questions (Marshall, 1996).
Given the fact that blockchain adoption in the construction industry is in its infancy, it makes sense to choose a qualitative approach since it would be challenging to showcase the quantitative implications of the technology in this industry.

2.2 Research Design

A research design can be described as a framework for collecting and analyzing data (Bell, Bryman, & Harley, 2018).

It can be thought of as a step-by-step method for moving from point A to B. “Here” can refer to the various questions that you want the study to answer, and “there” can refer to the multiple steps required to answer them, such as data collection, analysis, and interpretation (Yin, 1994).

The research design is much more than an action plan. The aim will be to prevent a scenario where the research data fails to answer the research questions. The value of creating a proper research design from the start cannot be overstated. It would be difficult to draw any accurate conclusions for the study if this is not done correctly (Yin, 1994).

The exploratory research method was used to define the research problem of this thesis. Exploratory research is increasingly advocated, especially when used in new research themes (P. Mason, Augustyn, & Seakhoa-King, 2010). Stebbins (2001) states that it is necessary to start looking at a phenomenon in a broad and nonspecialized term to understand it well. To gain familiarity or insight into a phenomenon, exploratory research should be used. (Kothari, 2004). This research design are divided into three different phases.

Phase one is preparation. Thinking about questioning principles, data collection, sampling, and data analysis were all part of this process. The process of formulating the research problem alongside the research questions started with investigating different supply chains. The author used a significant amount of time investigating several supply chains that could be a part of the research problem of this thesis. The author was determined to explore the opportunity of using blockchain in a supply chain, but the challenge was to pick an

industry where the technology could be beneficial. The phase consists of writing down several questions that could be relevant to the research.

Phase two, which is called development, involves deciding which questions should be asked, which techniques would generate the required data, who should respond to the questions, and how the questions should be analyzed (P. Mason et al., 2010).

In this research is it was necessary to do a detailed analysis of the information flow concerning the material used in the construction industry. Researchers may use qualitative methods to investigate dynamic theories in their contexts. When appropriately used, the technique becomes a powerful tool for studies to improve theory, analyze projects, and develop interventions (Baxter & Jack, 2008).

The last phase is called refinement and involves analyzing the different data collection techniques to ensure that the data collection could generate the required information to answer the questions of the study.

To guide the investigation of the research problem, three research questions were defined as well. In order to answer the research questions, the case study method where used. Case study research is distinguished by its emphasis on how and why questions, making it suitable for descriptive and exploratory studies (Myers, 2019). Case studies can help with theory development in areas where the present theoretical and conceptual framework is lacking (Chetty, 1996). This is why a general case study of the construction industry was initiated, and the author retrieved vital information to answer the research questions.

2.3 Data collection

The data collection is done using interviews with actors in the industry and experts.

Interviews are one-on-one conversations between an interviewer and a participant intended to collect information on a specific collection of topics (Harrell & Bradley, 2009). In this case, the individuals selected for the expert's interview were people with a lot of experience and knowledge on the subject.

Especially, I contacted one individual who had a lot of knowledge about the construction industry. With help from this individual, I contacted potential participants who had even more expertise concerning the topic of this case. After gathering the information, I needed

from the construction industry experts, I could now approach my second target group. These are experts from the supplier side and experts on tracking and registration of goods and materials. This was done to better understand how the information moves between the different actors and potentially discover essential bottlenecks by including the supplier side. Since blockchain needs supplementing technology between the IT systems of an actor and the blockchain itself, it was necessary to interview the ones that create the solutions regarding tracking and registration of materials. The last group consisted of blockchain experts that could enrich the authors' knowledge on blockchain technology and comment on the findings I made from the first group. This provided me with potential solutions to some of the challenges the industry is facing.

Seven interviews were conducted. The duration of the interviews varied as a result of how talkative the different individual was, but on average, the interview lasted about 50 minutes. A larger sampling size could be beneficial, but the author sees the sampling as adequate to generate enough data for this thesis.
It could be argued that there should have been conducted more interviews with blockchain experts but given the fact that blockchain in supply chain is a new practice, finding respondents with expertise is challenging.

Table one provides a summary of the individuals interviewed with a short description of their role. The individuals are marked with an ID that will be used to refer to the different quotes in the findings part. The ID is used for privacy reasons.

ID	**Position**
C1	Development Manager and VDC -leader
C2	Advisor at NTNU – Department of Manufacturing and Civil engineering
C3	Construction professional
I4	Provider of tracking and registration tools
S1	Business developer in logistics - Supplier
B1	Blockchain expert/Researcher
B2	Blockchain expert

Table 1: Interview objects

3.0 Theoretical background

The theoretical context in this chapter will link the study to the established theory and expertise required to address the research question. Three main topics were identified: blockchain technology, construction supply chain, and blockchain in the construction supply chain.
First, it describes the revolutionary Blockchain technology, its internal processes, and the different blockchain forms. Then it focuses on the supply chain in general before the construction supply chain gets investigated. At last, this chapter presents studies done on the integration between blockchain and the construction industry.

3.1 Blockchain

3.1.1 What is blockchain?

Blockchain technology was first described in 1991 by Stuart Haber and W Scott Stornetta. Still, the real breakthrough in the technology came in 2008 when Satoshi Nakamoto released a white paper that established the blockchain model behind the cryptocurrency called Bitcoin (Nakamoto, 2008).
Today, most of us know blockchain as the peer-to-peer distributed ledger where all transactions made are stored in the chain of blocks. Each time a transaction is made, a new block of information is added to the chain that continues to grow Z. Zheng, Xie, Dai, Chen, and Wang (2018).

Based on their work, Seebacher and Schüritz (2017) gives an in-depth definition of blockchain technology that gives you a clear idea of how the technology works:

A blockchain is a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions that are secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it can not be altered, turning a blockchain into an immutable record of past activity.

Blockchain is a technology that goes under the term distributed ledger. The goal with

distributed ledgers is to allow users that does not necessarily know each other to interact with another without having to rely on a trusted third party (El Ioini & Pahl, 2018).

In its purest form, distributed ledger technology (such as the Bitcoin blockchain) is a one-of-a-kind technology in two ways. To begin with, it is distributed in nature: rather than relying on confidence in a third-party intermediary, agreement about the state of the ledger is achieved by (remunerated) consensus by the network of users.

Second, due to the technology's cryptographic and distributed foundations, users may "deposit" digital objects (e.g. documents, actions, and states) on the ledger (blockchain), the record of which is made permanent, open, and auditable while remaining resistant to censorship and manipulation (Maull, Godsiff, Mulligan, Brown, & Kewell, 2017).

3.1.2 How does blockchain work?

It is viewed as beneficial when explaining the concept of blockchain to explain how bitcoin work, given the fact that they are very much indeed linked together. However, blockchain can come in many different forms and with different objectives (Crosby, Pattanayak, Verma, & Kalyanaraman, 2016).

The digital transfer of assets is initiated when a sender submits a transaction. This transaction is the broadcasted to all the connected peers on the where nodes, also called miners use a cryptographic algorithm to validate the submitted transaction (Angraal, Krumholz, & Schulz, 2017).
For two willing parties to conduct an online exchange over the Internet, Bitcoin employs cryptographic evidence rather than the trust-in-the-third-party mechanism. Each transaction is secured by a digital signature, is sent to the receiver's "public key," and is digitally signed with the sender's "private key."

Four key concepts

Shared ledger

Ledgers are nothing new; they have been used in double-entry bookkeeping since the 15th century. What has helped rethink business is the emergence of shared, distributed ledger technology. Transactions are reported only once in a shared ledger, removing the duplication of effort that is common in conventional business networks (Gupta, 2020). The public ledger has the following features:

1) The shared ledger is the system of record, the single source of fact, it records all transactions through the company network.
2) Is shared by all network participants; each has a duplicate copy of the ledger thanks to replication.
3) Is permissioned, because participants see only the transactions they are allowed to see; participants have identities that connect them to transactions, however they may select which transaction details other participants are authorized to see.

Permissions

Blockchain technology can be permissioned or permissionless. Each user in a permissioned blockchain has a unique identity, allowing policies to be used to limit network involvement and access to transaction data. Data privacy requirements, such as those outlined in the Health Insurance Portability and Accountability Act, can be more readily met by organizations. Permissioned blockchains are also better at monitoring the accuracy of data added to the network. A digital certificate, like a passport, contains identification details, is immune to forgery, and can be validated since it was issued by a reputable organization (Gupta, 2020).

Consensus

The challenge of reaching a consensus in distributed computing is a fundamental problem. Transactions may be verified and committed to the ledger by consensus in a business network where participants are identified and trusted (agreement). Consensus processes differ from one blockchain to the next, but they all contain the following:

1) Proof of stake is a method to validate transactions through holding a certain percentage of a networks total value. Proof of stake can provide improved network security by lowering the incentives for malicious attacks and making them very costly to carry out.
2) Multi-signature is a method that relies on having a majority of validators to agree on the validity of the transaction.
3) Blockchain also consist of an algorithm called practical byzantine fault tolerance, in order to settle any disputes among the computing nodes. This is used when one node in a set of nodes generates a different output than the other nodes.

Smart contracts

In 1994, Nick Szabo came up with the term “smart contract,” which he described as “a computerized transaction protocol that executes the terms of a contract.”

Smart contracts are scripts that are stored on the blockchain. They’re similar to stored procedures in relational database management systems. They have a distinct address since they are part of the chain. A smart contract is triggered by sending a transaction to it. According to the data included in the triggering transaction, it then executes independently and automatically on every node in the network in a specified manner (Christidis & Devetsikiotis, 2016)

A smart contract is an agreement or set of rules that govern a business transaction; it’s stored on the blockchain and is executed automatically as part of a transaction. A smart contract, for example, could specify the contractual conditions to which corporate bonds are transferred; it could also encapsulate the terms and conditions of travel insurance, which could be enforced automatically if a flight is delayed for more than six hours, for example (Gupta, 2020).

It should be mentioned that blockchain can reduce information friction. Not having the necessary information or being uncertain of the information can be a barrier in business. Properties in the blockchain technology can act as a mean to reduce the information, and these properties are shared ledger, permissions, cryptography and consensus.

3.1.3 Structure and architecture

According to Laurence (2017), the blockchain is made up of blocks that contain a number of transactions that are then connected (chained) together using cryptography to form the blockchain. Blockchains are made up of three major components: blocks, chains, and networks. The block is where all transactions for a given time are reported to a ledger.

The size, time, and triggering events for each block are dictated by the blockchain’s purpose, which is not the same for all blockchains. The blocks are distributed across the entire network to ensure the intended validity and consensus. The blockchain is made up of chains that are connected. Cryptographic hash functions serve as the glue that holds the blocks together and can be thought of as the fingerprint of the data from the previous block

to which it “chains” itself, referred to as the parent block. This method is known as game theory since complete nodes play against each other to find the right hash function and obtain the reward, which is normally a cryptocurrency coin.

Blockchain, like a public ledger, is a collection of blocks that store information about all transactions and are connected together by a reference hash from the previous block (hash block). The genesis block is the beginning or parent block. In general, a block consists of a block body (which includes transactions and the transaction counter) and a header (Liang, 2020).

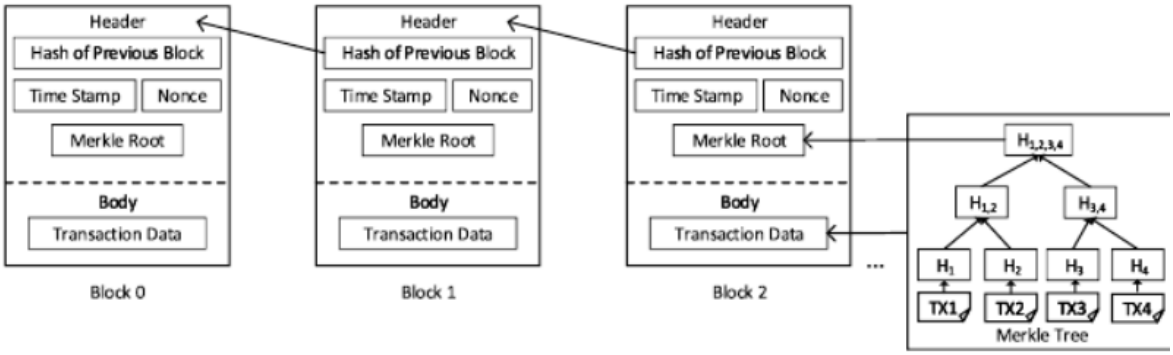

Figure 1: Structure of a blockchain. Fig. 5.1 (Liang, 2020)

3.1.4 Why is blockchain relevant for business?

How can blockchain create trust?

Since transactions cannot be tampered with and are authenticated by the relevant counterparties, any manipulation is readily evident. Blockchain is especially useful at raising the degree of confidence among network members since it offers cryptographic evidence for a collection of transactions.

Gupta (2020) claims that trust in a blockchain can be created by five attributes.

Distributed and sustainable

In near real time, the ledger is exchanged, updated with each transaction, and selectively repeated by participants. The blockchain platform’s continued life is not dependent on any single entity because it is not owned or operated by any single entity.

Secure, private, and indelible

Permissions and cryptography protect the network against unwanted access and ensure the users are who they say they are. Confidentiality is maintained by using cryptographic and/or data partitioning techniques to give participants selective access to the ledger; both transactions and transacting parties' identities can be masked.

Transparent and auditable

Since transaction parties have access to the same documents, they can check transactions and verify identity or ownership without the use of third-party intermediaries. Transactions are time-stamped, organized, and verifiable in near real time.

Consensus-based and transactional

A transaction's validity must be agreed upon by all related network members. Consensus algorithms are used to do this. Each blockchain network can define the terms in which a transaction or asset exchange can take place.

Orchestrated and flexible

Since business rules and smart contracts can be integrated into the platform, blockchain business networks can grow as they expand and support end-to-end market processes and a broad variety of operations.

Characteristics

Another way of identifying how blockchain can be relevant for business is to look at the characteristics of blockchain.

Z. Zheng et al. (2018) propose that blockchain technology has four key characteristics which are:

- Decentralization
- Persistency
- Anonymity
- Auditability

On the other hand, Seebacher and Schüritz (2017) identifies two principal characteristics, which is trust and decentralized nature. Within the principal characteristics called trust, they further describe three subcategories of characteristics which is transparency, integrity,

immutability. Within the decentralized nature, they list privacy, reliability and versatility as the characteristics.

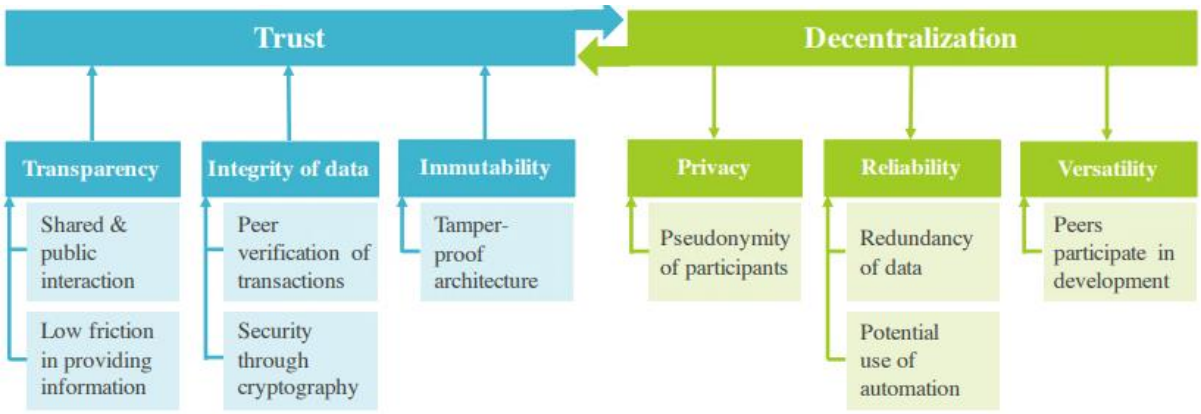

Figure 2: From (Seebacher & Schüritz, 2017)

Decentralization

There is no need for a control center since the blockchain system uses peer-to-peer networking. Every node in the network has the same system status. The created data blocks are maintained by all the system's nodes. All the nodes have registered and saved transaction data, improving the database's robustness (Wu & Tran, 2018).

There is no longer a need for a trusted third party which previously have been a bottleneck for cost and efficiency (Z. Zheng et al., 2018). (Ølnes, 2016)

Privacy is created since blockchain technology is built on a peer-to-peer network, it enables a high level of anonymity for its users. This is combined with the technology's capacity to encrypt communications between two people using public-key cryptography and the way that names are concealed behind pseudonyms (Seebacher & Schüritz, 2017).

Reliability can be obtain by in the system with the help of two factors. Firstly, transaction information is exchanged and processed in the network and is thereby handled redundantly. In this way the information will always be accessible even though some of the network would be disconnected (Sharples & Domingue, 2016). On the other hand, because the system is built on data and code, the implementation of automatic interventions is encouraged, which can eliminate human errors because there is no little need for manual interference (Weber et al., 2016).

Versatility

As Ølnes (2016) points out, social and technical diversity will increase by time since blockchain technology encourages the development of an open and versatile infrastructure by allowing its users to integrate their own systems, create and distribute their own code, and thus shape their own environment. We have already seen the rather new technology start out mainly with Bitcoin, and evolved from not only being applicable to finance, but also to be used in areas such as supply chain.

Trust

When it comes to trust as the findings of Seebacher and Schüritz (2017) supports the claims being made by Gupta (2020) listing the characteristics of transparency, integrity of data, and immutability.

3.1.5 Classification of blockchains

I we look at the basis of control mechanisms and authentication, the blockchain systems can be divided into three categories (Z. Zheng et al., 2018):

- Public
- Private
- Consortium

In the subsection below the mentioned categories will be explored.

Public blockchain

A public or permission less blockchain is a decentralized open source network that allows everyone to enter and mine regardless of their affiliation. Any participating node has the possibility to perform blockchain operations like publishing, interpreting, reviewing, and auditing (Puthal, Malik, Mohanty, Kougianos, & Das, 2018). Due to the open nature of a shared blockchain, each user collects transaction data and begins the mining process to obtain the reward.

The consensus mechanism is critical for maintaining block continuity throughout the blockchain and avoiding the situation where no nodes have several blocks that contradict each other.

Sybil attacks are viewed as the biggest threat to open blockchains, due to the participants are unknown and are free to create the block. In terms of addressing such issues, Proof-of-Work (PoW) consensus mechanisms are the most effective. To control the trade, the adversary must have 51 percent of the total mining capacity.

In blockchain, public key cryptography is used to encrypt transactions, with the hash value of each user's public key serving as the user's address.

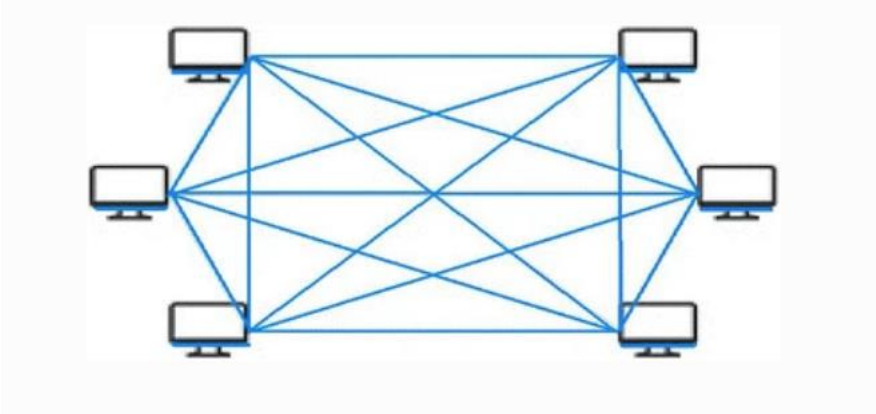

Figure 3: Illustration of public blockchain (Niranjanamurthy, Nithya, & Jagannatha, 2019).

Private blockchain

A private or permissioned blockchain is a decentralized network that enables a small group of people or an entity to share private data. The mining process in a private blockchain is controlled by selected individuals or a dedicated team, limiting access to unknown or new users until they are invited by some governing authority (Puthal et al., 2018) (D. Guegan, 2017).

Since private blockchains have a high transaction processing rate due to the small number of approved users, it takes less time to reach network consensus, and more transactions can be processed in a second (Yang et al., 2020).

But on the other side, since private blockchains have fewer nodes, it is easier for a bad actor to take control of the network. As a result, when opposed to public blockchains, the chance of hacking and data manipulation is higher in private blockchains.

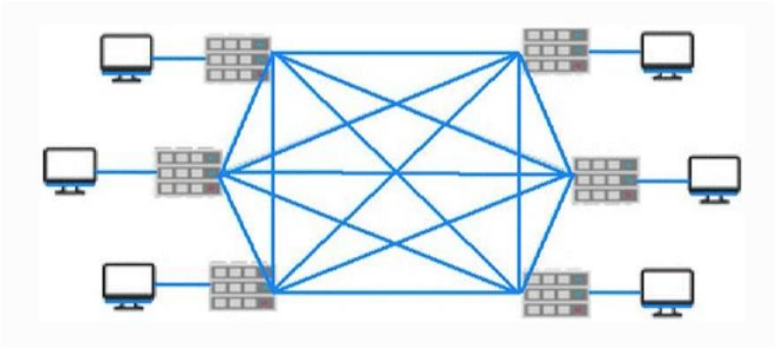

Figure 4: Illustration of private blockchain (Niranjanamurthy et al., 2019)

Consortium blockchain

A consortium blockchain is a hybrid of private and public blockchains in which a set of individuals is in charge of reaching consensus and validating blocks. In such a network, blocks are mined using a multi-signature scheme, and miner blocks are only considered legitimate if they are accepted and signed by the controlling node (Bhushan et al., 2020).

The consortium determines whether read and write permissions are public or restricted to network participants. Furthermore, confining consensus to a small number of nodes does not guarantee immutability or irreversibility, since a majority control of the consortium may lead to blockchain tampering (Puthal et al., 2018).

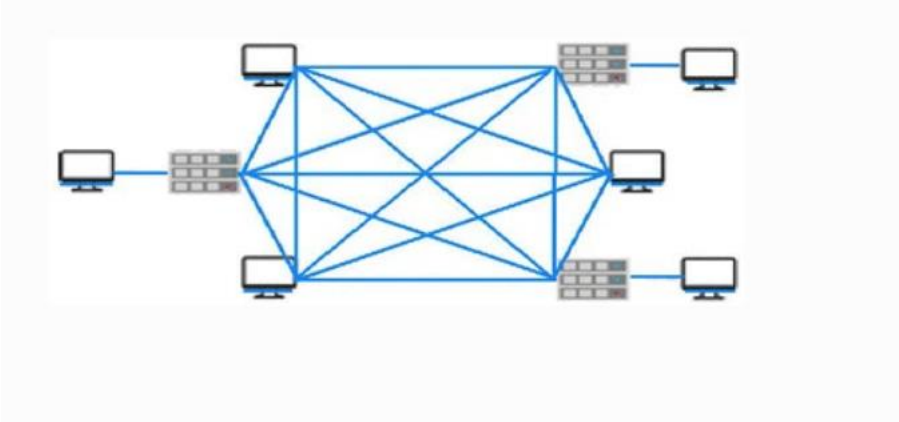

Figure 5: Illustration of consortium blockchain (Niranjanamurthy et al., 2019)

With this different options it might look difficult to know which blockchain to use for you operation. But Turk and Klinc (2017) presents a framework for choosing the optimal solution based on what need the company have.

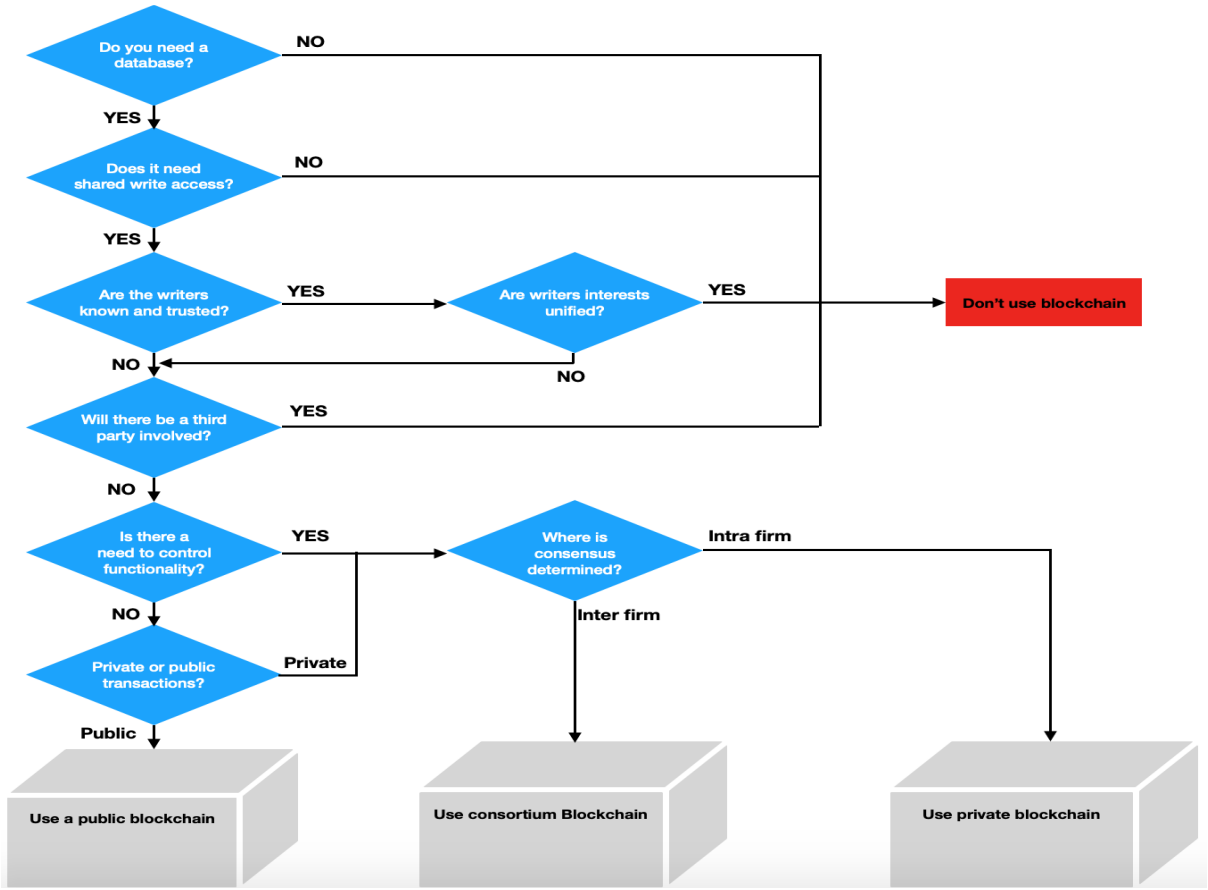

Figure 6: How to decide what blockchain to use. Inspired by Fig2 in (Turk & Klinc, 2017)

3.2.1 Supply chain management

In order to provide the reader with the necessary information, a short section will now describe what supply chain management is.

Firstly, it would be beneficial to define what a supply chain is, and one way of defining a supply chain is has been presented by Christopher (2017) which defines it as:

"A network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate customer."

But when it comes to supply chain management, Mentzer et al. (2001) claim it can be described with three characteristics:
1. A systems-oriented approach to viewing the supply chain as a whole and managing the total movement of product inventory from the producer to the final customer.

2. Strategic focus on collaborative efforts to synchronize and converge intrafirm and interfirm organizational and strategic capabilities into a single whole.

3. Focus on creating an unique and personalized source of customer value, leading to customer satisfaction.

3.2.1 Supply chain in construction industry

There is empirical evidence that indicates that the construction industry can make significant improvements to its supply chain (O'Brien & Fischer, 1993). The industry is one of the most diverse and dysfunctional sectors. It must incorporate a diverse range of specialist skills across geographically scattered short term project settings, as well as deal with large fluctuating demand periods, project-specific product demands, and unpredictable production conditions (Dainty et al., 2001).

They work with one-of-a-kind project where they are sought out to build a specific object for a specific client in a set time frame. The process and the involved parties' changes with each unique project and you can say that they have temporarily organizations and site productions. This prevents the industry from having as efficient flow as for instance in manufacturing (Application of the new production philosophy to construction). A typical supply chain in the construction industry consists of architects, engineers, main contractors, subcontractors, consultants and material suppliers. The architects, engineers and some other construction professionals have negotiated fees, but the rest of the actors are chosen typically by the "lowest bid" wins model (Dainty et al., 2001).

As an example, the general contractor who oversees a building project typically performs only a small portion of the "product" with its own staff and manufacturing facilities. The

majority of the product's value, approximately 75 percent or more, is built with the assistance of suppliers and subcontractors (Dubois & Gadde, 2000).

The complexity and diversity mean the project company will be able to choose its own services and supplies, resulting in unique supply chains that must be reorganized for each project (Pryke, 2009).

Below you can see a figure that showcase the different actors and their relation in the construction supply chain.

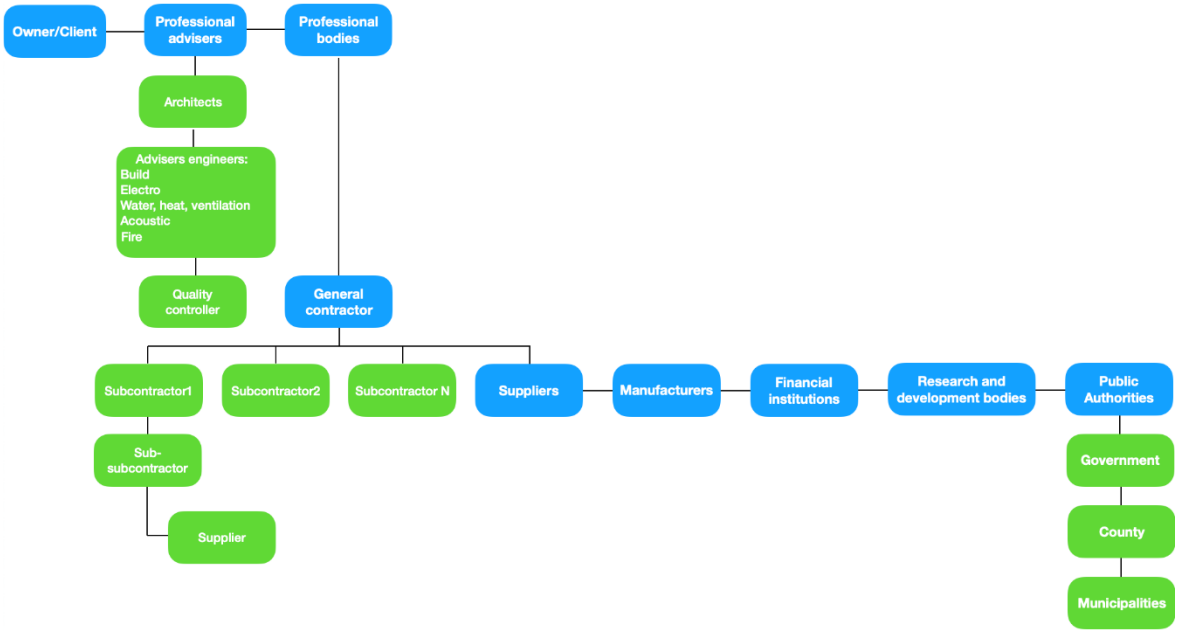

Figure 7: Inspired by Fig 1 in (Khalfan, Kashyap, Li, & Abbott, 2010)

With the combination of one-of-a-kind projects and a competitive bidding process for subcontractors and suppliers creates an industry with short-term relationships that results in poor information exchange and a lack of motivation for common learning. Behera, Mohanty, and Prakash (2015) continues to claim that there have been a construction supply chain revolution, where the industry have changed their strategy and tried to adopt some of the SCM processes found in the process industry.

Compared to other industries, the construction industry is lacking behind when it comes to digitalization. Trough a case study performed by Čuš-Babič, Rebolj, Nekrep-Perc, and Podbreznik (2014) it was discovered that there are insufficiencies in traceability and communications between the different parts of the supply chain.

What does the literature say about the visibility in the construction industry supply chain?

Young, Haas, Goodrum, and Caldas (2011) claims that much of the uncertainty in the construction industry arises because of the lack of visibility in the supply chain. In their article they explore the possibility on using Automated Materials Locating and Tracking Technologies (AMLTT) in a construction supply chain as a viable solution to this problem.

Dharmapalan, O'Brien, Morrice, and Jung (2021) have carried out a study to investigate the differences in the viewpoint of owners, designers, contractors and suppliers regarding the visibility of materials at different locations and different materials under an ongoing industrial construction projects. The owner, contractor, supplier, and designer groups have the least visibility at the offsite Tier-2 supplier, ports, and kitting site. In addition, as compared to the owner, contractor, and designer groups, the supplier group has adequate to extreme visibility at the Tier-2 supplier, kitting location, and during transportation. They also discovered that owners and contractors believe prefabricated material needs more visibility than all other material types.

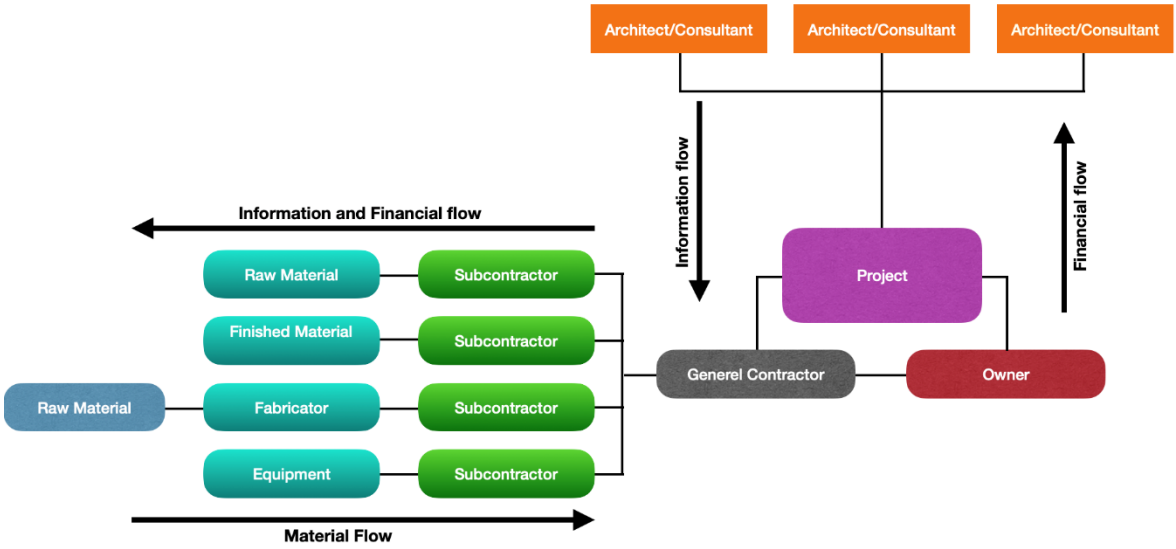

Figure 8: Information flow in construction supply chain. Figure inspired by Fig. 3 in (Vrijhoef & Koskela, 2000).

3.3 Supplementing technologies for blockchain

For the benefit of the reader I will in this segment give a brief introduction to technologies which blockchain can be implemented with. This will perhaps give a better understanding

of the following chapter where I review current literature on blockchain in the construction industry.

Internet of Things (IoT)

In general, the Internet of Things (IoT) refers to the networked interconnection of ordinary objects, all of which are fitted with pervasive information. IoT would improve the Internet's ubiquity by incorporating any entity for interaction through embedded systems, resulting in a massively dispersed network of devices interacting with humans and other devices (Xia, Yang, Wang, & Vinel, 2012). The fundamental premise behind this principle is the ubiquitous existence around us of a multitude of items or items – such as Radio-Frequency Identification (RFID) tags, sensors, actuators, cell phones, and so on – that can communicate with each other and collaborate with their neighbors to achieve mutual objectives through specific addressing schemes (Atzori, Iera, & Morabito, 2010).

Building Information Modeling (BIM)

A construction information model defines the geometry, spatial relationships, geographic information, quantities and properties of building elements, expense forecasts, resource inventories, and project timeline. The model will be used to illustrate the entire life cycle of a house (Azhar, 2011).

3.4 Blockchain in supply chain for better information sharing

Wan, Huang, and Holtskog (2020) article investigated how blockchain-enabled information sharing might repair and strengthen the aspect of information and data trust among supply chain actors. In this comprehensive literature analysis, they contributed by finding the substantial implications of deploying blockchain-enabled information sharing inside a supply chain. The major conclusion is that this technology assures that participants of the chain can obtain validated information, which improves collaborative partnerships. The usage of blockchain-based platforms with incorporated smart contracts can boost information exchange across trusted and untrustworthy entities while lowering security risks. This can improve any sort of supply chain by reducing information silos, which are common in practice.

Through their research Mackey and Nayyar (2017) could conclude that blockchain can improve the information sharing in the supply chain. In their case it could strengthen the procedure regarding detection of fake medicines.

Nakan proses a blockchain scheme for information sharing. This solution enables sharing of transaction data without having to rely on a third-party actors. This is made possible by the platform's combination of a blockchain and a homomorphic encryption solution. Users are not needed to trust any third parties and are constantly aware of the data that is gathered about them and how it is utilized.

3.5 Blockchain in construction industry

This segment offers a summary of the emerging state of the art for blockchain applications in the construction industry. Through a comprehensive search on the web, peer-reviewed academic journal papers, conference papers, and book chapters were selected for further reviews. All papers that did not primarily focus on construction business process were excluded. This chapter will be two-folded, the first part will include findings from literature that focuses on blockchain in construction industry in general, such as literature reviews and other papers that summarize the use of blockchain in construction industry. The second will include papers that focuses more on specific topics. In the search of literature concerning blockchain in construction industry, following search words have been used in different compositions:

- Blockchain
- DLT
- BIM
- Construction industry
- IoT
- Information sharing

The literature used is mainly journal articles and conference papers, but literature reviews and reports have been included. Oldest literature dates back to 2017, and the newest literature used was published in the current year.

Blockchain in construction industry in general

Barima (2017) research investigates blockchain technology with the goal of informing the construction sector about the technology's potential to improve value delivery. The research investigates the possible applications, advantages, problems, and consequences of blockchain technology for the construction sector. One significant aspect of the construction industry that can benefit from the usage of blockchain technology is construction procurement. This frequently comprises the acquisition of services, materials, and even the task itself. In each of the described procurement categories, blockchain technology may be used to monitor records/registers between devices, as well as between devices and their users/web services, in a transparent way.

Certain blockchain-based applications have the potential to be used to manage smart networked equipment through the internet of things. This can provide a transparent environment for learning, machine-to-machine interactions, and the assignment of obligations when liabilities arise. This potential will be especially valuable throughout the facility management phases of developed items.

Li, Greenwood, and Kassem (2019) have done a systematic review on blockchain in the built environment and construction industry. They make several findings, and one of their findings is the fact that data is more open, it may be exchanged more freely, enhancing collaboration and confidence among parties. Tokenization will incentivize parties to share data, while reputation ratings will promote more strategic collaboration. They also claim that blockchain combined with digital twinning can be a huge opportunity. Throughout the course of a developed building, a digital replica delivers useful information to all stakeholders. DLT facilitates digital twinning by boosting inspections through the use of IoT, drones, and real-time data. In terms of materials immutability improves the visibility and real-time tracking of materials in projects and supply chains by adding transparency to agreements and transactions.

Focused articles

There were 21 articles that was viewed as applicable to this section of the paper. This is including the reviews previously mentioned. While reading through the different articles, the author realized that the article touches upon some of the same topics. There it was

decided to organize the papers in a table that inform what type of paper it is, as well as what topic they include.

Article	Type of paper	Supply chain	Smart contracts and cryptocurrency	Information Management	Integrating blockchain with current technology
(Qian & Papadonikolaki, 2020)	Journal article	Shifting trust in the SC with BC	Smart contract as a mean for trust I SC	Discusses how BC can improve information sharing	BIM and IoT
(Lanko, Vatin, & Kaklauskas, 2018)	Conference paper	BC in SC combined with RFID	Smart contract with BC and RFID	How the use of RFID and blockchain can provide more information	IoT
(Wang, Wu, Wang, & Shou, 2017)	Journal Article	Investigating applying BC in construction SCM	Blockchain enabled contract management		BIM
(Shemov, de Soto, & Alkhzaimi, 2020)	Journal Article	Case study on applying BC in construction SC	Presents architecture for smart contract in early stages of SC.		
(Tezel, Papadonikolaki, Yitmen, & Hilletofth, 2020)	Journal Article	Investigates potentials and future direction of BC in construction SC.	Investigates the use of smart contracts in construction SC	Elaborate on how information can be better managed with BC.	BIM and IoT
(McMeel & Sims, 2021)	External research report		Token economy for trading construction waste, smart contracts for payment, smart contracts for material procurement		
(Ahmadisheykhsarmast & Sonmez, 2018)	Conference paper		Smart contract as a tool to prevent late payments.		

(Zhong et al., 2020)	Journal Article		Automated compliance check with smart contract	Designed a consortium blockchain system for quality information management.	
(Nanayakkara, Perera, & Senaratne, 2019)	Conference paper		Computes the stakeholder perspective on smart contracts is construction industry.		
(J. Mason, 2019)	Journal Article		Investigate if smart contract will work best with or without BIM		BIM
(Shojaei, Flood, Moud, Hatami, & Zhang, 2019)	Conference paper		Integrating smart contract, BIM and blockchain		BIM, IoT, RFID
(Altay & Motawa, 2020)	Conference paper		Investigates the applicability, possible benefits, limitations of smart contracts in construction industry		BIM
(Badi, Ochieng, Nasaj, & Papadaki, 2021)	Journal Article		Identify the factors that influence the adoption of smart contracts		BIM
(Turk & Klinc, 2017)	Journal Article			Investigated where and how blockchain can be useful	BIM
(Sheng et al., 2020)	Journal Article			Proposing a blockchain based framework for management of quality data	BIM
(Rodrigo, Perera, Senaratne, & Jin, 2020)	Journal Article			Investigates how blockchain can be used to estimate EC in construction supply chain.	

(Xue & Lu, 2020)	Journal Article				STD approach with BIM
(R. Zheng et al., 2019)	Journal Article				bcBIM model together with big data in mobile cloud
(Chong & Diamantopoulos, 2020)	Journal Article				Smart sensors, oracles, and BIM
(Liu, Jiang, Osmani, & Demian, 2019)	Journal Article			BIM + BC for Sustainable Building Design Information Management Framework	BIM
(Mathews, Robles, & Bowe, 2017)	Conference paper			How the blockchain can improve interaction between the stakeholders.	BIM, IoT

Table 2: List of paper used in this chapter.

Some academics claim that using blockchain technology to digitize potential construction business processes, such as automated conditional construction payment, blockchain-enabled contract management, blockchain-enabled supply chain management, and construction data management, would be advantageous. Historically, the building industry has been ranked as the second-lowest adopter of information technology. This raises the question of whether blockchain is just a technical fad or whether it has actual promise in the building industry (Perera, Nanayakkara, Rodrigo, Senaratne, & Weinand, 2020). In the next segment of this paper a review of how blockchain can enhance work processes in the construction industry.

Blockchain in Construction Supply Chain Management (CSCM)

Given the fact that a construction supply chain is rather fragmented, it can be a good match with the decentralized nature of blockchain. There are often several actors included in all

the phases of a build, and there is a need of trust and transparency between the different parties. Blockchain may serve as a neutral infrastructure to ensure supply chain transparency and traceability, which are critical in this industry.

Vendors and suppliers can easily exchange immutable licensed certificates for their certification to deliver specific goods and/or services using a blockchain network for supply chain management, and buyers can verify those certificates and evaluate their reputation by reviewing their previous track records on blockchain. Given the fact that you now have the ability to assess how the other part have operated in the past, it will be easier for buyers and vendors to establish trust between each other.

Qian and Papadonikolaki (2020) have done a study in order to examine how blockchain technology is the trust in construction supply chain. Their study points out that blockchain applications in a construction supply chain contribute more to cognition- and system-based trust, which can reduce the necessity of setting up relation-based trust. But that a further investigation on the nature of the decentralization is needed in order to gain the knowledge to define an appropriate DAO's that enables all the supply chain partners to trust it. Lanko et al. (2018) proposes that integrating blockchain and RFID technology in construction material logistics allows real-time monitoring of construction material distribution and estimation of delivery time, allowing for improved project preparation based on scheduling logistics delivery details and thereby minimizing losses from delivery delays.

As an example, on how to enable re-use and recycling materials possible, one article portrays the process from precast product (concrete product casted in reusable mold form) acquisition to final implementation as an example of blockchain technology use. All transactions in this phase can be registered on blockchains and verified by all relevant stakeholders along the supply chain, allowing for completely open inventory information and allowing for material re-use and recycling (Wang et al., 2017)

Shemov et al. (2020) states that there is a need for a cross-connected platform for all stakeholders attached to a project. An emergent system architecture for the use of smart contracts in the early stages of the CSC is introduced in a case study. The blockchain application that have been used falls in the category of consortium blockchain, where some of the data is open to multiple parties and some information are kept confidential. This balance enables more transparency and higher efficiency.

Through their study Tezel et al. (2020) found that blockchain cannot be completely leveraged in the AEC sector without significant changes to business models, procurement arrangements, and increasing productivity in the industry. These incremental improvements are needed to hit a plateau of efficiency in effectively integrating blockchain into project life cycles.

Cryptocurrency and Smart Contracts in Construction

However, the industry's decentralized and adversarial essence has long been up to debate for the inefficient procedures and poor levels of efficiency. These adversarial partnerships result in lack of trust, disputes, and win-lose behaviors. As a result, standard contracts obstruct the industry's ability to achieve the desired project results.

Through an extensive research period of two years McMeel and Sims (2021) three use-cases involving blockchain in the construction industry have emerged.

The first one is smart contracts for material procurement. Material procurement arose as a complex process which is in many cases are paper based. As a result, errors in directives are more likely to go unnoticed. The study investigated how smart contracts could automate, streamline, and offer a much simpler management overview of procurement processes.

The second use-case they present is about using smart contracts for payments. Late and disputed payments are major sources of controversy in the industry. Payments may be immediately activated when a contract is validated as completed, speeding up the process. They investigate how a smart contract system might appear in a construction project. The last one is a token economy for trading construction waste. Token economies make it possible to foster and incentivize particular types of trade. Construction waste is a big issue for the industry, with most of it ending up in landfills. This use-case examines how blockchain could allow the development of a sophisticated economy based on the trading of construction waste by providing financial incentives to handle and reuse it.

Ahmadisheykhsarmast and Sonmez (2018) explores how the building industry could benefit from smart contracts and blockchain technology, as well as potential options for insolvencies within the industry. The proposed definition discusses how the smart contract could be used in the building sector during the acquisition process and intermediate payments. Furthermore, the advantages of the proposed concept include eliminating third

parties, lowering administrative costs associated with tracking down payments, preventing parties from missing payment dates, decreasing mutual conflicts, and increasing competitiveness and confidence.

Zhong et al. (2020) uses smart contract in order to automate the compliance checking, that way they can assure the construction products/materials used in a project meets the regulation requirements.
Another paper looks into how the stakeholder perspective on smart contracts and blockchain in the construction supply chain is. Their key findings relates to what the stakeholders viewed as primary perspectives which was trust, efficiency, fair, security, transparent, accountability, compliance and standardization (Nanayakkara et al., 2019).

J. Mason (2019) wanted to investigate whether smart contracts are more likely to prosper with or without the use of BIM. He concludes that BIM's creators could not have predicted the availability of distributed ledger technology as an alternative to automating and digitizing the industry. The smart contract movement is a modern, more innovative idea that can decide to help current technology or write its own script. Compatibility with previous and subsequent developments is a sign of long-term stability and durability. This may be beneficial to smart contracts in the construction industry. The challenge for policymakers and lawyers remains on recognizing the need for a new contractual response and delivering it as quickly and efficiently as possible.

Shojaei et al. (2019) paper describes how smart contracts can be implemented by combining BIM and blockchain. To rule a hypothetical construction project, a blockchain network built on Hyperledger fabric is proposed and evaluated. The findings demonstrate that blockchain can be used to control construction project contracts by automating the repercussions of each agreement and keeping a tamper-proof database of project development, which is useful in any dispute settlement. Overall, this paper has shown how blockchain can be used to incorporate smart contracts in a building phase in a semi-automated manner. It may be used to link the real and digital worlds in order to preserve and monitor the cyber-physical space in several ways. Also, by combining IoT, RFID, and other sensory technology where material exit, arrival, and inspection are concerned, more automation can be accomplished.

Some of the literature are just investigating the applicability of smart contracts in the construction industry as Altay and Motawa (2020) have done in their study. They claim that despite the fact that smart contracts have certain drawbacks in this market, such as the complexity of modifying agreements and being legally binding, they have possible advantages in a variety of areas, most notably the solution of payment issues and high protection. The technology can be applied to basic and small-scale programs, or the semi-automation of operations, for example, may make it easier for people to implement it. Furthermore, it is thought that combining these innovations with Building Information Modeling (BIM) in construction projects would increase the project's value.

At last, Badi et al. (2021) have tried to identify what factors affect smart contract adoption in the construction industry. The framework that they used in this study is made up of twelve independent variables and one dependent variable, which is the plan to use smart contracts. To statistically evaluate the causal relationships between the eleven variables of the research model, ten hypotheses are created. The findings show the value of a perception-based paradigm that uses the TOE system to determine factors that affect smart contract adoption. The research leads to innovation diffusion studies in building project management by assisting "early adopters" at the technology's early stages of adoption.

Managing information in construction with blockchain

Mutual confidence may boost construction effectiveness and quality efficiency, which is dependent on immutable and traceable data records and real-time information sharing among various construction participants (Zhong et al., 2020).

They have designed a consortium blockchain framework to help construction quality control by discussing participants' knowledge permissions and lifecycle. Furthermore, this study describes in detail the consensus mechanism that seeks to resolve the issue of information fraud (Turk & Klinc, 2017).

They present four scenarios on how building information can be handled with blockchain.

1) *Chained and very decentralized*

Building information is copied into the blockchain in the chained case. Participants' workstations are copied with the blockchain. An operating system plugin presents it in a similar way to a shared Dropbox folder, with the exception that all versions of all files are retained, and each file has a legitimate "last" version.

2) *Chained and slightly decentralized*

The key issue with the chained scenario is that, like Bitcoin, the scale of the blockchain will quickly grow enormously big, far beyond the ability of individual workstations. The solution would be to spread the blockchain among a few main project partners while only providing clients with "wallet apps" on their workstations.

Communication patterns among participants indicate a peer-to-peer nature of relationships when using unrestricted technology. In such a setting, blockchain can provide a secure architecture for data management at all stages of the construction process.

A file would appear to be local to the client, but it would be taken from the blockchain and cached locally if and when required. At least one project partner would be required to host the blockchain, and any project partner who desired it would be able to do so.

3) *Unchained*

The files themselves are not stored in the blockchain in the unchained case, only their fingerprints and possibly metadata are. The files are kept on a file storage system or in the cloud. All team members will have a copy of the blockchain – evidence that a particular file existed at one point in time; they would also be able to show that the file is the one whose fingerprint is in the blockchain. Other software, on the other hand, would be responsible for ensuring that all the files listed in the blockchain were saved somewhere.

4) *Blockchain integrated with BIM*

This is a scenario where blockchain and BIM are integrated, and this will be discussed in the next chapter.

Nonconformances (NCRs) are low-quality products that are widespread in building projects. It can be difficult to determine who is solely responsible for them at times. In certain cases, NCRs are not registered or are incorrectly tracked, making it impossible to determine who is responsible for ensuring that work meets defined criteria.
To address this problem, Sheng et al. (2020) created the "Product Organization Process (POP) qualityChain," a blockchain-based platform for managing quality information. A Hyperledger-Fabric-based architecture and a number of blockchain implementations are covered.

Rodrigo et al. (2020) explores the potential application of blockchain for accurate estimation of EC in construction supply chains. In the study they compare a blockchain system with a traditional information system based on 10 features. The features are decentralization, anonymity and pseudonymity, security, immutability, auditability, veracity, transparency, disintermediation, trust (without a third-party), and scalability. As a part of their paper they claim that a blockchain system will be more suitable for accurate estimations of EC in a construction supply chain. It is wort mentioning that the research done is based on a qualitative methodology with the use of interviews.

Integrating blockchain with current technology (BIM, IoT, AI)

Various stages of a construction project will benefit from digital technology. This necessitates the integration of blockchain technology with other emerging technologies such as BIM, IoT, and artificial intelligence (Turk & Klinc, 2017).

As mentioned in previous chapter Turk and Klinc (2017) presents an architecture on how blockchain can be integrated with a BIM server in order to manage building information. The latter architecture they used have been implemented using “BIMserver.org's" open source BIM server and open source blockchain services. According to preliminary results, the blockchain would be one order of magnitude larger than the database on the BIM server, which is manageable with current technology. The effects on speed and usability are still unknown.

(Mathews et al., 2017) paper concludes with an overview of Blockchain Technology (BT) and its intersection with ground-breaking innovations such as the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), and financial/insurance items. They used Building Information Modelling (BIM) technology as their model network database to demonstrate this method. Interaction with the BIM database produces economic value, which can be calculated by an electronic token that rewards disassociated parties for maintaining and enhancing the database for the good of all, effectively replacing the 3rd party intermediary characteristic of legacy hierarchies with a clear and efficient "digital handshake."

Those attempting to combine building information modeling (BIM) and blockchain quickly run into the problem of data redundancy. Redundancy is still present in the storage of duplicated building information in decentralized ledgers, and this is intensified as the BIM model evolves and is used Xue and Lu (2020) have presented in their paper a novel semantic differential transaction approach in order to minimize the redundancy of information when integrating BIM and blockchain. With this approach, instead of storing an entire BIM model or its signature code in blockchain, SDT collects local model changes as SDT records and puts them together into a BIM change contract (BCC). As a result, a BIM project's version history becomes a chain of timestamped BCCs, allowing stakeholders to quickly synchronize BIM changes in blockchain. They state that their work can help the construction industry to move from the rhetoric phase and on actual implementation of blockchain and create operable blockchain based BIM systems. R. Zheng et al. (2019) paper, we propose a novel BIM framework model called bcBIM to address information security in mobile cloud architectures for the first time. Specifically, bcBIM is designed to make BIM data auditing for historical modifications in the mobile cloud with big data sharing easier using blockchain.

Based on a mixed research approach, (Chong & Diamantopoulos, 2020) suggest a framework for combining blockchain with smart sensors, oracles, and BIM to facilitate the automated payment system, which would enhance payment protection for various stakeholders.

Liu et al. (2019) claims that current application of blockchain and BIM in terms of sustainability design focuses primarily on smart energy and construction management. Little focus has been given to applying these technologies for sustainable design and proposing strategies for using these technologies in management of construction projects.

Therefore, they have proposed, validated, and optimized a conceptual architecture of BIM + BC for Sustainable Building Design Information Management Framework in building project management. The Framework is divided into two levels that include frameworks and flow. The high-level framework focuses on policy, while the low-level framework details technical components. This architecture, which assists project stakeholders in knowledge management, has the potential to achieve and ensure the realization of sustainable design goals through the interactive realization of smart contracts incorporated

into the user-driven BIM + BC framework and its documenting value exchange feature through three user-driven levels, namely user, system, and transaction.

Other literature

On a sidenote to the last section it is worth mentioning that it does exist a solution where blockchain and BIM have been integrated. BIMCHAIN is a project that is attempting to integrate the BCT capabilities into a BIM workflow. Furthermore, BIMchain is aiming to improve BIM workflows by developing a Deliverables Management System that incorporates BCT into the normal flow of information exchange between stakeholders on current BIM platforms. Its objective is to allow stakeholder cooperation through a single BIM model that can also serve as the project's contract (A. H. M. Guegan, 2018).

In their industry report Geipel (2017) states that blockchain technology disrupt trust so much that it is no longer needed.

By enhancing contract administration, permitting more transparency in supply chains, and providing the technical backbone required to incorporate components of the Circular Economy, BIM, IoT systems, and smart sensors, blockchain might help turn around stagnant production in construction compared to employment. It provides a new layer on top of internet infrastructure to allow for tamper-proof value and information transfers

4.0 Findings

In this segment the author will make use of findings made in the expert interviews to shed light on the current situation in the construction supply chain. The findings from the interviews will be marked with S for the supplier, C# for the construction industry experts, I for standardization expert, and the findings from blockchain expert will be marked with B#. Most of the interviews are translated from Norwegian, so it is not a direct quote. But the essence of the answers should remain intact.

4.1 Data collection process

Primary data collection

Collecting data is the crucial activity of a research project, and it is essential to choose the method of data collection based on the research question you have (Jacobsen, 2005).

When I created the questions for my interview, it was vital for me not to use any leading questions and keep the questions open. In this way, the interview object could speak more freely and elaborate on the topic providing me with information that it might not have thought about. In this way, I could ensure that no vital information was lost during the interviews.
All interviews, except one, were recorded and then transcribed to capture all the valuable information generated from the interviews. Not recording one of the interviews was due to technical problems, which made it not possible to do any voice recordings. This can be a weakness in the data gathering. Still, the interviewer made good notes during the interview and used confirmation questions to ensure that I had captured the essence of what the expert was saying. Using questions to confirm the information provided by the experts was used in all the interviews.

A question guide was created for each target group. The first one was targeting the construction industry experts and focused on discovering how the situation is today, the technology used, and how the communication and sharing of data were performed through the different parts of the industry. The second guide was for the interviews with the blockchain professionals, where the focus was to get their input on how the current situation could be improved with the use of blockchain.

Two separate guides were made for the supplier and the expert on tracking and registration.

When it comes to the language used in the interviews, it was seen as most natural to use the interview object's native language, except from the one interview with the blockchain expert. Since both have a different native language, we had to use a common language which was English.

As a result of the pandemic, the interviews were done digitally. This can be viewed as a weakness since people tend to be more comfortable and natural face-to-face meeting. But given the fact that people have been forced to conduct meetings digitally for over a year now, you could presume that it has become more natural and comfortable for most of us. It was also the most effective way, considering that some of the interviews' participants were geographically spread.

Secondary data

The secondary data was gathered to understand better the industry, current situation, and what type of research has already been done on this topic.

To better understand the current situation in the Norwegian construction industry, data was gathered from relevant institutions connected to the industry.

The literature concerning the construction supply chain and its visibility was gathered from published articles based on comprehensive research. The author has also attended several meetings with blockchain experts from Unisot, where the possibilities of blockchain within the supply chain, in general, have been discussed. This has given the researcher a better understanding of blockchain technology.

When it comes to blockchain theory, the literature was mainly gathered from research papers and whitepapers. The information gathered consists of how blockchain work, the structure of blockchain, and the characteristics and benefits of the technology.

4.2 Current situation

4.2.1 Information flow in construction supply chain

Since the scope of the research is focused on the information flow in relation to materials, a significant part of the question has been aimed toward this area of the construction industry. This has been done to understand the current situation better and discover potential areas for improvements and map current actions taken concerning this problem.

How is the information flow today?

When asked about the information flow in the construction industry today, the participants in the interviews were compatible in their answers. They responded that the information between the different actors is insufficient, and there are many reasons for this. Even though this industry is relationship-based and the actors know each other, the information does not run freely between the different actors. The experts point at some key aspects as the reasons for low information flow.

When I asked the construction professionals if they could describe to me how the construction industry is today and how the information flow is, they responded with:

C2:

"Welcome to chaos. Nobody knows anything, and nobody talks together."

C3:

"To put it nicely, you will be surprised."

When asked what the biggest challenge for the industry is, the respondents list the lack of communication and information sharing as the biggest. One of the responders stated that there are communication issues at the construction site because of the language barrier resulting from using workers from many different nations working together.

C1:

"Communication and information sharing is probably the biggest challenge we have."

C2:

"The lack of interaction. We do not communicate with each other. The generic value chain in itself is actually pretty good. But it does not work without the different links are talking with each other."

C3:

"Since the 90's the Norwegian construction industry started to use foreign workers, and the proportion of foreign workers have continued to increase. Today, the situation is that the industry has many workers who do not speak the language, which results in even lover degree of communication."

But the expert on standards brought up an important point concerning the nature of the products they are making. The construction industry is creating assets and not consumable goods. This changes the needs when it comes to information and the timespan the information needs to be available.

I:

"In the construction industry, the products might have to last 100 years which creates a need for the identification and data capturing to exist for a much longer time than normal. You create assets, not consumable goods."

Fragmented industry

When asked why they think the information flow and the communication is so poor, one of the reasons they mention is the fragmented nature of the industry. The fact that there are so many different players working together to build a construction creates challenges.

C1:

"In a big construction project, there are so many different players involved that the information gets lost on the way."

S1:

"When constructions are drawn in CAD, there are so many different subcontractors that need to communicate in order for the project to be finished. It can be hundred of thousands of different components used in construction, and tracking all these components all the way is challenging."

I:
"It is a very fragmented industry. When I visited a larger project, the main contractor had ten subcontractors, and there were five different native languages involved. So, in these environments, a lot of mistakes can happen because of lack of communication."

But does a supply chain with many players necessary result in a lack of information flow and communication? Or does the problem stick deeper than that? Some of the construction industry experts explain that the lack of communication and information sharing in the construction industry is just a part and a result of very complex and intertwined issues.

The fact that the industry is more or less the same as it was 40 years ago can result in the fact that it does not meet the criteria of what it needs to in this modern time.

C3:

"The industry has not evolved in the last 40 years. They still rely on technology from the 80's. And the sequence of events is the same as it was 100 years ago."

C2:
"The big actors will always press the smaller ones to take the risk. And we have not

managed to get away from the price aspect. The price is calculated at the wrong place, at the wrong time, and it gets calculated several times."

And the two things that dictate how things are done are the power level of the different actors and the price aspect. These two factors negatively affect transparency. It creates room for opportunistic behavior as well as cutting corners when it comes to the following regulation. The different actors withheld the information they sit on or gives inaccurate information for their winning.

This is a result of how the business is done in this industry. And this is vital knowledge to understand the fundamental mechanism of this industry. Everything starts with an owner that orders a construction. It gets put out in an open marked as a tender, where the owner lists the construction requirements. Then the contractors must compete in order to win the tender, and the one that wins is the one with the lowest price. This is where the problem starts. The contractors create offers where they price-delay the most significant expenses such as windows and doors. They create an offer with the cheapest windows and doors since no one has specified which windows and doors they want at this stage. But what happens when the contractor has been chosen? Well, the work will start. The architects come in and say, hey, we do not want that door. We want this door. And then there comes the regulations, and suddenly they need to have 40 fireproof doors instead of the cheap and regular ones. And in this way, the price and power positions affect the transparency of the business.

C3:

"A smart contractor will hand in a price proposal that contains the cheapest options. This way, they trick the owner into choosing them based on an inaccurate price estimate. But when they start working on the project, the materials used will continuously be replaced, and the price will continue to rise."

C1:

"There is a problem with opportunistic behavior. The big actors continuously press the smaller actors to take most of the risk. They might not tell about changed regulation that can result in higher cost, because they know this cost will fall onto the smaller actors."

Digitalization

Another reason for the lack of information flow in this industry is the slow rate of

digitalization. The construction industry is lacking when it comes to digitizing processes in their operation.

C3:

“It is a very conservative industry, and to be honest, it hasn’t taken digitalization into use as of now. The industry has kept everything that we used to do in the stone age, but now you got some help in the way that you don’t always have to carry around a pile of paper.”

C1:

"We have come a long way when it comes to technology on-site, as well as in the engineering process. Each company working on a project has a lot of information. But the digitalization of this information is still lacking."

C2:

If you want to achieve something, this is the ideal industry to get involved with. The reason for it is because we are stone age people. You don’t have to invent the weal; you need to make minor changes that will result in significant changes.”

S1:

"A big achievement would be to when a piece of information is recorded in the system once, and you would never have to print it out on paper and make adjustments with a marker. Everything floats in the system, and everyone that needs the information can access it. This would be optimal with the digitalization, especially if this happens in the various links of the value chain."

As of today, the industry has yet to digitalize the transactions between the different actors. When materials are ordered, they are usually not ordered in a digital system. Much of the orders are done through mail, phone, even social media applications. This creates a situation where the same information needs to be recorded several times in different systems.

C1:

“The situation as it is today is tedious. When I need to order materials or products, I must either make phone calls or send out emails to different distributors or suppliers. Here we must communicate back and forth, and I need to compare different options against each other.”

C1 provided the author with a floating chart mapping the process of ordering a door for construction. To fit in a document, the author decided to divide the flow chart in before and after transport because of how complicated the process is. This shows how complex a procurement process can be in this industry, and there is a lot of back and forth between the different actors. Below you can see the flow chart of the activities that goes down when ordering a door.

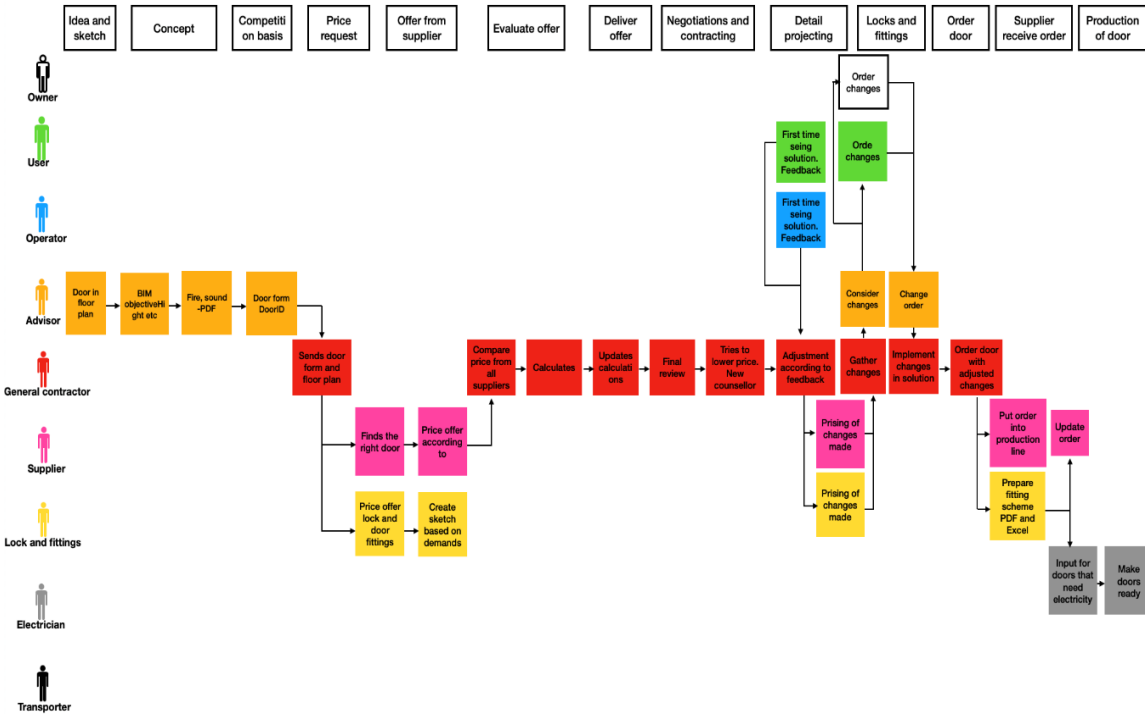

Figure 9: Flow chart of activities when ordering a door (Before transport).

C2:

"The UN states that an owner of a construction has the right to know what his construction consists of. But the big problem is that the order process is not happening as e-commerce. Order can come inn via paper, mail, phone call, messenger, Snapchat, you name it. A mail does not generate any information into a system. This must be done manually. And nobody has the time or resource to put this information into a system."

Information Silos

As a result of the fragmented supply chain, the industry is faced with the challenge of information silos. Each actor sits on their information without an optimal solution for

sharing this information with the other actors in the industry. There are also problems with sharing the information between the different IT solutions internally across the various actors.

S1:
We can trace our product all the way down to each individual three, so the information is there on our side. The problem with sharing this information further down the supply chain is two-folded. We do not have a way of distributing this information digitally in an effective way. Secondly, we feel a lack of initiative from the construction industry to obtain this information.

C1:

There are many sound systems that the different actors rely on, but the problem is that they do not talk to each other. As a result, we end up with information silos."

When asked why the systems are not talking to each other, the construction professionals pointed at the lack of standardized names for the materials as a big challenge. A material might have several different names based on what system it is viewed in. This makes it difficult to first of all, find the product in the different systems, but also to share the information about the materials across systems.

C1:

There is no standardization of materials name in the different systems. The suppliers have one name for it in their systems, and when we receive the material, we must change it to fit in our systems. This makes the process very tedious.

S1:
"A big challenge in the construction industry is to standardize the material number, because how it is now is very confusing for the end customer. But it is important for the suppliers that this is done so that the end user can recognize which supplier has made the product."

4.2.2 Traceability

There is a difference in the supplier side when it comes to traceability than in the construction industry side. In the case of the supplier interviewed in this paper, the traceability from their side was very good, and they could trace their product to the source. But along the way down the supply chain, when other actors take over the product's responsibility, the traceability disappears. This has to do with the previously mentioned lack of information flow between the different links in the value chain. Some of the questions in the interviews relate to how the traceability of materials used in construction is. The data gathered in the interviews indicates that the traceability is close to non-existing.

When asked if they can trace material from the source all the way to the completed building, the simple answer is no.

C2:

"We do not have tracking on our outgoing logistics, so if a transporter forgets to deliver one part of the total delivery, we have no way of knowing this."

C1:

"We are struggling with no traceable product data. We have no idea of what material a finished construction consists of. Tracing this is impossible as it is right now."

S1:

"We do have traceability, but we have a challenge when it comes to digitalize it completely."

One of the supply chain professionals points to logistical issues when products or materials are delivered to the working site. There is no actual procedure when it comes to the delivery of materials at the construction site.

C3:

"A big problem is when the materials are getting delivered, it is often workers that had nothing to do with the order process. They also might not speak the language and do not always follow the correct procedures. It has also been documented that 35 percent of all

deliveries are not even taken care of by any of the workers at the site. The transporter just "dump" it of the trailer and leaves."

I:

"If only they could do a good receipt at the construction site. Then you would know which individual received the materials, and this person may know where on the site the product was placed. This could have saved a lot of time searching for materials and products on site."

The fact that nobody knows where the materials are stored when arriving at the construction sites creates a huge problem in knowing where the materials are at all times. Since they don't have any quality processes of handling the materials at arrival and in terms of storing, they use a substantial amount of time searching for the materials at the site when they are supposed to be used. This results in delays, damages to materials, etc.

4.2.3 Important systems and technologies

Blockchain cannot operate on its own. It needs supplementing technologies to feed it with information. Some of the questions have been related to what types of systems and technology the industry is currently using for collecting, storing, and sharing material information.

Most important systems

To map what systems are currently being used in regards to material information, the construction professionals were asked what the most important systems is:

C1:
"BIM is where the construction is designed, so this is an important system. It gives the information about how many doors the building will have, or what the dimensions will be."

C2:
"Nobb.no is where all the information about the different materials is stored. Here you can look up all the materials with different attributes. But you cannot order from this database when you have looked up the materials you want. You then have to order from the supplier or wholesaler."

S1:

"ERP is the core system. This is where the master data is stored. Every parcel is shipped with the information"

BIM

BIM is an important tool in the planning process. In the Norwegian construction industry, BIM is yet to be fully capitalized. They use BIM as a model instead of a module, and this hampers the effect of BIM in the construction supply chain.

C3:

"In the Norwegian construction industry, they use the BIM wrong. The M in BIM does not really mean model. It means module. A process that gets put into a system above the value chain. But in order to manage this, they need new technology. It is too time-consuming and costly to input all information into the BIM manually."

As a result of not updating the BIM along the way, when changes are made, and different materials and products are chosen, the model slowly dies. When the construction project is completed, there have been so many changes in the material composition along the way that the materials listed in the BIM are no longer used.

I:

"Changes in materials do not get registered in BIM. I have never heard about a case where they can provide an updated digital twin when the construction is completed. So, the model slowly dies during the project because they do not update it."

It is also stated that a reason for not including all the information in the BIM is because the models get extremely "heavy," so it can be wise to separate some of the data."

Most important technology

During the interviews, there was a word that continuously was mentioned, and that is standards. It became apparent that this is an important feature that can support the use of blockchain in this industry. The standards are created by a non-profit organization called GS1, which makes global standards for business communication. They are most recognized for the standard we all know called barcode which can be scanned and triggers an event. This is implemented in the paper because it will most likely be a vital tool for integrating blockchain in the industry. Blockchain is dependent on other technologies to do the data capturing. It can also act as a key for the user of the blockchain to access the data.

I:

"We have standards that are divided across three axes, which are: identification, data capture, and sharing of data. We have common standards that work globally. If you apply an indicator on a product in Norway, then it will make sense in many other countries to."

One of their standards is able to track what they call event data, and they call it Electronic Product Code Information System (EPCIS).

I:

"It can be connected to the digital flow of goods, digital information, or it can be connected to the physical flow."

They have created a way to track and trace a product through the entire supply chain. And the way they do it as following:

I:

A producer get tagged with a unique Global Location Number (GLN). Then the producer tags the product with a Global Electronic Trade Item Number (GETIN) before placing the product in a box tagged with a Serial Shipping Container Code (SSCC). The box will then be placed in a pallet that gets tagged with a Global Returnable Asset Identifier (GRAI), and the pallet will eventually be placed on some means of transportation. This can be a truck that gets tagged with a Global Individual Asset Identifier (GIAI). This makes it possible to trace the product all the way, and the truck can be identified by a Geofence so you now when and where the truck is. There is a GLN at every point, even at the loading dock."

A great information flow is of no use if the information is inaccurate. Therefore the industry needs to start implementing these standards to register and track data along the supply chain. The industry has begun to implement the standards, and the materials and products are marked with a GETIN.

As the interview went on, I got the impression that if you scanned a barcode, QR-code, RFID, etc., you would receive all the information concerning the product, and therefore I asked.

I:

"No. You dependent on having a database where you can look it up. We only deliver stupid

standards with no logic. We do not have a global database for storing product information. But what we do are connecting our standards to others database."

The respondent then continued to explain that in the construction industry they are using the GETIN as a connecter between the material information and the material list in the BIM.
I then explained that I believe it would be ideal if the BIM could trigger events in the supply chain. As an example, that BIM could trigger the ordering point of the different materials and products. I asked if he believed this could be possible.

I:
"This is in some way the holy grail. But that is a long way ahead, and there are many reasons. But the BIM can be used as a visual interface for planning, project management, and many other things. The challenge is that the purchasing process is decentralized and often happens during meetings, through telephones or mail."

This supports my previous findings concerning the purchasing process. The fact that it is not e-commerce hurts the information flow regarding materials and products. With the transactional information, they also lose the material information.

I:
"The thing is, there is a lot of great work done in terms of digitalization in the face before the project starts, with the engineers, etc. But it all falls apart when it comes to the construction site. Both in terms of the lack of digital purchasing process and the lack of registering and documenting what's been delivered and installed in the construction."

Therefore, I asked the individual if there are ways that can digitalize the process. It becomes clear that the problem is complex and has several causes. One of them is the lack of incentives from the contractors. They just charge the owner for the extra expenses.

I:
"I have talked to purchasing managers in the biggest firms on the contractor side, and they told me that reception of goods at the construction site is not necessary. Malicious tongues claim that the reason is that expenses will be transferred to the owner of the project anyway, so they don't care."

Another problem in terms of digitalizing the purchasing process is that the industry is operating with moving measurements. When operating in BIM, the measurement of a door changes several times throughout the design process. This makes it difficult to predict the price because you might need a product or material that needs customized measurements.

I:
"Since the measurements are constantly changing during the project, it is difficult to calculate a fixed price because of the extreme amount of change notifications. And in some cases, you lose the control."

The individual thinks it will be difficult to achieve a fully functional e-commerce in the industry but mentions a solution to improve transparency. If the contractor could ask the supplier to send an order confirmation digitally, they could kickstart the digital material information.

I:
"There is a possibility to kickstart the digital value chain again by having the producer/supplier sends an order confirmation back to the contractor. At least the contractor can obtain control over their purchases."

The standard expert was also asked about solving the problem with several different names on the same product.
I:
"This can be solved by using GETIN on all the products. In Sweden, they have demanded that all products are going to have GETIN on all products because of all the wrong purchases and returns.

4.3 Blockchain in construction supply chain

In this section, I will present how the construction industry professionals view the possibilities of implementing blockchain and the findings made during the interviews with the blockchain professionals. The blockchain professionals were asked what blockchain is and why it is a good fit for supply chains in general. After that, I asked about some of the problems the construction industry is facing and how blockchain can be used to solve

them. They were also challenged with some of the concerns from the construction industry professionals.

The construction industry professionals' thoughts and concerns

The construction professionals were given a short introduction to blockchain technology and how it might affect the industry. Most of them was positive to the technology, but there were some concerns. There are many misconceptions around blockchain, and therefore it is some skepticism around it.

C1:

"I must say that I am far from a blockchain expert, but I know there are a lot of interesting projects going on in that area."

C2:

"If it is a technology that could help with bridging the information gap between the different actors in the industry, it is more than welcome."

C3:

"I have very little belief in using blockchain in the construction industry because the product that we make is a place where people are going to work or live. So, there is a huge privacy issue. Another problem is that it only takes one bad actor for it not to work."

S1:

"What I have heard about it, it is a new and exciting technology. But I have heard that it is a very power-demanding technology, and given the increased focus in the environment, how does blockchain fit in?"

I:
"... I believe that in 99 percent of all cases, using the EPCIS is sufficient, and you don't have to use blockchain."

4.3.1 Blockchain in general

When asked if they could briefly explain what blockchain is, the blockchain experts answers can be seen as compatible. They both emphasize the

B1:

"Blockchain builds on decentralization. It is a decentralized and immutable database where you can perform secure transactions."

B2:

"Blockchain is a globally distributed data layer that everyone can use, but no one controls. This technology has solved the problem of sharing data securely on a public network."

One of the questions in the interview was relating to why blockchain fits so well and should be used in supply chains.

B1:

What blockchain is going to bring is technology-driven trust. It will bring trust in a trustless environment. Blockchain brings the ability that if I give you information, you cannot misuse this information."

B2:

"It is two structures that are very much alike. A supply chains usually are more than just a chain; it is a network of companies. Just like the blockchain, which are a distributed network consisting of several nodes. That's why it makes sense to connect the different companies in a supply chain as nodes in a blockchain."

When asked if they think blockchain will be the future of supply chain, both were pretty sure that it will.

B1:

"Supply chain will be the biggest customer of blockchain, it is just a matter of time. I can tell you that within the next 2-3 years a lot of thing will happen."

B2:

Absolutely, I think that blockchain is the most revolutionary technology ever created, even more disruptive than the internet. So, the blockchain technology will be used in the future supply chains."

But when asked about the difference between public and private blockchain, it became obvious that the two experts do not have the same ideas. The impression was that one of the experts prefers private, while the other one prefers public.

B1:

"A public blockchain is when you have several nodes in the network communicating with each other. My computer will communicate with your computer. A private blockchain is when the nodes are hosted in cloud service by a company. Then you don't have to run the nodes yourself, and there is a company that decides what the governance is going to be."

B2:

"*No, no. There is only one blockchain, and that is the public blockchain. Everything else, like private blockchain, does not exist. It is just a database, a replica. It becomes less safe, more expensive, and slower."*

If blockchain expert 2 is correct, it will have huge implications on future work within the blockchain. Therefore, a follow-up question was asked. The question was, "so you have no faith in any other blockchain than the public?".

B2:

"As soon as you try to make a blockchain private, you will remove the features that make blockchain what it is. Even though sharing information in an open network was solved 12 years ago, with the invention of bitcoin, people still try to solve what they think is an issue. They think that proof of work is an issue, and that a public blockchain is unsafe. It is the complete opposite. It's just the network that is public, the business layer is encrypted."

There was no point in asking blockchain expert number 2 what type of blockchain should be implemented in the construction industry, given the previous answer. What's interesting is expert number 1's answer, which contradicts this statement completely.

B1:

In your case with the construction industry, a public blockchain is a no-go. You cannot do this in a public blockchain. You have to do this in a private blockchain."

This is very interesting. B1 suggested using a blockchain called Cardano, a private blockchain that uses proof of stake as consensus. When confronted with this, B2 answered:

B2:
"Poof of stake has been proven since the 90's not to work. Proof-of-stake is a regular trust-bank system that we have used for 100 years. This was the exact problem that Bitcoin blockchain solved.

B2 also mentions that there only exist two blockchains and elaborate on the differences between them:

B2:
"It only exists two public blockchains, that is Bitcoin and Ethereum. Ethereum is not scalable, it is not safe, and it is costly. Another thing is that you cannot have it like it is in Ethereum, where the developer launches updates all the time. That does not work. With Bitcoin SV, there will be no changes. The protocol is fixed. And the Bitcoin blockchain is scalable, secure, and cost-effective."

Barriers

Since one of the research questions of this paper is to identify the barriers to implementing blockchain in the construction industry, it was necessary to ask the blockchain expert what they think is the most significant barrier for blockchain in general.

B1:

"The biggest barrier is the idea about decentralization. Blockchain builds on decentralization, and it is challenging for top managers to start thinking decentralized. Everything would need to change in terms of business culture and how decisions are made. People don't want to lose their power, and therefore it will face big resistance."

B2:

"It is mostly the reputation blockchain has from all the misconception about the technology. 90 percent of all blockchain projects fail or get shut down because they are not real blockchain. They have used private blockchain, and that is meaningless. Because of this, people have gotten the wrong impressions about the technology."

4.3.2 How can blockchain improve the information flow?

After cowering the basics, the interviews then continued to collect data concerning how blockchain can be used to improve the information flow in the construction industry.

But before we go into that, the author will present the findings made when the blockchain experts were challenged with the concerns from the construction professionals regarding blockchain.
C3 did not believe that blockchain would work because of issues concerning GDPR. This was supported by I:
I:

"When it comes to smart building, they have come a long way in Asia. Material information can be stored and easily accessed in terms of repair and renovation, which makes the building smarter. But they don't have to worry about GDPR. This could be a problem here I Europe."

When the professionals were asked about how privacy issues can be resolved, they answered in the following way:

B1:

"The biggest challenge in blockchain when it comes to GDPR is the right to be forgotten. The thing is, you should have the ability to delete your data. Data cannot be deleted in a blockchain, but you need a private key to be able to access the data. So, if you want the data to be lost forever, simply "lose" the private key. You can also run the nodes just inside the European Union, with a private blockchain compliant with the GDPR. Then the data will remain inside the European Union."

B2:

"In our system, we can store data in a blockchain, but we can also choose to store it in a decentralized database. So sensitive GDPR data we will not save in the blockchain but in the decentralized database. With this method, you can also keep sensitive information inside the country, for example, with military data."

C3 was also critical to how blockchain works and stated that it only takes one bad actor before the whole thing will not work. B2 explained in the following way:

B2:

"Not at all. This is a question I have received multiple times. You don't have to have all the supply chain actors to join the blockchain. You can start with one actor and then reach out to their suppliers and customers. From there, you can grow it. But obviously, the network benefits are not to be neglected. The more participant, the more effective it will be."

Another concern came from the supplier, which asked about the blockchain's power consumption. The supplier is focused on the environmental aspect of their operations and wondered how this could be solved.

B1:

"Power consumption depends on the kind of consensus protocols you define. So if you look at bitcoins consensus protocol, they use proof of work, and it is very hungry for power consumption. But now we have new protocols like proof-of-authority, which is not power intensive. And if you use a private blockchain, power consumption is not a problem."

B2:

"If you think about BTC, which does five transactions per second globally, and it uses the same amount of energy as Denmark. Yes, then it will be a lot of power consumed per transaction. But BTC does not work, and this is not what is being used. With the original Bitcoin SV, we can do 20 000 transaction every second globally. And then, the power consumption is reconcilable. These are just strawman arguments. It is just false."

The claim from the standardization expert about blockchain being unnecessary made the author wonder if he had the wrong impression about blockchains role.

I:

"... I believe that in 99 percent of all cases, using the EPCIS is sufficient, and you don't have to use blockchain."

From his statement, it kind of felt like he thinks blockchain will take over the EPCIS function. B2 was then challenged with this.

B2:
"EPICS is one of several different standards for exchanging information, which means that different players in the Supply Chain speak the same language. A "shovel" is a "shovel" for both the seller and the buyer.

Blockchain is the global communication network for secure sharing/transfer of information, formatted according to various standards; GS1, ISO, EDIFACT, etc.

It is possible to use EPICS without blockchain. Still, blockchain makes it much more efficient, more secure, provides opportunities to monetize information using nano transactions, providing new business models and incentives. EDI is a part that we can do with advantage via Blockchain, making it much more flexible, faster, safer, and cheaper.

The company you have spoken to is skeptical of Blockchain as it replaces part of their data sharing business…."

With the concerns from the construction industry professionals, I will now present the data gathered from the interviews regarding how blockchain can solve some of the problems in the construction industry.

Integrating blockchain with current systems

Since ERP plays a vital role in all supply chains, the experts were asked about how integrating blockchain with ERP is. Yet again the professionals do not concur with each other.

B1:
"Current ERP systems are not designed for blockchain. They would have to change for blockchain."

B2:
"What we do, is to offer an ERP-plugin. This plugin gets connected to the business processes. That can be an invoice. Instead of sending it out in the traditional way, the invoice will be sent to the blockchain, and from the blockchain, it gets sent to the recipient.

It is straightforward to change into the blockchain solution for the ERP system."

On a follow-up question B2 was asked if this could be done with other systems:

B2:
"Yes, absolutely. We just use standards to connect the different systems together."

Standardization

Since the industry has its issues with standardization, and there are different names for the same products or materials, the experts were asked if there is a way of solving this using blockchain. The responses are in some way unanimous. They just use a different term for the same approach. But to sum it up, they propose creating a digital entity for the product.

B1:

"This can be solved by using the process of tokenization. Tokenization is a process where we covert a real-world asset/product into a digital world product. Then you can say that it cannot accept any name for this product. You need to give me a standard name. This can turned into into something very interesting. A non-fungible token can be used. In products, you can create NFT's for each of those products. You do not have to worry about the name of the product. This is also an exciting way of managing inventory. I am also working on another research paper where I look at how NFT's and inventory management."

B2:

"Absolutely. We are working with our digital twins, which have their own unique digital ID code in the blockchain. Or a transactions ID. To this digital twin, we can connect as many numbers as we'd like to. It can be a number from the supplier, a number from the entrepreneur and the government for an example."

B2:
"What's interesting is that there are many incentives on building systems that can help with project handling and deliveries. But nobody talks about the data layers. There are

some talks about standards, GS1 for each product, and stuff like that. But still no talk about the data layer."

Incentives for sharing data

Another problem in the construction industry is the willingness to share data, and therefore I wanted to investigate how blockchain can provide better incentives for data sharing. Both experts point to tokenization as an important aspect. If this method was to be successfully implemented, it could have huge benefits for the information flow. The actors could now make a profit of their information.

B1:

"This is very simple. You can use smart contracts. You have a product, certain functionalities of the product, certain data of the product. When they buy a product, they will get the whole historical trail of the product. It is already there in the product's DNA. And when you tokenize it, that's the beauty of blockchain. The data cannot be changed."

B2:

"This is where the function in blockchain where you can have a token that you can use to do nano transactions. You can sell and buy information for a meager price. You can monetize all your data."

B2 also mentions that blockchain can be a good tool for serious actors, and therefore be an incentive for sharing of data:

B2:
"Serious suppliers get the opportunity to show their product quality to their buyers. And when one supplier starts sharing their information to prove that their material holds high standards, others will also eventually start doing the same"

Interconnected system

When it comes to solving the issue with systems not talking with each other, the expert claims that this is the exact purpose of blockchain technology.

B2:

"That has been a problem for 20 years now. This is exactly what blockchain is. A data layer. A communication layer that can retrieve and share information in a very secure way. This is where blockchain comes in the picture, by using GS1 standards and connect all the systems. We have solved this with the public blockchain."

In table 2 the author will include the key findings done during the interviews with the different experts. This is done to give both the author and the reader a clear overview of the most important made in this chapter.

Key findings

Current situation	Blockchain in construction industry	Barriers for blockchain	Important systems and technologies
Information sharing is a big problem.	Mixed view on blockchain in the industry among the construction professionals.	When it comes to barriers, the biggest barriers are the idea of decentralization and misconceptions around the technology.	BIM
Fragmented industry with many different actors makes it difficult to achieve a good information flow.	The blockchain experts states that blockchain will bring technology driven trust and that the blockchain technology are a distributed network just like the construction supply chain.		ERP
There is a lack of digitalization in the industry.	One of the surprising finding was the different views the expert had on private vs. public blockchain.		IoT
There are problems with opportunistic behavior as a result of power imbalance and information asymmetry.	Blockchain can also be a tool for creating incentives to share data with other actors.		Standards like GETIN

No e-commerce and tedious procurement processes. This creates a breach in the digital information flow.	One of the blockchain expert stated that it should not be a problem integrating blockchain with current systems used.		Nobb.no is an important tool where the all the information about the materials currently is stored.
They struggle with information silos. This is caused by standardization issues and systems not talking to each other.	Standardization can be solved by using NFT's or a digital twin. The experts also state that blockchain can be the solution for braking down the information silos.		

Table 2: Summary of findings

5.0 Analysis and discussion

In this chapter, the author will use the findings in the previous chapter combined with the theoretical background from chapter 3 to answer the given research questions. All this to solve the research problem of this thesis, *"How can blockchain improve the flow of information in relation to materials throughout the construction supply chain?".*
The author will answer the RQ's chronological, which makes the most sense since the first research question concerns how the information flow is today.

5.1 RQ1 – What is the current state when it comes to information flow in the construction industry

The construction industry is an exciting industry, where small changes could result in considerable efficiency improvements. During the research, the author got introduced to the industry's challenges and the root of the cause. With the expert interviews, it became apparent that the industry has significant problems in terms of communication and interactions between the different actors. Given the lack of communication and interactions between the actors, the information flow gets affected negatively. Dainty et al. (2001). describes the industry as one of the most diverse and dysfunctional sectors
The root cause of this problem is highly complex, and to fully understand the situation for

an outsider would be very challenging. Through the research of this thesis, the author has managed to discover some key points to why the case is as it is today.

Not just a digitalization problem

One of the biggest impactors is how fragmented the industry is. There is a need for specialized skills, scattered short-term project settings, project-specific product demands (Dainty et al., 2001). This is supported by the findings in the interviews, where they describe a work environment where you have multiple actors in terms of contractors, subcontractors, and their suppliers. Since there is a lack of native construction workers, the Norwegian construction industry is heavily dependent on foreign workers in their daily operations, adding to the lack of communication.

The power ranking of the different actors also comes into play as a reason for low information flow. The bigger actors constantly press the smaller actors to take the risk in a project. That combined with the fact that the industry is very price-fixated, and the margins are close to nothing, the actors withhold information from each other for their winning. This comes significantly into play when the project gets put out on tender. The contractors are typically chosen by the lowest bid (Barima, 2017). The contractors under-communicate the actual cost of the project to win the tender. This results in a price estimate based on materials with the lowest cost instead of the materials that the construction needs. By doing this, they get in a situation where materials and products need to be changed throughout the project's lifespan. This affects the whole supply chain and creates a kind of bullwhip effect. They are also operating with moving measurements. Every building is unique, and adjustment needs to be made during the construction. This means that the different measurements for materials and products need to be changed accordingly. This is an ongoing process. Since a project does not have a specific material list when the projects start, it is challenging to achieve e-commerce in this industry. And this is where the real problems begin in terms of the material information.

The digitalization problem

The lack of a digital purchasing process hurts the flow of material information in a

significant manner. It was pretty shocking to hear how the actors in this industry perform their procurement compared to other sectors. When the procurement of materials is handled in verbal meetings, phone calls, mail, and social media, it will be difficult to transfer the material information. This is a breach in the digital material flow, and it is a big problem for the industry. As one of the experts mention, there is a lot of information going back and forth between the contractor and the supplier since many products need to be customized. Putting this information back into a system takes too much time, so nobody does that.
Some materials or products might be difficult to order electronically, but it should be possible to order most of the products in a system. There are plenty of ways you can order products with customized measures. The author believes that it is possible, but the will to transform might not be there.

The lack of incentives, especially from the contractor's side, seems to be another thing that weakens the information flow in the construction industry. It is in the link between contractors and supplier a lot of the material information gets lost. As mentioned in the findings, even though the order doesn't happen digitally, all suppliers can send an order receipt to the contractor, but they feel a lack of incentives from the contractors. Nobody asks for the order receipt. If the order receipt was sent out, the digital material flow could be in a way kickstarted again. This would have improved the foundation for improving the information flow immensely. This opens the possibility for the contractor to digitalize their material information by using the order receipt. It might be a part of the solution in terms of the traceability of the materials. The contractors have close to no traceability of the materials they use in the constructions. That is because they do not register the product at different points in their supply chain. The materials often get delivered without any personnel from the contractor are there to receive them. It does not get registered to go into the construction site. And when the material gets mounted into place in the construction, it does not get registered in any way.

This practice leads to not having any information on what materials are used in the construction when it is done. That means that neither the owner nor the end-user has any information about the materials used in their construction. That can be problematic in the future in terms of maintenance, as well as renovation.

Below you can see a simplified figure of how the material information flow through the supply chain. It is just meant to showcase where the information flow gets broken and how that affects the information. It does only concern the information flow after the material is ordered.

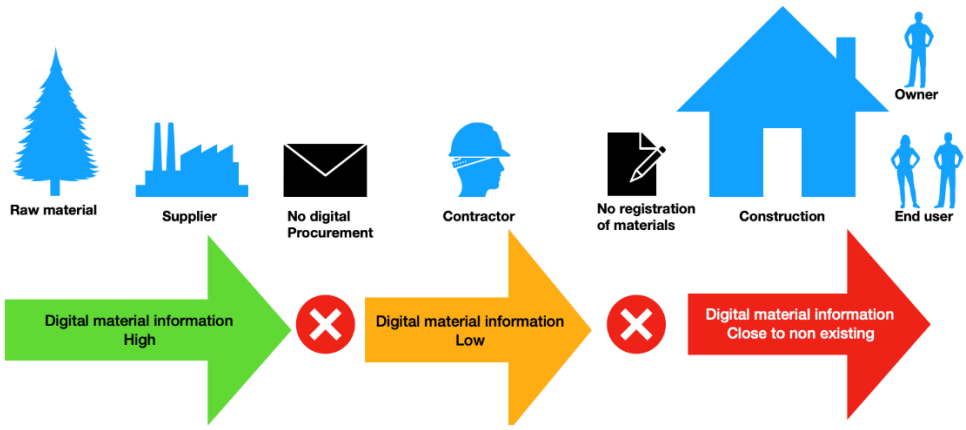

Figure 10: Digital material information flow.

5.2 RQ2 – What are the barriers for the implementation of blockchain in the construction industry

This research question was introduced because in order to implement blockchain in the industry, you need to be aware of the barriers. Bellow, I will discuss the barriers that are most significant.

Misconception about blockchain

One of the barriers you would have to overcome is the misconceptions people have about blockchain technology. There is a certain skepticism around blockchain between the construction industry professionals. That might be because of lack of knowledge on how blockchain operates. This is supported by Wan et al. (2020) on barriers for implementing blockchain in supply chain in general. One of the reasons might be that several attempts to integrate blockchain in other supply chains have not succeeded. One of the reasons for the projects failing could be that they used a type of blockchain that is not functional.

Another reason is that some have the impression of blockchain being unsafe and easy for bad actors to take advantage of the information shared in the blockchain. This is the complete opposite of what blockchain can bring to a supply chain. And one of the actors is afraid that storing all information about a construction in a blockchain will not work because of GDPR.

At last, one of the persons that were interviewed told me that he thinks you don't need blockchain in 99 percent of the cases. But he might not be aware of the fact that blockchain is more effective in terms of sharing and storing data compared to the current network solutions. It should also be mentioned that the opinion of this individual might not be completely bias, since blockchain might take over some of their operation regarding sharing data.

Dysfunctional supply chain and lack of digitalization

Through the research done in this thesis, the author has become aware that the problem blockchain was supposed to resolve, might be the barrier for implementing blockchain. Early in the research it became clear that the construction industry is a very fragmented sector. And the literature pointed at blockchain as a technology that could bind the industry digitally together. But the author was unaware of how fragmented and dysfunctional the construction industry actually is. There are several aspects that might have to be resolved before blockchain can be introduced to the industry. It seems to be a general attitude among the different actors that I won't bother to do it as long as it doesn't affect me. But when all the actors have this attitude, the whole sectors suffer from it. There needs to be a change in the general attitude in the business. They need to think of a long-term strategy and not just on the next project. There are some pressing charges that the industry needs to resolve. The first one is defining standards that the whole industry can agree on. This is a matter that the industry already has started working on and has started implementing the standard called GETIN. Establishing these standards would have an immense effect on the digitalization process in this sector. You now have a global entity ID on the materials or products that makes it easier to identify and trace throughout the supply chain.

This could also be a part of the solution for some of the other barriers.

According to Wan et al. (2020), there seems to be a limitation in the knowledge and understanding concerning how BIM should be used. This is backed up by the interviews,

where it becomes clear that the industry mainly uses BIM for illustration purposes. They are not exploiting the full potential of BIM by having both the illustrative data and the materials and product data in it.

The lack of e-commerce is a massive barrier to implementing blockchain to improve the information flow. When the procurement does not happen digitally, a lot of the material information gets lost right away. And as one of the construction professionals mentioned, how will you register products when the procurement did not happen digitally. You will have nothing to scan at arrival. And that brings us to the last barrier in this section.

The products are not registered digitally in any way at arrival. If you want to have information about where the materials are, what materials are actually used in the building, you are dependent on registering the material along the way. If you don't register the materials, there will be no point in having a blockchain since you have no data to store and share in the blockchain. To use blockchain to store and share data, you are dependent on having some input of data. And this is probably the biggest barrier for blockchain in this industry—the lack of digital information.

A new technology

After reading literature and interviewing blockchain experts, it was evident that this technology is new and, in many cases, just in the theoretical phase. There are some successful integrations with supply chains, but it is not common. Mostly the blockchain has been tested out in a closed environment and not in the real world. Therefore, there seems to be some different opinions on how it should be used.

There is no guarantee for this technology to improve supply chain efficiency. Even though the blockchain experts are highly enthusiastic about their work, it is only tested out in a test environment. I asked one of the experts if they had any efficiency numbers from before and after the blockchain was implemented, but they did not. Therefore, you cannot know if the technology will work or not. And that is why many still are skeptical about the technology because there is no proof of it working in their industry. As soon as they see a successful integration of it, more will join.

5.3 RQ3 - What type of supplementary technology can blockchain benefit from?

In order for blockchain to reach its full potential, blockchain is dependent on getting fed with information (Turk & Klinc, 2017). But doing this manually would take too long. Therefore it needs some supplementing technology to provided it with valuable information. During the research, the author has identified the most significant technologies.

BIM

BIM has become a vital part of the design process, and therefore a lot of information are accumulated in the model. But if the industry could use BIM more as a module, the possibilities could be endless with integrating blockchain and BIM. If BIM included both the visuals and the material list, blockchain could be a link between BIM and procurement. In this way, you could use smart contracts for procurement, at least on some materials. Blockchain could also be used to update the BIM along the way, and in this way, you could have a BIM that included all the correct materials and parts when finished. Another aspect is using a smart contract with a BIM as a tool to govern that contracts are followed as well as automating the procurement process for some of the materials used (Shojaei, Flood, et al. 2019). The holy grail would be to automate the procurement process by using the information in BIM together with smart contracts.

But succeeding with the integration of blockchain and BIM is difficult. As the literature states, one of the problems that occur is data redundancy. The amount of data stored in a BIM can be challenging to manage, especially when there are several challenges to the model.

ERP-Systems

When working on the current literature, the author did not think of ERP systems, but it became clear that this is important to incorporate during the interviews. The ERP systems are a great source of information, and this information can be stored or share with a blockchain.

IoT

Internet of things devices can be an excellent asset for blockchain to collect data and information about the materials along the supply chain. Automatic and semiautomatic modes are available for document filling and reading. Technology allows data on the materials to be recorded remotely (while in motion) on a tag in the vehicle. Data such as production time, exit from the concrete plant's territory, and entry to the customer's site can automatically be registered, saving time. Which again will improve the information flow. The use of RFID and blockchain technologies together would dramatically reduce losses due to the human factor and deliberately false information and remove the issue of confidence between participants in the turnover (Lanko, Vatin, et al. 2018).

5.4 RP - How can blockchain improve the flow of information in relation to materials throughout the construction supply chain?

This is the section of the thesis where all the previous work has been analyzed and discussed in order to answer the research problem. How can blockchain improve the information flow in relation to materials in the construction industry? Research question one were used to identify what needs to be improved in the current construction supply chain to answer this question.

The key findings are:

- Information getting lost because of lack of digitalization
- Problems with opportunistic behavior
- Lack of digital procurement
- Lack of tracking or registration of materials
- Systems not talking to each other
- Lack of standards
- No visibility in regards to materials used in constructions

When it comes to information getting lost along the way down the supply chain, this could easily be solved if the information were stored in a blockchain. That is one of the blockchain's attributes. When you do a transaction or store information in it, it will remain

there for an eternity. In supply chain management, blockchain technology offers solutions for data monitoring, contracting, and sharing resources. These applications help supply chain partners avoid the risks and costs of opportunistic behavior in partnership by moving trust from relational to system-based and cognition-based trust (Qian and Papadonikolaki 2020). Blockchain enables the storage of an immutable record of changes made to a BIM model by a stakeholder. These documents can be kept indefinitely and are guaranteed to be tamper-proof and time-stamped. The metadata (timestamps, author information) and the history of modifications are secured by the equivalent of a cryptographically secure digital signature (Turk & Klinc, 2017). So, if any changes in terms of material combination are done, this could easily be registered in a blockchain. Previously, this data could only be shared internally where the data is stored in a centralized database. But with the use of blockchain, stakeholders working on a project can now share these kinds of records with external stakeholders (Geipel, 2017). This can be an incentive for tracking of materials all the way. If they have a record of which actor is supposed to insert material into a building, they must register the material before it is put into place. If this is not done, this can be seen in the records. The current BIM system cannot accurately verify whether specific information has been approved by the issuing party, resulting in a gap between the occurrence of an incident and its reporting.

(Geipel, 2017) provide an illustration in which the foreman might digitally sign off each dataset in near real-time, and a hash of this could be applied to the blockchain with a timestamp, which could then be counter-signed by other team members to verify the information using a popular data setting (CDE).

But the problem in the construction industry is making the information available for all systems and networks. They have yet to fully provide global standards for the materials used. This is a necessity to be able to make sense of the information. There is no need to store information if you cannot link the information to the actual material. From the interviews, the author was introduced to two different solutions for this problem. The first option the author has decided to call the full blockchain approach. With this approach, you create a digital twin or a non-fungible token for the specific material. This can be described as a way of creating a digital copy of the material, to which you can attach all the necessary information to.

The other solution the author has decided to call the hybrid approach. This consists of using standards created by organizations such as GS1 as a ledge to which information can be attached. And then, this is stored and shared via blockchain, which operates as a data layer and can be a safer, more transparent, and effective option compared to the old-fashioned network solutions like EDI. Doing this opens up the possibilities to solve the other problems that the industry is facing. By using standards or digital twin, you can know the specific material, which can bring significant improvements to the procurement activities. This opens up the possibilities of connecting BIM and the procurement process and automating it for uncomplicated materials. If the BIM is enriched by either a digital twin or a standard like GETIN, the efficiency in material procurement could become much more effective. You could then apply a smart contract for material procurement. By using GETIN-number, for instance, the smart contract would then know exactly what material should be ordered. And you could then include order point, quantity, etc. The industry could create a set timeframe for when the different materials or products should be ordered. This could be safely shared with the suppliers, and in that way, they could customize their production plan accordingly. In this way, you can step towards just-in-time deliveries at the construction site and reduce the time spent either looking for materials or waiting for materials to arrive. The possibility of digitalizing the procurement process is supported by Chong and Diamantopoulos (2020) proposed framework on how blockchain technology combined with intelligent sensors, intelligent contracts, and BIM can facilitate an automated payment system.

It will also open for improved possibilities for tracking and registration of material along the way, which will increase traceability. By giving the material a unique ID, you can start labeling the materials with identifiers such as barcodes, QR-codes, etc. The identifiers can then be recognized by IoT devices which transmit information about the material directly to the blockchain, where the digital twin gets updated continuously. This can enrich the material information by adding location and how many times the material has been moved around. Using a RFID-tag on the pallet or batch, you can always know where the material is located. This could have a huge impact on the industry because the biggest source of waste is time spent waiting or searching for materials. When the technology is combined with the Internet of Things (IoT), microchips can be used to monitor components from the manufacturer to the site, according to (Geipel 2017). This will also aid in the reduction of

waste and carbon emissions that may result from overproduction. You could also attach movement sensors that register every time the materials are moved. One of the individuals interviewed stated that a product gets moved on average seven times at the construction site. This could significantly impact a pallet with plaster, where you have leakage every time the plaster is moved. The RFID tag may take the place of the supporting documents, which are nearly impossible to falsify. The RFID tag is used to create a record of the output (the first transaction). As previously mentioned, a variety of product details can be included in this transaction (Lanko et al., 2018).

This is also a solution to the problem of not knowing what materials a construction exists of. Having an identifier on the materials directly linked to a GETIN-number or a digital twin makes it possible to scan the material when put in place in the construction. This information gets attached to the material, and this information can then be shared implemented in a BIM. If all materials and products get registered via a standard or digital twin, you can then continuously update the BIM throughout the project. Blockchain technology can be used to link physical components built on the job site to their digital counterparts on BIM (Mathews et al., 2017). The BIM will then be an updated digital twin of the construction that can be stored accessed through the blockchain when the project is completed. This will be beneficial in the future, with the increased environmental focus. The owner will now have complete visibility of materials used in the construction, and maintenance will be more efficient. Blockchain can also be a solution for managing the quality information in regards of materials used. Sheng, Ding et al. (2020) built a prototype of POP-model-based quality information using consensus mechanisms, smart contracts for processing quality information. According to the findings, their case study showed that the proposed framework will decentralize quality information management, resulting in clear and stable quality information management.

At last, it should be mentioned that blockchain can act as a solution to the problem with systems not talking with each other and the information silos created by this problem. Through the interviews with blockchain experts, the writers understand that the blockchain can be used as a plugin to current systems such as ERP. If you were to create a blockchain

plugin to all the systems, the blockchain could then access the information from every system and act as a link between the different systems and the different actors.

Visualization of how blockchain can improve material information

The author wants to conclude this chapter by gathering all the discussion into a proposal on how blockchain might improve the information flow regarding materials. Many different approaches could be made when creating such a proposal. Still, the author has chosen a simple visualization that shows how blockchain can connect the various stages and actors by acting as a data layer between the different links in the value chain. Or as represented in the model below, blockchain can be a pipeline for information between the different actors.

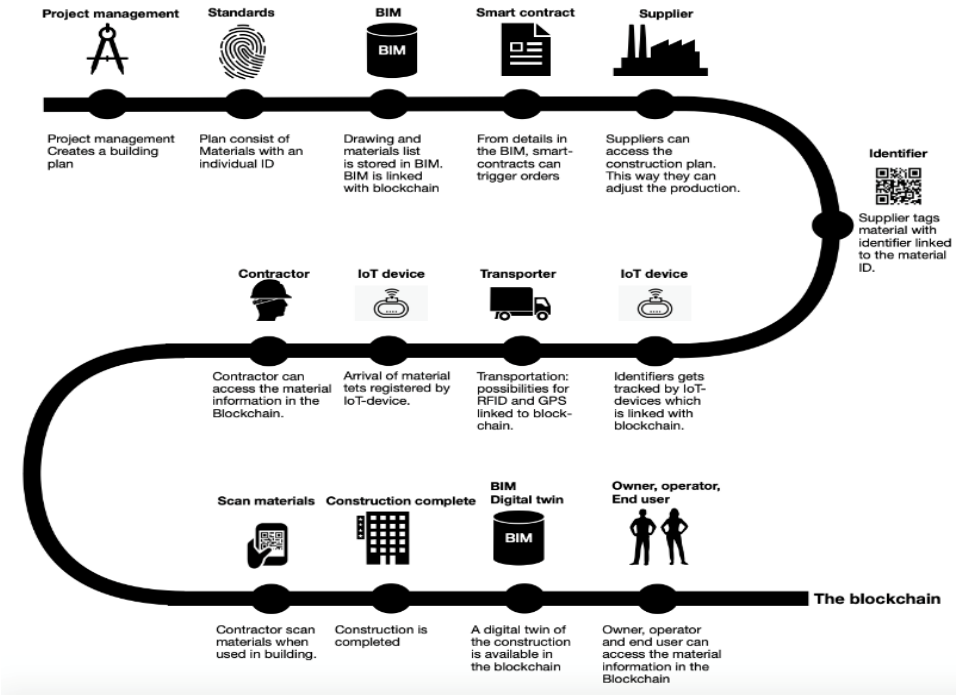

Figure 11: Proposed solution for blockchain integration

But it is important to state that it does not take into account the challenges of implementing blockchain. It is also simplified. It is merely supposed to give an idea of how it might be.

5.5 Qualitative data analysis

Data collection and interpretation have coincided, as with any other qualitative research. In the analysis of this paper, the data that are up for analysis is a mix of data collected during interviews with field experts and data collected from the current literature on the topic.

After each interview where conducted, the interview was transcribed to prevent any loss of valuable data. When the interview was transcribed, the researcher analyzed the data collected to obtain essential information on the topic. Yin (2003) states that returning to the propositions is an important procedure during the analysis phase of any case study for various reasons. This is to prevent the temptation to evaluate data that is beyond the scope of the research questions. This approach leads to a more oriented study. Some of the interviewers were more talkative than others, and occasionally some of them went a bit off-topic.

One risk of the research process is that each data source is handled individually, and the results are recorded separately. A case study is not intended to be used in this manner. Instead, the researcher must ensure that the data are converged to explain the overall case, rather than the different sections of the case or the contributing factors that affect the case.

5.6 Trustworthiness and authenticity of the research

Bell et al. (2018) state that Lincoln and Gupa (1985) have proposed two new criteria for assessing the quality of a qualitative study. The two criteria are trustworthiness and authenticity.
Trustworthiness is made up of four criteria which are:

- Credibility
- Transferability
- Dependability
- Confirmability

When it comes to credibility, there are several ways to ensure it.

Credibility

One technique is called triangulation, and in qualitative research, it refers to the utilization

of many methodologies or data sources to obtain a thorough knowledge of phenomena (Carter, Bryant-Lukosius, DiCenso, Blythe, & J.Neville, 2014). This paper has benefited from using data source triangulation. This has been done by collecting data from several interviews with different experts and ensuring multiple perspectives and data validation.

Transferability

Qualitative research should produce what is called “thick descriptions” about the “culture” studied (Geertz, 1973). In plain English, that means that a qualitative study should have a rich account of the detail of the subject studied for others to judge whether the research is transferable to other subjects. In the author's opinion, this is ensured with the substantial amount of data collected during the research.

Dependability

One way of doing this is by auditing and ensure that all records are kept of the research performed like problem formulation, transcript etc. (Lincoln & Guba, 1986). This has partially been done by explaining the different steps of the research, detailed description of methods, and interview guides are included in the appendix section.

Confirmability

Complete objectivity is impossible, but it should be apparent that the author has not let personal values or theoretical inclinations affect the research and findings. The author believes that the research is conducted in good faith and has been open to whatever results research finds.

6.0 Conclusion

6.1 Research conclusion

During this master thesis, the author has investigated how blockchain can improve the information flow relating to materials in the construction supply chain using an exploratory research method.

A literature review was undertaken to define blockchain technology and the construction industry. The findings from the literature review made the foundation for future work. A big part of the data used to answer the research problem is based on expert interviews. This

gives the study a unique insight into the Norwegian construction industry and ensures the thesis's authenticity.

Three research question were developed together with one research problem. The first research question is what is the current state when it comes to information flow in the construction supply chain? The key findings from this research question are that the industry suffers from a fragmented supply chain and a low level of digitalization. Systems do not talk to each other, creating information silos and the general information flow is poor.
The second research question investigates the barriers to the implementation of blockchain in the construction industry. The main barrier to the implementation of blockchain is the misconception of the technology. It is a new technology that has yet to get its foot holding in supply chains, and the fact that the construction industry is not ready for the technology because of its dysfunctional supply chain.

With the last research question, the thesis has investigated what type of supplementary technologies can blockchain benefit from? To utilize the full potential of blockchain technology, it should be integrated with BIM, ERP systems, and IoT devices. It should also be mention that either a digital twin or standards need to be developed for each material before the integration can be successful with these technologies.

Should blockchain be implemented in the construction industry or not?
This study discovered that blockchain has great potential in regards to improving the flow of material information. It will take time, as with any other technology, for industries to embrace blockchain technology. Many barriers need to be solved, both in relation to the technology itself and within the construction industry. Nonetheless, the authors conclude that there will be significant opportunities for blockchain adoption in the construction industry, especially if customers, governments, and other actors with significant market influence seek a better information flow in the supply chain.

6.2 Limitations

At the beginning of the investigation on the topic of this thesis, it became clear that there are some limitations in terms of previously conducted studies done on the author's research scope. There is currently a lack of research done on blockchain technology in the construction industry. But by combining all the previous research gave the author a sufficient theoretical foundation.
Because of the pandemic, fieldwork has become more challenging, and traveling around visiting companies should be avoided in these times. This prevents the author from getting a first-hand experience of how processes are done.
Another limitation is the lack of actual real-life implementation where there are possibilities for conducting quantitative research. The author did not have the chance to interview more construction professionals. Therefore some essential information may have been missed. The same goes for the blockchain experts.
It should also be mentioned that blockchain technology is complex, and the author did not have a fully comprehensive understanding of the technology.

The timeframe of a master thesis is also very limited. The construction supply chain is very complex, and so is blockchain technology. To fully understand both of them demands more time spent on the subjects.

6.3 Future research

We can see from the thorough analysis of this thesis that Blockchain technology is still in its infancy. Still, the successful implementation of pilot projects in a wide variety of applications shows that it has a bright future. Since any business requires an evident bond of confidence between parties, which blockchain technology provides. Even though there are some successful pilot projects with blockchain, there is a need for real-world implementation to quantify the technology's effect. For the construction industry, some areas stick out. Future research should be focused on the following:

Blockchain for more effective procurement

Since the lack of digital procurement has a significant impact in negative aspects on the materials information flow, it should be a focus area for future research to solve this problem.

Integration with BIM and IoT

This is where blockchain could significantly impact the current construction supply chain—finding the solution for effectively integrating IoT and blockchain to register information about materials that could be shared in the BIM via blockchain.

7.0 References

Ahmadisheykhsarmast, S., & Sonmez, R. (2018). *Smart contracts in construction industry.* Paper presented at the 5th International Project & Construction Management Conference.

Altay, H., & Motawa, I. (2020). *An investigation on the applicability of smart contracts in the construction industry.* Paper presented at the Workshop Proceedings.

Angraal, S., Krumholz, H. M., & Schulz, W. L. (2017). Blockchain technology: applications in health care. *Circulation: Cardiovascular quality and outcomes, 10*(9), e003800.

Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. *Computer networks, 54*(15), 2787-2805.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering, 11*(3), 241-252.

Badi, S., Ochieng, E., Nasaj, M., & Papadaki, M. (2021). Technological, organisational and environmental determinants of smart contracts adoption: UK construction sector viewpoint. *Construction Management and Economics, 39*(1), 36-54.

Barima, O. (2017). Leveraging the blockchain technology to improve construction value delivery: the opportunities, benefits and challenges. *Construction Projects*, 93-112.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report, 13*(4), 544-559.

Behera, P., Mohanty, R., & Prakash, A. (2015). Understanding construction supply chain management. *Production Planning & Control, 26*(16), 1332-1350.

Bell, E., Bryman, A., & Harley, B. (2018). *Business research methods*: Oxford university press.

Bhushan, B., Khamparia, A., Sagayam, K. M., Sharma, S. K., Ahad, M. A., & Debnath, N. C. (2020). Blockchain for smart cities: A review of architectures, integration trends and future research directions. *Sustainable Cities and Society, 61*, 102360.

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & J.Neville, A. (2014). *The use of triangulation in qualitative research.* Paper presented at the Oncology nursing forum.

Chang, J., Katehakis, M. N., Melamed, B., & Shi, J. J. (2018). Blockchain design for supply chain management. *Available at SSRN 3295440*.

Chetty, S. (1996). The case study method for research in small-and medium-sized firms. *International small business journal, 15*(1), 73-85.

Chong, H.-Y., & Diamantopoulos, A. (2020). Integrating advanced technologies to uphold security of payment: Data flow diagram. *Automation in Construction, 114*, 103158.

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and smart contracts for the internet of things. *IEEE access, 4*, 2292-2303.

Christopher, M. (2017). *Logistics & supply chain management*.

Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). Blockchain technology: Beyond bitcoin. *Applied Innovation, 2*(6-10), 71.

Čuš-Babič, N., Rebolj, D., Nekrep-Perc, M., & Podbreznik, P. (2014). Supply-chain transparency within industrialized construction projects. *Computers in Industry, 65*(2), 345-353.

Dainty, A. R., Millett, S. J., & Briscoe, G. H. (2001). New perspectives on construction supply chain integration. *Supply chain management: An international journal*.

Dharmapalan, V., O'Brien, W. J., Morrice, D., & Jung, M. (2021). Assessment of visibility in industrial construction projects: a viewpoint from supply chain stakeholders. *Construction Innovation*.

Dubois, A., & Gadde, L.-E. (2000). Supply strategy and network effects—purchasing behaviour in the construction industry. *European journal of purchasing & supply management, 6*(3-4), 207-215.

El Ioini, N., & Pahl, C. (2018). *A review of distributed ledger technologies.* Paper presented at the OTM Confederated International Conferences" On the Move to Meaningful Internet Systems".

Garas, G. L., Anis, A. R., & El Gammal, A. (2001). Materials waste in the Egyptian construction industry. *Proceedings IGLC-9, Singapore, 86*.

Geertz, C. (1973). Thick Description: Toward an Interpretive Theory of Culture 1973.

Geipel, K. (2017). *Blockchain Technology: How the Invention Behind Bitcoin are Enabling a Network of Trust for the Built Environment*. Retrieved from Arup.com: https://www.arup.com/perspectives/publications/research/section/blockchain-technology

Guegan, A. H. M. (2018). Retrieved from https://bimchain.io/

Guegan, D. (2017). Public blockchain versus private blockhain.

Gulghane, A., & Khandve, P. (2015). Management for construction materials and control of construction waste in construction industry: a review. *International Journal of Engineering Research and Applications, 5*(4), 59-64.

Gupta, M. (2020). Blockchain for dummies. 3rd IBM Limited Edition. In: John Wiley & Sons. Taking a Look at How Blockchain Works.

Harrell, M. C., & Bradley, M. A. (2009). *Data collection methods. Semi-structured interviews and focus groups*. Retrieved from

Jacobsen, D. I. (2005). *Hvordan gjennomføre undersøkelser?: innføring i samfunnsvitenskapelig metode* (Vol. 2): Høyskoleforlaget Kristiansand.

Khalfan, M. M., Kashyap, M., Li, X., & Abbott, C. (2010). Knowledge management in construction supply chain integration. *International Journal of Networking and Virtual Organisations, 7*(2-3), 207-221.

Kong, S. C., Li, H., Hung, T. P., Shi, J. W., Castro-Lacouture, D., & Skibniewski, M. (2004). Enabling information sharing between E-commerce systems for construction material procurement. *Automation in Construction, 13*(2), 261-276.

Kothari, C. R. (2004). *Research methodology: Methods and techniques*: New Age International.

Lanko, A., Vatin, N., & Kaklauskas, A. (2018). *Application of RFID combined with blockchain technology in logistics of construction materials.* Paper presented at the Matec Web of conferences.

Leite, F., Cho, Y., Behzadan, A. H., Lee, S., Choe, S., Fang, Y., . . . Hwang, S. (2016). Visualization, information modeling, and simulation: Grand challenges in the construction industry. *Journal of Computing in Civil Engineering, 30*(6), 04016035.

Li, J., Greenwood, D., & Kassem, M. (2019). Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in Construction, 102*, 288-307.

Liang, Y.-C. (2020). Blockchain for dynamic spectrum management. In *Dynamic Spectrum Management* (pp. 121-146): Springer.

Lincoln, Y. S., & Guba, E. G. (1986). But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation. *New directions for program evaluation, 1986*(30), 73-84.

Liu, Z., Jiang, L., Osmani, M., & Demian, P. (2019). Building information management (BIM) and blockchain (BC) for sustainable building design information management framework. *Electronics, 8*(7), 724.

Mackey, T. K., & Nayyar, G. (2017). A review of existing and emerging digital technologies to combat the global trade in fake medicines. *Expert opinion on drug safety, 16*(5), 587-602.

Marshall, M. N. (1996). Sampling for qualitative research. *Family practice, 13*(6), 522-526.

Mason, J. (2019). BIM fork: Are smart contracts in construction more likely to prosper with or without BIM? *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 11*(4), 02519002.

Mason, P., Augustyn, M., & Seakhoa-King, A. (2010). Exploratory study in tourism: Designing an initial, qualitative phase of sequenced, mixed methods research. *International Journal of Tourism Research, 12*(5), 432-448.

Mathews, M., Robles, D., & Bowe, B. (2017). BIM+ blockchain: A solution to the trust problem in collaboration?

Maull, R., Godsiff, P., Mulligan, C., Brown, A., & Kewell, B. (2017). Distributed ledger technology: Applications and implications. *Strategic Change, 26*(5), 481-489.

McMeel, D., & Sims, A. (2021). Chip of the new block (chain): blockchain and the construction sector.

Meland, Ø. H. (2000). Prosjekteringsledelse i byggeprosessen: suksesspåvirker eller andres alibi for fiasko.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business logistics, 22*(2), 1-25.

Müller, M., Krick, T., & Blohmke, D. J. (2020). Putting the construction sector at the core of the climate change debate. Retrieved from https://www2.deloitte.com/ce/en/pages/real-estate/articles/putting-the-construction-sector-at-the-core-of-the-climate-change-debate.html

Myers, M. D. (2019). *Qualitative research in business and management*: Sage.

Nakamoto, S. (2008). A peer-to-peer electronic cash system. *Bitcoin.–URL: https://bitcoin.org/bitcoin.pdf, 4*.

Nanayakkara, S., Perera, S., & Senaratne, S. (2019). *Stakeholders' perspective on blockchain and smart contracts solutions for construction supply chains.* Paper presented at the CIB World Building Congress.

Niranjanamurthy, M., Nithya, B., & Jagannatha, S. (2019). Analysis of Blockchain technology: pros, cons and SWOT. *Cluster Computing, 22*(6), 14743-14757.

O'Brien, W. J., & Fischer, M. (1993). *Construction supply-chain management: a research framework.* Paper presented at the Proceedings of Civil-COMP.

Ølnes, S. (2016). *Beyond bitcoin enabling smart government using blockchain technology.* Paper presented at the International conference on electronic government.

Perera, S., Nanayakkara, S., Rodrigo, M., Senaratne, S., & Weinand, R. (2020). Blockchain technology: Is it hype or real in the construction industry? *Journal of Industrial Information Integration, 17*, 100125.

Pryke, S. (2009). *Construction supply chain management: concepts and case studies* (Vol. 3): John Wiley & Sons.

Puthal, D., Malik, N., Mohanty, S. P., Kougianos, E., & Das, G. (2018). Everything you wanted to know about the blockchain: Its promise, components, processes, and problems. *IEEE Consumer Electronics Magazine, 7*(4), 6-14.

Qian, X. A., & Papadonikolaki, E. (2020). Shifting trust in construction supply chains through blockchain technology. *Engineering, Construction and Architectural Management*.

Rodrigo, M. N. N., Perera, S., Senaratne, S., & Jin, X. (2020). Potential application of blockchain technology for embodied carbon estimating in construction supply chains. *Buildings, 10*(8), 140.

Seebacher, S., & Schüritz, R. (2017). *Blockchain technology as an enabler of service systems: A structured literature review.* Paper presented at the International Conference on Exploring Services Science.

Sharples, M., & Domingue, J. (2016). *The blockchain and kudos: A distributed system for educational record, reputation and reward.* Paper presented at the European conference on technology enhanced learning.

Shemov, G., de Soto, B. G., & Alkhzaimi, H. (2020). Blockchain applied to the construction supply chain: A case study with threat model. *Frontiers of engineering management, 7*(4), 564-577.

Sheng, D., Ding, L., Zhong, B., Love, P. E., Luo, H., & Chen, J. (2020). Construction quality information management with blockchains. *Automation in Construction, 120*, 103373.

Shojaei, A., Flood, I., Moud, H. I., Hatami, M., & Zhang, X. (2019). *An Implementation of Smart Contracts by Integrating BIM and Blockchain.* Paper presented at the Proceedings of the Future Technologies Conference.

SSB. (2018). Produktivitetsfall i bygg og anlegg. In. ssb.no.

SSB. (2019). Bygg- og anleggsvirksomhet, strukturstatistikk. In: ssb.no.

Stebbins, R. A. (2001). *Exploratory research in the social sciences* (Vol. 48): Sage.

Tafazzoli, M., Nochian, A., & Karji, A. (2019). *Investigating Barriers to Sustainable Urbanization.* Paper presented at the International Conference on Sustainable Infrastructure 2019: Leading Resilient Communities through the 21st Century.

Tezel, A., Papadonikolaki, E., Yitmen, I., & Hilletofth, P. (2020). Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions. *Frontiers of engineering management*, 1-17.

Turk, Ž., & Klinc, R. (2017). Potentials of blockchain technology for construction management. *Procedia engineering, 196*, 638-645.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European journal of purchasing & supply management, 6*(3-4), 169-178.

Wan, P. K., Huang, L., & Holtskog, H. (2020). Blockchain-enabled information sharing within a supply chain: A systematic literature review. *IEEE access, 8*, 49645-49656.

Wang, J., Wu, P., Wang, X., & Shou, W. (2017). The outlook of blockchain technology for construction engineering management. *Frontiers of engineering management*, 67-75.

Weber, I., Xu, X., Riveret, R., Governatori, G., Ponomarev, A., & Mendling, J. (2016). *Untrusted business process monitoring and execution using blockchain.* Paper presented at the International Conference on Business Process Management.

Wu, J., & Tran, N. K. (2018). Application of blockchain technology in sustainable energy systems: An overview. *Sustainability, 10*(9), 3067.

Xia, F., Yang, L. T., Wang, L., & Vinel, A. (2012). Internet of things. *International journal of communication systems, 25*(9), 1101.

Xue, F., & Lu, W. (2020). A semantic differential transaction approach to minimizing information redundancy for BIM and blockchain integration. *Automation in Construction, 118*, 103270.

Yang, R., Wakefield, R., Lyu, S., Jayasuriya, S., Han, F., Yi, X., . . . Chen, S. (2020). Public and private blockchain in construction business process and information integration. *Automation in Construction, 118*, 103276.

Yin, R. K. (1994). Case study research: Design and methods, applied social research. *Methods series, 5*.

Young, D. A., Haas, C. T., Goodrum, P., & Caldas, C. (2011). Improving construction supply network visibility by using automated materials locating and tracking technology. *Journal of Construction Engineering and Management, 137*(11), 976-984.

Zheng, R., Jiang, J., Hao, X., Ren, W., Xiong, F., & Ren, Y. (2019). bcBIM: A blockchain-based big data model for BIM modification audit and provenance in mobile cloud. *Mathematical Problems in Engineering, 2019*.

Zheng, Z., Xie, S., Dai, H.-N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: A survey. *International Journal of Web and Grid Services, 14*(4), 352-375.

Zhong, B., Wu, H., Ding, L., Luo, H., Luo, Y., & Pan, X. (2020). Hyperledger fabric-based consortium blockchain for construction quality information management. *Frontiers of engineering management, 7*(4), 512-527.

8.0 Appendix

Interview guide for construction industry specialists.

Forskningsspørsmål	
How can blockchain provide better material information in construction industry?	
Introduksjon til intervjue	
I forbindelse med min masteroppgave ønsker jeg å fordype meg i hvordan blockchain teknologi kan brukes for å forbedre informasjonsflyten knyttet til materialer brukt i byggebransjen. Gjennom foreløpig arbeid med dette temaet sitter jeg igjen med et inntrykk av at tilgjengelighet på informasjon angående materialer som blir bruk i et prosjekt er lav. Jeg mener at blockchain kan være en teknologi som kan forbedre informasjonsflyten mellom de ulike aktørene, noe som kan føre til at bransjen kan bli mer effektiv, økt samarbeid og bedre sporbarhet av materialer. Det jeg ønsker med dette intervjuet er å kartlegge hvordan situasjonen er i dag, og identifisere eventuelle utfordringer.	
Temar	**Sprøsmål**
Bakgrunn	▪ Hvor jobber du, og hva er din rolle?
Informasjon om bransjen	▪ Hvilke utfordringer sliter dere med i dag? ▪ Hvordan er tilgangen på informasjon? ▪ Er det åpenhet mellom de ulike aktørene? - *Oppfølging*: Hva er grunne til at det er liten grad av åpenhet? ▪ Er det mangel på tillit mellom de ulike aktørene som følge av manglende informasjon? ▪ Hvordan jobber dere i dag for å forbedre informasjonsflyten mellom de ulike aktørene?
Hvilke teknologier bruker dere i dag?	▪ Hva er de viktigste systemene dere bruker i dag? ▪ Hvilke systemer er tilknyttet materialinformasjon? ▪ Kan noen av de nåværende systemene brukes til sporing/registrering av materiale

	▪ Snakker disse systemene sammen? ▪ Ser du for deg at nåværende systemer/teknologier kan integreres med ny teknologi? ▪ Hvordan er villigheten til å investere i ny teknologi?
Informasjons- og data deling	▪ Hvordan er informasjonsflyten gjennom bransjen i dag? ▪ Hvordan er sporbarheten av materialer i dag? - *Oppfølging:* Kan man spore en type materiale hele veien? ▪ Hvordan er samarbeidet med leverandører i dag? - Oppfølging: Kan teknologier som BIM og CAD ▪ Finnes det noen oversikt over hvilke materialer som er blitt brukt i et bygg? - *Oppfølging:* Kan eventuelt sluttbruker ha tilgang til denne informasjonen - Kan denne informasjonen brukes ved vedlikeholdsarbeid (Livssyklus) ▪ Er det et behov for å vite hvilke materialer som er brukt? (I forhold til krav og lover)

Interview with supplier

Forskningsspørsmål
How can blockchain provide better flow of material information in supply chain of construction industry?
Introduksjon til intervjue
I forbindelse med min masteroppgave ønsker jeg å fordype meg i hvordan blockchain teknologi kan brukes for å forbedre informasjonsflyten knyttet til materialer brukt i byggebransjen. Gjennom foreløpig arbeid med dette temaet sitter jeg igjen med et inntrykk av at tilgjengelighet på informasjon angående materialer som blir bruk i et prosjekt er lav. Jeg mener at blockchain kan være en teknologi som kan forbedre informasjonsflyten mellom de ulike aktørene, noe som kan føre til at bransjen kan bli mer effektivt, økt samarbeid og bedre sporbarhet av materialer. Det jeg ønsker med dette intervjuet er å kartlegge hvordan situasjonen er i dag, og identifisere eventuelle utfordringer.

Temar	**Sprøsmål**
Bakgrunn	▪ Hvor jobber du, og hva er din rolle?
Informasjon om bransjen	▪ Fortell kort om bedriften? ▪ Hvor kommer råvarene fra? ▪ Hvem er deres kunder? ▪ Hvilke produkter har dere? -Prefabrikkerte moduler f.eks -Hvem er deres kunder? -Hvordan er prosessen ved bestilling av hos dere? ▪ Har dere noen spesielle utfordringer i dag? ▪ Baseres en handel kun på tillit? - Finnes det en database med oversikt over tidligere transaksjoner? En måte man kan identifisere useriøse aktører på? ▪ Hvordan er åpenheten mellom aktørene?

	▪ Hvordan er prosessen rundt sikring av materialkvalitet, sertifikater og tilsyn? - Hvor lagres informasjon rundt dette? - Hvem deles det med?
Hvilke teknologier bruker dere i dag?	▪ Hva er de viktigste systemene dere bruker i dag? ▪ Hvilke systemer er tilknyttet materialinformasjon? - Transaksjonsdata ▪ Kan noen av de nåværende systemene brukes til sporing/registrering av materiale - Eventuelt, bruker dere teknologi som RFID eller GPS sporing? ▪ Snakker deres systemer sammen med kundenes systemer? - Kan deres data legges rett inn i kundens system? - Ville det vært interessant med et system for deling av informasjon? ▪ Ser du for deg at nåværende systemer/teknologier kan integreres med ny teknologi? ▪ Hvordan er villigheten til å investere i ny teknologi?
Informasjons- og data deling	▪ Hvordan er informasjonsflyten gjennom bransjen i dag? ▪ Hva slags informasjon blir utvekslet mellom de forskjellige leddene? ▪ Hvordan er sporbarheten av materialer i dag? - *Oppfølging:* Kan man spore en type materiale hele veien? ▪ Finnes det en klar oversikt over hvem som har ansvaret for varen/materialet til enhver tid? ▪ Finnes det en etterspørsel etter informasjon om materialene? -Tenker f.eks på levetid, bærekraft og miljø

Blockchain	▪ Introduksjon Blockchain har egenskapene til å kunne spore hvert steg i supply chain et produkt går gjennom med tanke på opphav, autentisitet, lokasjon, ansvar og kvalitet, (med andre teknologier) og å skape åpenhet mellom aktører i supply chain og skape en sikker informasjonsflyt. ▪ Tror du en slike type teknologi kan være nyttig for dere? ▪ Hva er de største barrierene for å implementere ny teknologi som for eksempel blockchain?

Interview with Blockchain expert 1

Forskningsspørsmål
How can blockchain improve the flow of information in relation to materials throughout the construction supply chain?
Introduksjon til intervjue
In connection with my master's thesis, I want to investigate how blockchain technology can be used to improve the flow of information related to materials used in the construction industry. Through preliminary work on this topic, I am left with the impression that the availability of information regarding materials used in a project is low. I believe that blockchain can be a technology that can improve the flow of information between the various players, which can lead to the industry becoming more efficient, increased collaboration and better traceability of materials. I wish that with this interview I can map how blockchain potentially can be implemented in a construction supply chain.

Temar	**Sprøsmål**
Bakgrunn	▪ Who are you? What are your experience and your current role.
Blockchain	▪ Could you give a short explanation of what blockchain technology is? ▪ What features makes blockchain attractive for a supply chain? ▪ What is the difference between private and public blockchain? - Is there any difference in performance?

	- Do you prefer one over the other? - Will the type of industry or the area of use have any influence on what type is most suitable? ▪ How can blockchain be used for storing and sharing information? ▪ Can blockchain be used for tracking of products/materials? - If so, how? ▪ How can blockchain change the way trust between different actor's work? ▪ Can blockchain be integrated with other technological solutions such as ERP systems? - Is this process complex? ▪ What other technical solutions must be applied to maximize the benefits of blockchain in terms of transparency and traceability? ▪ What are the biggest barriers for blockchain implementation in supply chains as of now? ▪ What positive changes can a supply chain expect as a result of implementing blockchain?
Blockchain in the construction industry	The construction industry is a fragmented and complex industry. There are many actors involved in big projects, and the information through out the supply chain is poor. ▪ Do you believe that integrating the ERP-systems with blockchain would be benefitting the industry? ▪ What benefits does blockchain provide that the current ERP-systems do not? ▪ Can blockchain act as a technological infrastructure where information from other systems can be stored and shared? ▪ One problem in construction supply chain is that the different system does not talk with each other. There is also a lack of standardization in the data. The supplier has one name for a material, and the buyer have another name for it. Can blockchain be a solution to his?

	▪ The construction industry experts say that it is difficult to find information on the materials hey receive. The supplier on the other hand claim they have all the necessary information about a product, but there are no initiatives from the next link in the supply chain to obtain this information. How can blockchain be used to solve this issue. ▪ Can blockchain be a tool against fraudulent behavior and materials. - How can you ensure that the materials being used in a construction follows the regulations and rules?

Interview with blockchain expert 2

Forskningsspørsmål	
How can blockchain improve the flow of information in relation to materials throughout the construction supply chain?	
Introduksjon til intervjue	
I forbindelse med min masteroppgave ønsker jeg å fordype meg i hvordan blockchain teknologi kan brukes for å forbedre informasjonsflyten knyttet til materialer brukt i byggebransjen. Gjennom foreløpig arbeid med dette temaet sitter jeg igjen med et inntrykk av at tilgjengelighet på informasjon angående materialer som blir bruk i et prosjekt er lav. Jeg mener at blockchain kan være en teknologi som kan forbedre informasjonsflyten mellom de ulike aktørene, noe som kan føre til at bransjen kan bli mer effektivt, økt samarbeid og bedre sporbarhet av materialer. Det jeg ønsker med dette intervjuet er å kartlegge hvordan situasjonen er i dag, og identifisere eventuelle utfordringer.	
Temar	**Sprøsmål**
Bakgrunn	▪ Hva er din erfaring og rolle?
Blockchain	▪ Kan du fortelle litt kort om blockchain teknologi? ▪ Hvilke egenskaper ved blockchain gjør at det er aktuelt for supply chain? ▪ Wha er forskjellen på privat og public blockchain? - Er det noen forskjell I ytelse? - Foretrekker du en ovenfor den andre?

	- Er bransjen eller aktiviteten blockchain skal brukes i avgjørende for hvilken man skal velge? ▪ Hvordan kan blockchain brukes til lagring og deling av informasjon? ▪ Hvordan kan blockchain brukes I sammenheng med sporing av produkter/materialer? ▪ Hvordan kan blockchain endre tilliten mellom de ulike aktørene i bransjen? ▪ Kan blockchain integreres med nåværende systemer? F.eks. ERP-systemer? ▪ Hvilke andre teknologiske løsninger er blockchain avhengig av for å maksimere nytten i forhold til sporing og synlighet? ▪ Hva vil du si er de største barrierene for blockchain i supply chain? ▪ Hvilke effekter kan en supply chain forvente ved bruk av blockchain?
Blockchain in the construction industry	Byggebransjen er en veldig fragmentert bransje, med mange forksjellige aktører som jobber sammen for å skape et produkt. Byggebransjen er i dag preget av manglende informasjonsflyt mellom de ulike aktørene. ▪ Tror du at en integrering av blokchain og ERP vil være fordelaktig for bransjen? ▪ Hvilke fordeler kan man få ved å integrere blockchain og ERP som man ikke har om man bruker ERP alene? ▪ Kan blockchain fungere som en digital infrastruktur for deling og lagring av data for fler type systemer? ▪ Et av de store problemene man har i byggebransjen er at man har mange ulike systemer som ikke snakker sammen. Tror du blockchain kan være en løsning til dette? Eventuelt hvordan? ▪ Eksperter fra byggebransjen sier det er vanskelig å finne informasjon om materialene de mottar. Leverandøren jeg har

	snakket med sier imidlertid at de har all nødvendig informasjon om produktene, men føler det er et manglende insentiv fra neste ledd i verdikjeden for å motta inforamsjonen. Hvordan kan blockchain være en del av løsningen på dette problemet? ▪ Can blockchain be a tool against fraudulent behavior and materials. - How can you ensure that the materials being used in a construction follows the regulations and rules?

Interview with standard expert

Forskningsspørsmål	
How can blockchain improve the flow of information in relation to materials throughout the construction supply chain?	
Introduksjon til intervjue	
I forbindelse med min masteroppgave ønsker jeg å fordype meg i hvordan blockchain teknologi kan brukes for å forbedre informasjonsflyten knyttet til materialer brukt i byggebransjen. Gjennom foreløpig arbeid med dette temaet sitter jeg igjen med et inntrykk av at tilgjengelighet på informasjon angående materialer som blir bruk i et prosjekt er lav. Jeg mener at blockchain kan være en teknologi som kan forbedre informasjonsflyten mellom de ulike aktørene, noe som kan føre til at bransjen kan bli mer effektivt, økt samarbeid og bedre sporbarhet av materialer. Det jeg ønsker med dette intervjuet er å kartlegge hvordan situasjonen er i dag, og identifisere eventuelle utfordringer.	
Temar	**Sprøsmål**
Bakgrunn	▪ Hva er din erfaring og nåværende rolle?
Informasjonsstandarder	▪ Kan du forklare kort hva GS1 er og hva dere holder på med? ▪ Hvordan skiller byggenæringen seg fra de andre bransjene dere samarbeider med? ▪ Hva vil du si er de største utfordringene for bransjen? ▪ Hvordan jobber dere for å løse disse problemene?

	▪ Kan du forklare hva GTIN og SGTIN er? ▪ Jeg leste på sidene deres at dere bruker digital tvilling, kan du forklare hvordan dere gjør dette? ▪ Hvordan er datasikkerheten i dag?
Hvordan kan de ulike problemene i byggebransjen løses ved bruk av deres metoder?	▪ Har du noen formening om hvordan man kan involvere BIM i større grad med tanke på material og produkt informasjon? ▪ Hvordan kan man få en digital varehandel? ▪ Hvordan løser man at et produkt har mange ulike navn? ▪ Kan dere bidra til at de ulike systemene i byggebransjen kan snakke mer sammen? ▪ En av leverandørene som jobber med trelast sa at det var vanskelig med RFID tags på produktene deres, siden de forstyrrer signalene til hverandre. Er det en løsning på dette? ▪ Hvordan kan man sikre sporing av produktene ▪ Hvordan kan levering på byggeplassen gjøres bedre når det gjelder å sikre informasjonen rundt produktene? ▪ Hvilke barrierer finnes det for å implementere deres løsninger? ▪ Hvordan fungerer f.eks en RFID? Hvor sendes dataen? ▪ Det ble nevnt i et intervju at mye av informasjonen rundt materialer og produkter er lagret på pdf som ikke er maskinlesbart. Har dere en løsning på det? ▪ Hvordan kan GS1 være med på å forbedre tilliten mellom aktørene?
Blockchain	▪ Har du hørt om blockchain? - I så fall, hva er dine tanker rundt denne teknologien? Blockchain har løst problemet med å dele data i et offentlig nettverk på en sikker måte. Her har du et globalt datalayer som alle kan bruke, men ingen kontrollerer.

	▪ Tror du blockchain kan være en del av løsningen sammen med dere?