Tampereen yliopisto

Sini Makkonen

IMPROVING PROCESS FLOW IN FRAME ERECTION PHASE OF A RESIDENTIAL BUILDING

Master’s thesis
Rakennetun ympäristön tiedekunta
Kalle Kähkönen
Harri Haapasalo
June 2023

TIIVISTELMÄ

Sini Makkonen: Prosessivirtauksen parantaminen asuinkerrostalon runkovaiheessa
Tampereen yliopisto
Rakennustuotanto ja -talous
Kesäkuu 2023

Betonielementtirakentaminen on Suomessa paljon käytetty ratkaisu asuinkerrostalojen rungon rakentamisessa. Betonielementtisen asuinkerrostalon runkovaiheen oletetaan usein olevan selkeä ja hyvin hallittu prosessi, joka on saatu toimimaan hallitusti ajantuoman kehityksen myötä. Kuitenkin lähempää tarkasteltuna virheitä esiintyy työmaalla päivittäin ja elementtien toimitusketjut ovat pirstaloituneita. Pirstaleisuus näkyy betonielementtien toimitusketjuissa eri toimijoiden välillä tapahtuvana siiloutumisena, mikä johtaa betonielementtirungon prosessin virtauksen heikkenemiseen ja hankaloittaa toiminnan kehittämistä.

Diplomityön tavoitteena on edistää betonielementtitoimitusketjun prosessin toimintaa tunnistamalla siinä esiintyviä ongelmakohtia, sekä löytämällä mahdollisia kehityskohteita kvalitatiivisesti ja tutkivasti kirjallisuuden, sekä case-tutkimuksen kautta. Työn tarkoituksena on tuoda ilmi tietoa ja lisätä alan tietoisuutta case-kohteen kaltaisien toimitusketjujen ongelmakohdista. Tutkimuksessa käytetään Lean ajattelua ja transaktiokustannusten näkökulmaa toimitusketjussa esiintyvien ongelmien tulkitsemiseksi. Ongelmien tutkimusta tuki toimitusketjujen arvovirtakartoitus, joka kuvasi toimitusketjujen toimintoja elementtien matkan varrella hankinnasta työmaalla paikoille asennukseen asti. Ongelmia tutkittiin kvalitatiiviselle tutkimukselle tyypillisesti monesta eri lähteestä haastatteluissa, työpajoissa, sekä aikaisemmin toteutetun case-kohteen asennushäiriöiden tutkimuksen tuloksista. Ongelmia käsiteltiin työpajassa, jonka tuloksena tutkimus muodosti juurisyyluokittelun, jota pystyttiin vertaamaan kirjallisuuden ja haastattelujen pohjalta muodostettuun luokitteluun.

Tutkimuksen päätuloksena toimitusketjussa esiintyvät ongelmat jaoteltiin ryhmiin kommunikaatio, dokumentaatio ja tiedonsiirto, riittämätön ennakoiva suunnittelu, ihmisten johtaminen ja inhimilliset virheet, ongelmien luokittelun ja virheiden dokumentoinnin puutteet, prosessin tiedon tuottamisen ongelmat, sekä odottamattomat ongelmat. Tutkimusten perusteella toistuvimpana toimitusketjun ongelmana eri tarkasteluissa on ongelmat informaation virtauksessa toimijoiden välillä. Empiirisessä tutkimuksessa hukkien osalta toistuvimmat ongelmat olivat odotus, liike ja kommunikaatio ja dokumentaation ongelmat. Ongelmien ratkaisemiseksi tutkimus ehdottaa suuntaa antavia kehitysehdotuksia, joissa esiintyy oleellisena prosessin standardointi, integraation ja maturiteettitason nostaminen, sekä informaatiovirtauksen parantaminen. Ratkaisuehdotusten avulla asuinkerrostalon runkovaiheen prosessi saadaan virtaamaan paremmin.

Avainsanat: betonielementtitoimitusketju, toimitusketjun hallinta, hukka, transaktiokustannukset, arvovirta, integraatio.

ABSTRACT

Sini Makkonen: Improving process flow in frame erection phase of a residential building
Master's thesis
Tampere University
Construction Management and Economics
June 2023

Precast concrete element construction is a widely used solution in Finland for the construction of the frame of residential apartment buildings, and the framing phase of a precast residential apartment building is often assumed to be a straightforward and well-controlled process that has been developed over time to work well. However, when taking a closer look, errors occur on the construction site daily, and the element supply chains are fragmented. Fragmentation can be seen in precast concrete supply chains as the supply chains functional groups forming silos, which hinders the flow of the precast concrete frame process and makes it challenging to make developments.

The master's thesis aims to promote the functioning of the supply chain process by identifying the problems of the precast concrete supply chain and by finding possible development targets qualitatively and exploratorily through a literature review and a case study. The study opens the topic and increases the industry's awareness of the problems existing within the precast concrete supply chains. The research uses the perspective of Lean thinking and transaction costs to interpret the problems occurring in the supply chain. The study of the problems was supported by the value stream mapping of the supply chains, which described the functions of the supply chains, from the acquisition of the elements on to their installation on the site. The problems were collected in a fashion typical for qualitative research, where many different sources were used. The problem information was collected from interviews, a workshop, and preexisting data on installation malfunctions on the case site. The problems were discussed in a workshop setting, resulting in a root-cause classification. The resulting classifications were compared to the classification formed based on the literature review and interviews.

As the main result of the study, the problems occurring in the supply chain were divided into the categories of communication, documentation and data transfer, insufficient proactive planning, human management, and human errors, deficiencies in the classification of errors and documentation of errors, problems in the production of process information, and unexpected problems. Based on research, the second most pressing problem in the supply chain in different reviews is the problems in the flow of information between the actors. In the empirical study, the most frequent problems regarding accidents were waiting, motion, communication, and documentation problems. To find solutions to these problems, the research proposes a few development actions, where standardization of the process, raising the level of integration and maturity, and improving the flow of information are essential. By applying these suggested improvements, the process flow of the residential building's frame erection phase can be enhanced.

Key words: Precast concrete element supply chain, supply chain management, waste, transaction cost, value stream, integration

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

Compared to other industries, the construction industry suffers from poor productivity that trails far behind other industries. Many factors affect productivity, but some of the main reasons have been credited to the nature of the construction industry. The construction industry is deeply fragmented vertically, horizontally, and longitudinally, resulting from the specialization of processes, competition between firms, and the project-based nature of the construction, respectively (Hall et al., 2020). These fragmentations are the prime mover of many of the problems the construction industry faces daily, and to combat these fragmentation-caused problems, a comprehensive outlook is needed. Instead of focusing on individual functional construction processes, a broader perspective on the supply chain is necessary.

Inspired by global innovations and productivity leaps in other industries, the construction industry in Finland has been awakened to the need for change. Achieving this change is hindered by the construction industry's fragmented perspective caused by the different parties' partial views (Costa et al., 2023). To combat this, many of the industry's influential organizations have agreed that the necessary changes cannot be made individually. Different parties need to work together to change the configuration of the industry. Lavikka et al. (2021) present that currently the innovations in the construction industry are most often autonomous innovations that are limited to one organization (Lavikka et al., 2021). Hall et al. (2020) open this phenomenon by stating that the systematic innovations needed to make global improvements are often overlooked in favor of easier-to-implement in-organizational solutions (Hall et al., 2020).

At the heart of the change, that the construction industry needs, is construction industrialization. There are many different contributions to defining construction industrialization. Costa et al. (2023) proposes a definition where construction industry is defined as a new form of production and management with the objective to improve the productivity and sustainable development. The industrialization is driven by applying various construction, industrial engineering and management innovations. (Costa et al., 2023) Prefabrication is a significant part of the industrialization and as such, is an interesting subject of research.

1.2 Objectives and research problem

This thesis aims to be a part of this change and find areas needing development through an exploratory case study. To form substantial and accurate results from this study, the study is conducted as a single case study so that it will not be limited to a general level but rather collect more specific information about the actual state of the supply chains. Lavikka et al. (2021) state that to implement systematic innovations, the analysis of all of the parties included in the construction project is necessary and that recognizing communication patterns, different barriers, possibilities, and enablers for value creation is essential to implement changes (Lavikka et al., 2021). This thesis focuses and investigates the problems of the supply chains of the precast concrete elements across the organizational boundaries to find ways to better the frame erection phase. Supply chains are defined as links that connect all the steps needed to produce a product from source to a customer (Sople, 2012). By focusing on these links, it is possible to review the connection between different facilities, companies, demand and supply points and service providers.

The case is a residential building design and build project where the frame is a precasted concrete element frame. The scope of this thesis is limited to the supply chains of the precasted concrete elements to keep it to a manageable extent. This scope allows a fitting perspective into the problem, as these types of projects are prevalent and typically include many different stakeholders. This thesis aims to find ways to better the flow of the frame erection phase of a residential building. It is crucial to understand the problems we are trying to solve to form a solid base on which these improvements are built. This study will use the scope of a supply chain to avoid following the trend of partial optimization around different functional groups involved in the project. This leads to the first research question:

R1. What kind of problems hinder the flow in the supply chain of a construction project, why do these problems occur?

Understanding how and why the current supply network operates as it does is the first step to understanding what needs to be changed. By understanding the strengths and weaknesses of the current operations and why they are operated in the way they are, it is possible to pinpoint the things that need to be improved. Finding these changes is aided by the theoretical base of the types of waste and transaction costs in the supply chains. This step is compressed into the second research question:

R2. How is the current supply network organized, and what are its main sources of waste, transaction costs and other problems?

To bring this research to an end, and to fulfill the main objective, a way to improve this network of different functional parties is needed. These improvements will be founded as an answer to the last research question:

R3. What kind of changes should be implemented in the supply network to create more value with less effort, aligned with the objective of optimizing the flow in the construction process?

The supply chains contain many different kinds of flows such as material, information and product flow (Sople, 2012), but the flow referred to in this thesis is the process flow.

1.3 Case project

This thesis is conducted as a case study of one construction project which implemented as a design and build project with Fira acting as the main contractor. The chosen project is a good example of a residential construction project using precast concrete element frame with many different stakeholders and element manufacturers.

The client is the housing corporation of the building. The contract follows the contract terms of YSE 1998 and the contract includes everything needed to achieve a finished building ready for residential use. The client will not make any purchases or supply any of the building materials. The building is an apartment building with three stairs with six to seven floors with 136 apartments altogether. The building of the case project is illustrated in figure 1.1.

Figure 1.1 The Case project building's data model.

The building frame is made with precast concrete (PCC) elements. The floors are hollow core slab structures. The facades are mainly brick and partly graphic and painted sandwich elements. The designing was made using Fira's apartment library which is a data bank with a collection of standard solutions for architecture, structures, and HVAC. The bathrooms are carried out as a modular construction, where the bathrooms are prefabricated off-site and then installed onsite along with the PCC elements.

During the erection of the frame, the case site was supposed to be used as a prototype for takt time, but due to a change of plans this plan was not fully actualized. This change of plans leads to the element installation changing tactics midway through the frame erection phase.

1.4 Structure of the thesis

The thesis will explore the overall circumstances around value creation in a supply chain of a concrete frame residential building on a qualitative level. The goal of the first chapter of this thesis is to set the premises for the thesis and to open the reasonings behind the chosen topic and scope.

Chapter two will be a preface to the methods applied in the research and justification of their use. This part details the research approach, methods and tools used in the literature review and the empirical study such as the methods of data collection and analysis, namely theme interviews, workshops, and root-cause analysis. It opens the interview themes and what each theme tries to accomplish.

The main subject matter begins in chapter three, which consists of a literature review. The review starts by setting a theoretical framework that forms the theoretical base for the thesis. After the framework is established, a review of the problems existing within the supply chains of the precast concrete elements is conducted. These problems are investigated from the two perspectives of waste and transaction cost difficulties.

Chapter four starts by presenting the findings regarding the current state of the supply chains. The current state is presented from the viewpoint of the business models of the supply chain parties, the products being made and the value stream of each supply chain. After which, there is an analysis portion where the problems are presented, and the goal is to find root causes for the problems found in the supply chain.

In the end of chapter 4, the empirical findings and the literature review are tied together and then used as input to find ways to improve the supply network holistically. The improvements will be made using insights from Lean principles and supply chain management theories.

To bring the thesis to its conclusion, chapter five outlines the main findings of the thesis. The findings are assessed in the scope of the thesis, and the limitations are considered. Lastly, this study will reflect on the possible courses of action to continue this research and identify the needs of some possible future research.

2. RESEARCH METHODOLOGY

2.1 Research approach

The primary purpose of this thesis is to find ways to investigate the process flow of the supply chains of a precast concrete element frame phase of residential construction project by discovering different problems existing within the structures and activities in it. The study uses the viewpoints of Lean wastes and transaction costs as a way of identifying these wastes and finding the causes behind them. The adopted research design is a qualitative exploratory case study. Qualitative research is characterized by Hammersley (2012) as a flexible research design which utilizes verbal forms of analysis with the emphasis of subjectivity of the research process. The data used in this kind of research is often relatively unstructured and the objective of analysis is not placed on proving existing theories but studying the phenomena. The phenomena is often studied in small samples of cases. (Hammersley, 2012)

As Robson (2002) defines it, a case study is a research strategy often used in qualitative research where the subject of an empirical investigation is a particular phenomenon viewed in its actual context. A case study often contains various methods of data collection from different sources. (Robson, 2002) This thesis approaches the case and the problems found from the orientation of identifying causes. The approach of identifying problems and finding their causes is illustrated in figure 2.1.

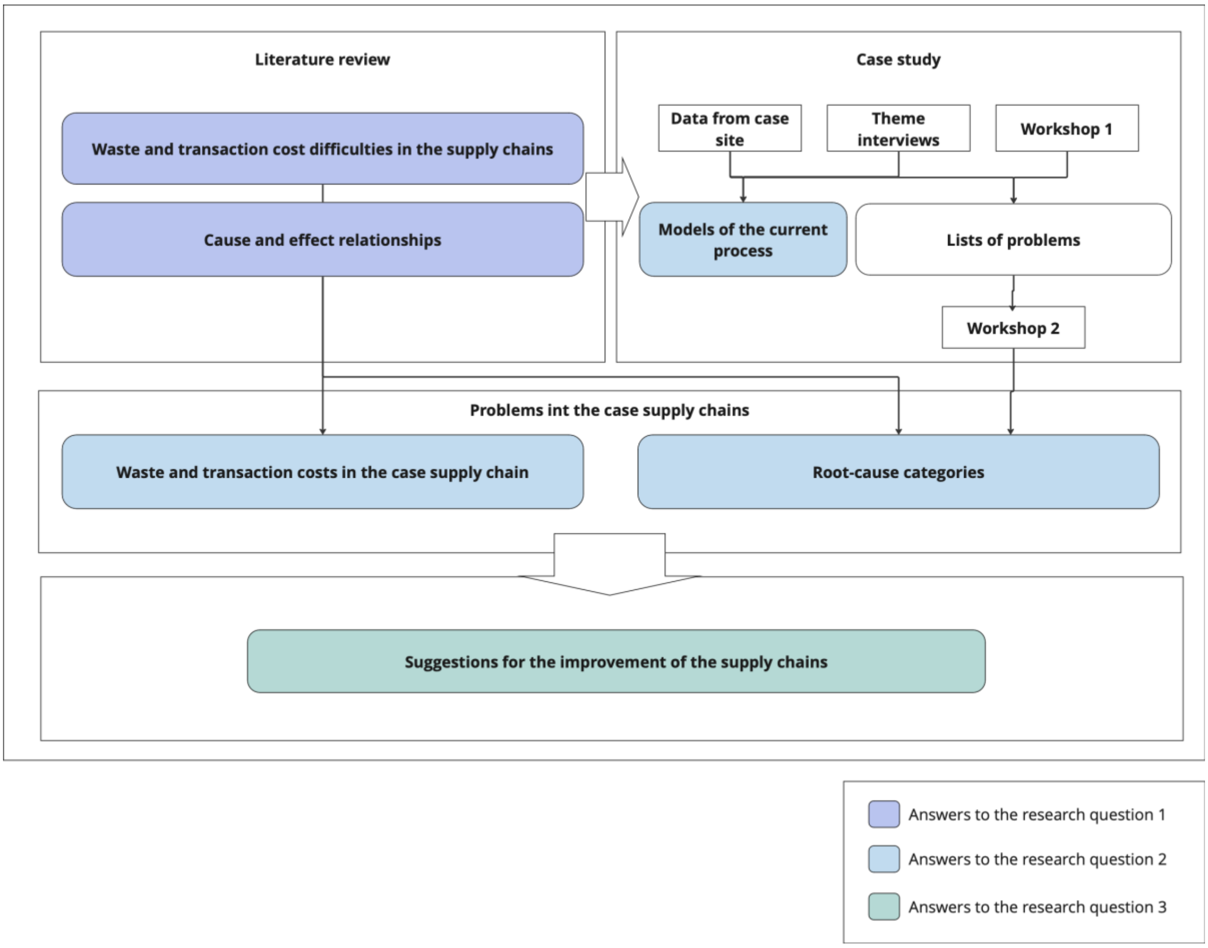


Figure 2.1 The research approach for identifying and categorizing problems and finding solutions.

2.2 Research setting and scope

The value chain of a construction project of a residential building with a precast concrete element frame can be divided roughly into 5 phases. This case study will concentrate on the phases most closely connected to the production of PCC elements, namely the prefabrication, and assembly and on-site manufacturing phases presented in the figure 2.2.

Figure 2.2 The phases of a construction project of a residential building with prefabricated concrete element frame modified from (Teriö et al., 2003).

In this thesis the prefabrication begins from finding the element manufacturers for the project and includes all the activities needed for the element to arrive on site. To limit the scope of the research, the foundation works, and water roofing works are limited outside of the study and the focus is placed on the PCC element supply chains inside these limits.

In this thesis, activities included in the prefabrication phase are creating a contract, element design, production planning, manufacturing, and transportation. The assembly and on-site manufacturing in this case contains the activities performed on-site needed to get the elements installed and to create the capacity to build the water roof on time. These activities include scheduling, ordering elements to the site, installing the elements, installing electricity tubing, preparations of the floor casting, and the floor casting.

2.3 Literature review

2.3.1 Data collection

The data used in the literature review is collected with a combination of digital and manual methods, with most of the sources being digital. The sources to be used are published literature sources where the topic fits within the scope of the literature review. As the literature review will be used to answer to the first research question, the scope is formed around it. The sources are searched using the search engines and data bases of Andor and Scopus which makes it easier to found reliable peer reviewed sources.

The searches were made using English language and the search terms were chosen around the topics of waste and transaction cost in construction industry. The PCC elements and their supply chains are emphasized in the used materials to fit in the aim of this study, but as the number of articles with these specifications is relatively small, the scope is extended to cover the bigger subject area of the construction industry. Also, as Lean thinking and transaction cost perspective are their own entities, some sources outside of construction industry were used to form a basis for their study in the context of construction projects.

To avoid using out-of-date information, the more recent articles will be favored over the older ones. However, the usage of older sources can be excused in small amounts as the development of construction industry is relatively slow compared to many other industries.

2.3.2 Data analysis

The data analysis is done firstly to find the most relevant waste and transaction cost difficulty categories and secondly to investigate how they are attached to the structure of the supply chain. The most referenced waste types will be determined by adding up the times they were mentioned in the materials used for the study. The 10 most common types are chosen for a closer study.

There are different ways of looking at the transaction cost difficulties. The thesis presents 3 different aspects to how they are determined. From these three, there are seven different difficulties that the study takes a closer look at. The seven difficulties are chosen from how well they present different transaction cost raising phenomena and structures. The difficulties that are given less attention to are the ones divided by were the problems originate from. These problems are intertwined with the other difficulties and can be combined into the other types of difficulties.

The Ishikawa diagrams or fishbone diagrams are a way to present different causes to an event under consideration. It forms a tool that can be used to investigate how different problems in the supply chain are formed. In this thesis, the diagrams for the previously defined 10 most common waste types is compiled by collecting cause and effect relationships presented in different scientific articles that discusses waste in construction. The sources for the causes are presented after the cause to make it possible for the reader to investigate the matter more thoroughly.

2.4 Study of the structure of the supply chain

2.4.1 Value Stream Mapping

Values stream mapping is a value stream management tool for visualizing the components and value-added activities of a process. It is used to improve the flow of the operations. The mapping starts from the study of the current state and finding the problem points and the types of waste in them. A future state map is then drawn to visualize what the process could look like without these wastes. After that it is time to find ways to implement the changes needed to go from the current state map to the future state map (Martin and Osterling, 2014). Due to the scope limits, the thesis will not include future state maps of the supply chains.

Sisson and Elshennawy (2015) present Value Stream Mapping (VSM) as one of the key tools to be used in the early stages of lean implementation, in finding places to focus the improvements to (Sisson and Elshennawy, 2015). Rafique et al. (2019) state that VSM is the most important and commonly used tool in Lean implementation (Rafique et al., 2019). Kanai and Fontanini (2020) did a case study on prefabricated concrete panels using VSM and presented the benefits of this tool being that it allows the process to be visualized and makes flow easier to see, it makes it easier to identify wastes and their sources and it can be used as a basis for the Lean implementation (Kanai and Fontanini, 2020). These visualization properties are the most important features for this thesis, as it is used to display the current state of the supply chains.

Value stream mapping will follow the approach presented in figure 2.3. and it starts with making a baseline version of the value stream that will be completed and elaborated via an interview with interviews with prefabricated concrete element manufacturers. After completing the model, possible wastes and transaction cost difficulties are identified based on the established current state model.

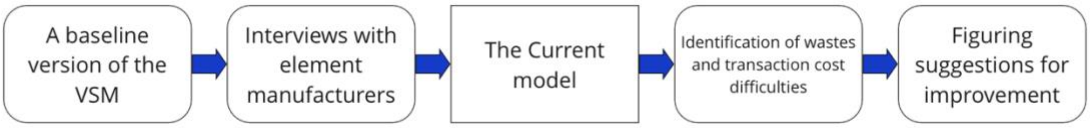


Figure 2.3 The stages of value stream mapping in this thesis.

In this thesis the problem identification from the VSM model relies heavily on the literature review portion of the thesis. It makes it possible to visualize the cause-and-effect relationships of the problems.

2.4.2 Business model

Business models are a way to portray how a business creates value. Kinnunen et al. (2013) present that a typical business model contains some or all of the following elements: business actors, value creation structure, offering, capabilities, resources, revenue or cost (Kinnunen et al., 2013). The business models of the case PCC manufacturers are presented in a map of business ecosystem, where the offerings and the revenue logic between the PCC manufacturers and the main contractor is presented.

The purpose of the business models in this thesis is to gather information about how the supply chain parties business models work and what is the value that they create. By studying the business models of the different parties of the supply chain, it is possible to investigate the interfaces between different functional groups. This will also help with finding transaction costs that might exist in the transactions between these parties as many transaction costs are linked with how the parties are connected.

2.5 Empiric data collection

2.5.1 Theme interviews

Fitting in with the qualitative nature of this thesis, the interviews were carried out as theme interviews where the structures are not strictly defined beforehand. According to Robson (2002) theme interviews as semi-structured interviews have predetermined list of topic headings or themes. The sequence and emphasis of the topics can be changed to fit the situation, so as to obtain as relevant information as possible. (Robson, 2002) The themes of the interviews in this thesis are as follows:

- value creation activities,
- functional group’s role in the supply chain,
- problems (including waste, transaction costs and other).

These themes were chosen around the different aspects that the thesis explores. Value creation activities are the cornerstone of bettering the flow. It is essential to understand and recognize these activities to be able to make any comprehensive observations regarding the flow of the supply chain. VSM is used as a tool to present these activities in an easy-to-comprehend-manner. To supplement the knowledge of the functional group gathered around the first theme, the second theme tries to open how different stakeholders are connected and how the business models are organized. The idea is to find out what the functional groups offering to the other parties, how its revenue is formed and what resources are needed.

The interviewees are chosen from the organizations involved in the case project. The interviews are from different functional groups to gather information from multiple sources. The focus is mainly put on the precast concrete element manufacturing firms of the case project, as they are the biggest external parties connected in the frame erection phase. Other interviewees are representatives from the case site and the procurement. Often the problems of the earlier processes are noticed only on the construction site, which is why it is important to gather knowledge how these problems are seen on the site. As construction projects rely heavily on contracts to regulate and guide the activities of the parties involved (Wang et al., 2018), it is important that the voices of the people making these contracts are heard.

To obtain relevant information, the background and objectives of the thesis were presented to the interviewees. The interviews were recorded to get accurate recounting of the answers saved for further analysis. To heed the suggestion of Robson (2002) notes were taken of the main points during the interview. This was done partly as a precaution of any problems with the recordings and partly to help with assessing the importance of points later. The interviewees are presented in table 2.1.

Table 2.1 The interview respondents.

Firm	Role of the interviewee	Role in the supply chain
A	Solution coordinator	Hollow core slab manufacturer
A	Element designer	Hollow core slab manufacturer
B	Production designer	Precast concrete technical shaft element manufacturing
C	Production manager	Interior and exterior wall and balcony slab manufacturing
D	Procurement	Main contractor’s PCC element procurement
D	Site foreman	Main contractor’s site management in the frame erection phase

According to Robson (2002) interview is an adaptable and flexible way to find information about a topic. When conducted face-to-face, interviews enables the interviewer to guide the interview in a way that makes it possible to investigate underlaying motivations and conditions surrounding different answers. (Robson, 2002) The ability to guide the interviews to investigate any interesting topics that come up is important in the qualitative study such as this thesis where the goal is to find new previously uninvestigated information.

2.5.2 Workshops

Workshop as defined by Ørngreen and Levinsen (2017) is an arrangement where people come together around a specified issue to learn, acquire knowledge, carry out problem solving, or innovate (Ørngreen and Levinsen, 2017). In the case of this thesis, the workshops were conducted to bring together the different functional parties of a PCC concrete supply chain. It was conducted as a part of a different project with the goal to showcase the many problems that the current model contains.

Workshop 1

The first workshop was held on 20th of January and with the duration of 4 hours. The participant were various professionals from 5 different firms. The session began by each participant introducing themselves by name and a short description of their background. All the participants were gathered in one room where the participant was divided into teams depending on which part of the PCC supply chain, they had the most experience with. The teams were formed around the activities included in the PCC element procurement, design and element design, production, and the site management. The goal of the first workshop was to map out the process and collect problems that surface in different parts of the supply chain. The mapping was done on a large sheet of paper were the teams placed color-coded post-it-notes to represent different activities, the different responsible parties for the activities, the information needed for different actions and problems that arise in different places along the supply chain. The problems were collected to a list in connection to where in the supply chain they came up in. The participants of the 1st workshop are presented in table 2.2.

Table 2.2 The participants of the 1st workshop.

Company	Role of the interviewee	Role in the supply chain
D	Conceptual Structural Designer	Design
D	Procurement manager	Procurement
G	Department head	Procurement
A	Solution coordinator	Production
D	Foreman	Site management
D	Thesis worker	Site management
H	Development manager	-
J	Associate professor	-
D	CTO	-
D	Thesis worker	-
H	Thesis worker	-

Workshop 2

The second workshop was held on 4th of April, and it was held as a hybrid meeting with the possibility to participate through Teams. The meeting was held in two 2h portions with a lunch break in-between. The first portion was spent preparing for the root-cause analysis of the problems collected in the first workshop. The results of the last workshops were presented to the participants along with the values stream maps that are attached in the appendices D, E and F.

The second portion of the workshops was used to going through the problems and debating different possible root-causes. Root-cause analysis is one of the main tools used in total quality-management (Rosenfeld, 2014). It is a way to prevent reoccurrence by enabling the identification of sufficient preventable actions. If a problem is solved only with a short-term solution aimed at the immediate cause, there is a risk of reoccurrence. Rosenfeld (2014) brings up four important definitions regarding root-cause analysis: root cause, direct cause, symptom and consequence (Rosenfeld, 2014). The workshop broke down the problems into consequences, symptoms and causes. Root cause is the base reason for the existence of a problem. It is not always apparent what the root cause is just by looking at the problem, but by eliminating it, the reoccurrence of the problem can be avoided. Direct cause is the easily seen cause for the problems. A symptom is a situation that arises as a consequence of these causes. (Rosenfeld, 2014) The participants of the second workshop are presented in the table 2.3. The invitations for both the first and the second workshop were sent to the same people, but the people in attendance varied.

Table 2.3 The participants of the 2nd workshop.

Company	Role of the interviewee	Role in the supply chain
D	Conceptual Structural Designer	Design
G	Department head	Procurement
A	Solution coordinator	Production
D	Foreman	Site management
D	Thesis worker	Site management
I	Logistics manager	Logistics
H	Development manager	-
J	Associate professor	-
D	CTO	-
H	Thesis worker	-
I	Director of digital services	-

The root-causes form categories that are used in the chapter 4.2.2. in comparison to the root-cause categories that were found from the interviews. The problems are presented in the appendix C.

2.5.3 List of disturbances on site

The theme interviews and the workshops produced list of problems that occur on within the PCC supply chains. One of the things that came up in both the interviews and the workshops is that many of the problems are only noticed on the site. To broaden the inspection of occurring problems, this thesis uses data collected from the case site to see how the problems accumulate concretely on site during the frame erection phase.

Fira has collected a list of different kinds of problems occurring on site during the frame erection phase. This list was collected by having a person stay at a site for 3 weeks and collect to a list the different problems that came up in the frame erection. This was done on 4 different sites, one of which was the case site of this thesis. For the purposes of this thesis, only the data gathered from the case site is used. The list of problems on the case site contains 75 different problems observed during a period of three weeks. The list contains the date, the work activity, the affected element, the severity level, the duration, the apparent cause of the problem and the description of the problem. The problems were observed from the viewpoint of the element installation and as such it might leave out problems that affect other work activities. In this thesis, this list of disturbances presents how the problems in the supply chain affect the progress of the element installation.

2.5.4 Other data sources

Preliminary research into the topics was required to get the most benefit from the interviews. This research enabled the preparation for initial models of VSM for the different supply chain parties, that aided the interviews. By having an idea of the value streams of different functional groups, it is easier to attain relevant information from the interviewees.

The secondary data sources used to make the preliminary versions of the models were mainly the contracts between main contractor and the supply chain parties and other additional information on the procedures of a construction process of a residential building. The contracts are an essential part of how the supply chain works, as it details the requirements of each party and how they are enforced.

Information about the activities on site was collected from a standard operating procedure (SOP) that Fira has. It includes the frame erection activities that are done by the subcontractor on site but does not consider the work done by the site foremen.

2.6 Data management and analysis

2.6.1 Data management

The recordings from the interviews were transcribed. The transcriptions were made from the audio recordings of the interviews using Microsoft Word’s tool. The transcriptions were combined with the notes taken during the interview to combat any possible mistakes of transcription. The data gathered from the interviews were used to supplement the VSM and to list the problems that came up during the interviews. After the VSM was finished, they were sent to the interviewees via email for a cross-check to eliminate any possible misunderstanding or gaps of information which may have appeared during the interviews. The problems identified by the interviewees were listed and presented in connection to the functional group they were identified by. To supplement the identified problems, if the interview came up with a possible cause for the problem, they were listed next to the problems in question.

The data gathered from the contracts is collected collectively from all the relevant contracts. First the necessary information is defined and then they are found from the contracts. The findings are presented in tables to enable comparison of different contracts.

The language of the interviews, and the contracts is Finnish as it is the common language between different parties. The lists of disturbances that is presented in appendix A-C are in Finnish to avoid any information distortion that might happen during translation. The analysis of the problems is done in Finnish and the results are then translated to English. This is done as to limit the possible misunderstanding caused by language barriers in the analysis portion.

2.6.2 Validation

Godwill (2015) defines the validity of a good study as one where the generated results answer the addressed questions correctly and with minimal bias. There are many different sources of errors and bias in research that can directly impact the conclusion of the study. These errors can occur from multiple sources and can be divided into categories based on different characteristics. (Godwill, 2015)

There are two kinds of validity: internal and external. Internal validity refers to the ability of the researcher to rule out other explanations for the results produced so that the results are valid. External validity refers to how well the results reflect the general situation. (Godwill, 2015) Robson (2002) lists 12 threats to internal validity that can exist in research. When these threats are eliminated, internal validity is reached. These threats are connected to how the participants view the research, how they are chosen and how well they represent the general situation, how the tests and measurements are conducted, and how causality in the results is defined. (Robson, 2002) In this thesis, where root-cause analysis is one of the chosen methods, one significant threat is the ambiguity of causal direction, meaning there is a risk of a non sequitur being made regarding the causality.

Robson (2002) states that validity can only be proved with evidence, not with methods. Methods are only ways to gather evidence, not the solutions (Robson, 2002). Evidence to support the conclusions is needed to validate the results of the root-cause analysis. To validate the results made based on the interviews and the literature review, they will be compared with the results of the workshops where different professional came together to discuss the PCC element supply chains from different perspectives.

3. LITERATURE REVIEW

3.1 Theoretical framework

This chapter presents the theoretical framework used in this study to review how the current supply chain operates based on a case site and how its flow can be improved. The literature review aims to answer the first research question of what kind of problems hinder the flow in the supply chain of a precasted concrete frame in the frame erection phase, by examining previous studies made on the subject.

Flow is a central aspect in the Lean ideology, and it is heavily linked to the formation of customer value. Tzortzopoulos et al. (2020) express that while Lean is a critical aspect of understanding the phenomena surrounding different managerial disciplines, there is a lack of connection between these managerial disciplines and the concepts and disciplines of Lean (Tzortzopoulos et al., 2020). To fill in this disconnection, this thesis forms a more comprehensive theoretical base by applying supply chain management to the Lean ideology to give it structure and options on how to manage processes.

According to Sople (2012) the activities in an organization can be divided into primary activities that result in the formation of customer value and secondary activities that support the primary activities (Sople, 2012). Lean ideology is heavily focused on the aspect of creating value to the customer and as such it is easy to limit Lean thinking to the primary activity level. However, to make comprehensive improvements that include all operations in the supply chain, it would be important to look at the supply chain from a wider perspective. One way to broaden this view of the supply chain is to use transaction cost theory to study the possible problems existing within different transactions. Lavikka et al. (2021) state that to enable systematic changes in the construction project one important step is to look into each of the construction project parties to disclose any hidden agendas, mistrust or lack of capabilities (Lavikka et al., 2021). These are all themes that transaction cost theory tries to tackle. These additional theories of supply chain management and transaction cost theory can supplement any possible gaps that Lean ideology does not consider.

This thesis focuses on identifying and examining problems that occur in the supply chain and the literature review is a vital part of this investigation as it forms a frame of reference for the evaluation of these problems. Figure 3.1. shows how the theory units are divided into the subject areas of the thesis.

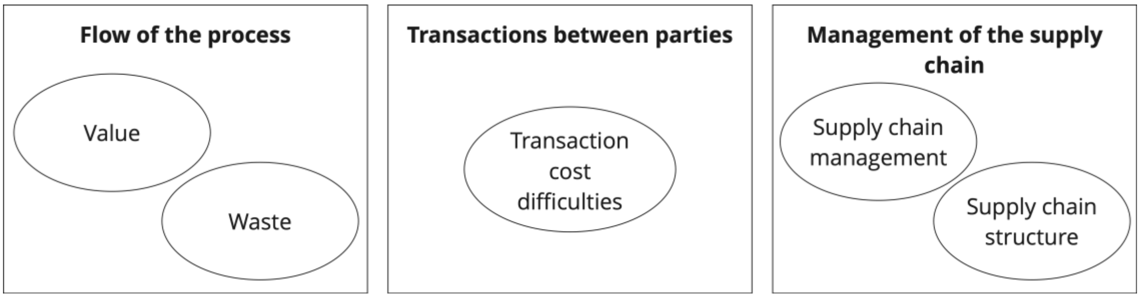


Figure 3.1 The theoretical base of the thesis.

Lean ideology and flow are used as a measurement of how well the supply chain operates and one easy way to make the measurements is to study how much waste the process contains. There are many ready existing definitions of waste that can be used in this thesis. Similarly to waste, the transaction costs have a set of pre-defined problems the existence of which can be examined in the case project's supply chains. The supply chain management gives insight into how the supply chain is managed and how it could be improved.

3.1.1 Lean and value

Lean is an ideology of production management with the goal of producing more value with less. Womack and Jones (2003) describe Lean thinking as an antidote to waste. There are many different types of waste that can be combated through lean by specifying the value from the viewpoint of the customers, arranging value-creating actions in the optimal way, performing these activities without interruptions when they are requested and only when necessary, and performing them constantly in a more efficient way. These means are derived from the five main principles of Lean that are value, the value stream, flow, pull, and perfection (Womack and Jones, 2003). This study uses the term waste to refer to the non-material waste found in the processes.
The starting point in achieving a better flow of value, according to Womack and Jones (2003) is to define the value and identify the value stream. After this is done the next steps are to focus solely on the product in question and remove obstacles that prevent continuous flow. To achieve this one must forget the existing boundaries of organizational structures formed around functions and remove any backflows, stoppages and scrap (Womack and Jones, 2003).

Lean construction is one branch of Lean. According to Meng (2019) there are two opposing ideas regarding Lean and construction. One idea is that for Lean methodology to be utilized in construction production, it needs more industrialization and standardization to be more like manufacturing. The other idea is that Lean thinking should be utilized on a more philosophical level on top of which construction industry should find new project management methods that are suitable for construction industry (Meng, 2019).

Value

Defining the customer value is the starting point of establishing a flow. After it is defined, value can be used to gauge which of the actions are defined as value-added and which actions are waste. Value is a central factor in this thesis as it defines what the goal of bettering the flow of the supply chain is.

Tzortzopoulos et al. (2020) state that forming a unified definition of value in Lean construction industry is an ongoing effort focusing on the goals of defining value, identifying the customers, and finding ways to manage value in construction. Generation of value can be displayed as act of delivering to the customers what they want, at the moment they want it and in the amount desired. (Tzortzopoulos et al., 2020)

Figuring out what the value is to the customer is a crucial point that should be done thoroughly to avoid any misunderstandings and inadequacy. Womack and Jones (2003) state that one problem with defining value is to define value in parts and not as a whole product. This problems is especially common when there are many different firms connected in the value creating process and every firm defines the value in a way that suits their existing operations. (Womack and Jones, 2003) Forming a uniform definition of value which includes all the value created in the supply chains, is a first step in understanding the current process and creating suggestions for improvement.

3.1.2 Transaction cost

When speaking about costs in construction, it’s easy to focus only on the production costs but as Li et al. (2015) state it also includes the costs of many different supporting activities that are determined as transaction costs by the studies of economic organizations (Li et al., 2015). According to Williamson (1981), transaction cost approach is a study of organizations that is formed based on the theories of economic literature, organization theory, and contract law literature (Williamson, 1981). Using transaction cost approach as a lens in the case study will give it an interdisciplinary base that allows for more holistic solutions for improving the supply chain. Transaction costs can be viewed internally within a firm or between different parties, which makes it a versatile way to view the problems in the supply chain (Williamson, 1981).

While transaction cost theory is a commonly used theory in economics, Li et al. (2015) argue that transaction costs don’t have one universally accepted definition and that especially in the construction industry the transaction cost isn’t widely recognized concept (Li et al., 2015). Despite the lack of clear concept in literature, the project based temporal nature of the construction industry often promotes complexity, low frequency, high asset specificity and uncertainty (Wang et al., 2018).

3.1.3 Supply chain structure

A supply chain is a connection of facilities and companies, which links together the upstream suppliers and the downstream customers. Through this link the products, services, information and finances flow to meet the customer needs (Sople, 2012). Bier et al. (2019) define supply chain structure as complex networks where various different actors or entities are connected in many a tiered structure (Bier et al., 2019).

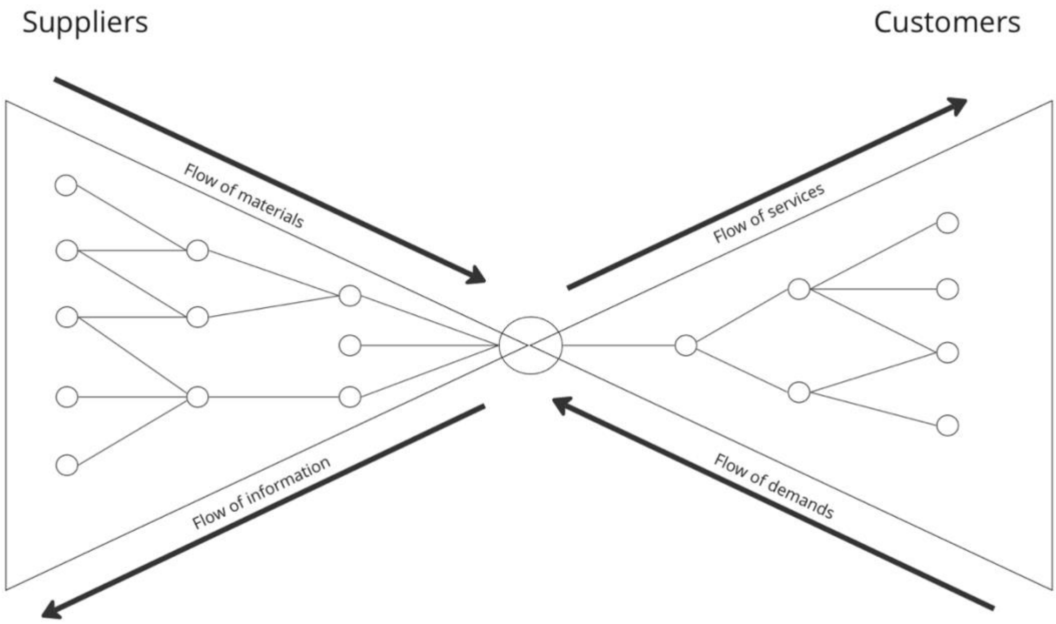


Figure 3.2 The meeting point of the supply chain and the demand chain modified from (Segerstedt and Olofsson, 2010).

Bier et al. (2019) bring up the point that the disruptions are often noticed only when after the disruption has occurred (Bier et al., 2019).

The value creation of the supply chain can be increased by also considering the demand chain in the development process. The supply and demand meet at the order placement point and the value offering point. The order placement point (OPP) can be used as a way to affect the delivery time and the level of inventory (Sople, 2012).

The placement of the OPP determines how upstream the product is attached to the client.

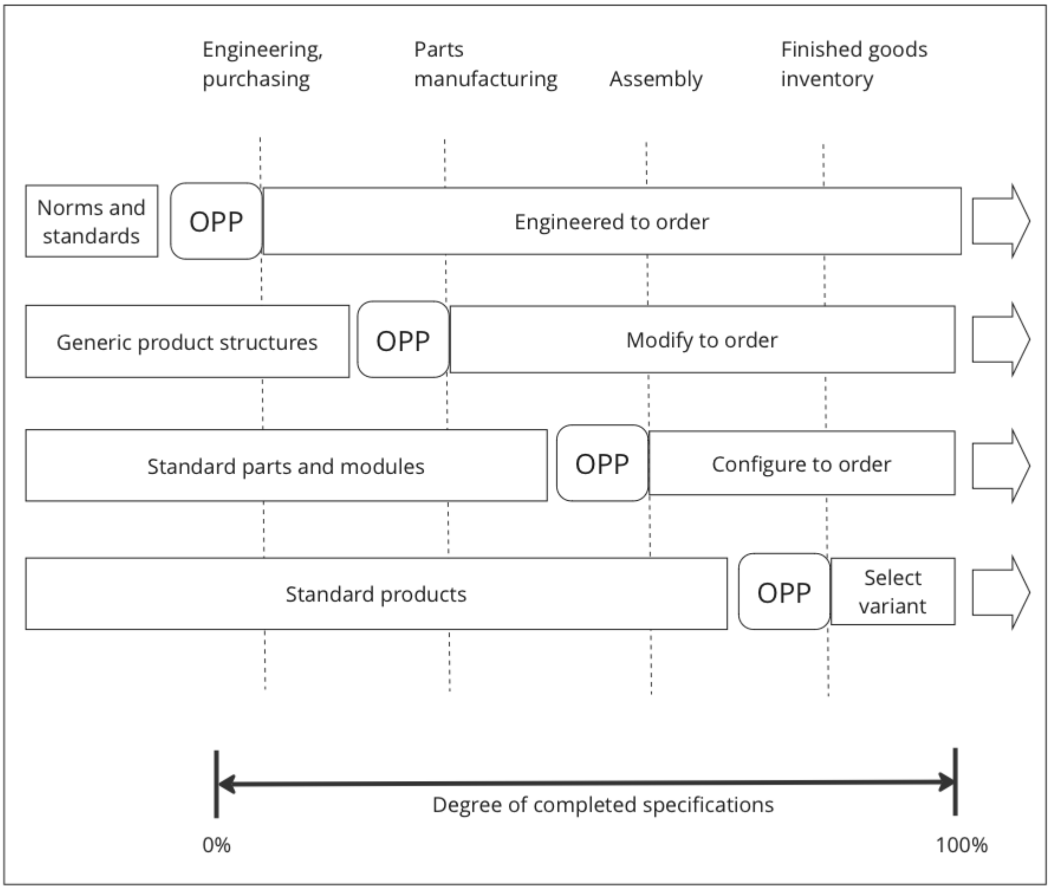


Figure 3.3 The level of product specification process in construction, modified from (Segerstedt and Olofsson, 2010)

When speaking about the construction project, Segerstedt and Olofsson (2010) determine that in the engineered to order, the order placement point is upstream in the production process and depending on the contract engineered to order can either be classified as concept to order and design to order depending on the type of contract between the client and the contractor. The modify to order is defined as the situation where the design uses technical platform to form a generic structure and defining technical solutions to be used. The configure to order type of product is defined as the situation where the customer value in the design is fulfilled with a configuration of modules and standard parts.

3.2 Common problems in construction production

3.2.1 Waste in construction and precast concrete manufacturing

To better the flow of the frame erection phase of the construction we need to understand which tasks and activities are necessary to creating value to the customer and which are unnecessary. When resources are being used but no value is added to the final product, the action is considered to be waste (Igwe et al., 2022). Womack and Jones (2003) divide actions into three categories of: value creating actions, unavoidable non-value-creating actions (type 1 waste), and avoidable non-value-creating actions (type 2 waste) (Womack and Jones, 2003). The type 2 waste is the worst kind of waste that should be eliminated before the value can flow. Knowledge about different types of wastes and their connections to different processes will make it easier to be able to spot and eliminate these wastes from the supply chain.

In Lean there are typically seven to eight recognized types of waste that are overproduction, waiting, inefficient operations, transport, inventory, motion, poor quality and misused resources (Womack and Jones, 2003). However, as Koskela et al. (2013) argue, the wastes are very much connected to the context around them. It is important to consider different process specific factors when determining what is waste. (Koskela et al., 2013)

There is some variation between different sources as to what is the biggest and most impactful waste. For example, according to the study of Igwe et al. (2020), waiting along with transportation are the most impactful wastes from the flow perspective but then some other studies mention making-do, or communication as the biggest source of waste (Halttula et al., 2017; Igwe et al., 2022; Tzortzopoulos et al., 2020). Even without the varying evaluations of the wastes it is important to acknowledge that the supply chains of the precast concrete frame erection phase include two big and presently very different processes of element manufacturing and the on-site installation and as such the impact of different wastes can differ between these two processes (Ahmad et al., 2019). To collect a list of wastes that is relevant to the case study, a compilation of different commonly referenced wastes is compiled from literature of construction and precast concrete manufacturing. This list is presented in table 3.1. where the number of references is used to determine the importance of detection of each waste.

Table 3.1 The types of waste based on preceding research.

Source:	Scope:	Transportation	Quality deviations	Inventory	Waiting	Motion	Overproduction	Human potential	Extra-processing	Making-do	Communication & documentation	Poor constructability	Other (weather conditions theft etc.)	Unfinished work	Making wrong products or services	Safety	Work-in-progress	Overloading	Stoppages
(Igwe et al., 2022)	Industry-wide	x	x	x	x	x	x	x	x	x									
(Aravindh et al., 2022)	Industry-wide	x	x	x	x	x		x	x		x		x		x				
(Lavikka et al., 2021)	Precast concrete	x	x	x	x	x	x		x										
(Tzortzopoulos et al., 2020)	Industry-wide	x	x							x				x			x		
(Bajjou and Chafi, 2020)	Industry-wide	x	x	x	x	x	x	x		x	x	x	x			x			
(Belvedere et al., 2019)	Industry-wide		x	x	x		x	x	x										
(Ahmad et al., 2019)	Precast concrete	x				x					x								
(Halttula et al., 2017)	Industry-wide	x	x	x	x	x	x	x		x	x	x	x		x	x		x	
(Emuze and Saurin, 2016)	Industry-wide	x	x	x	x	x	x		x	x		x		x					x
(Wu and Low, 2011)	Precast concrete	x	x	x					x		x								
(Ray et al., 2006)	Precast concrete	x	x	x	x	x	x	x											
(Womack and Jones, Daniel, 2003)	Lean	x	x	x	x	x	x	x											
In total		11	11	10	9	9	8	7	6	5	5	3	3	2	2	2	1	1	1

10 most referenced types of waste according to the commented literature review are transportation, inventory, quality problems, waiting, overproduction, motion, human potential, making-do, extra processing and problems with communication and documentation.

Transportation

Ohno (1988) defines transportation as waste where materials are handled with cost but no value is added (Ohno, 1988). Tzortzopoulos et al. (2020) state that transportation can be affected by the logistics of a construction site where obstacles in the access routes, inappropriate equipment, poorly planned storage of materials, or shortage of labor can lead to the waste of transportation. The set-up, stoppages and how the equipment are used on site, are the leading causes of the transportation waste on site. (Tzortzopoulos et al., 2020) Ray et al. (2006) list poor layout, poor process flow design, work-in-process storages, temporary storages and disorganized storage areas as causes of transportation in precast concrete manufacturing (Ray et al., 2006). Different causes of transportation are collected from various literary sources and presented in figure 3.4. in a fishbone diagram. Bajjou and Chafi (2020) state that with standardized transportation methods and appropriate planning of distribution of materials and equipment it is possible to make the logistics to flow well (Bajjou and Chafi, 2020).

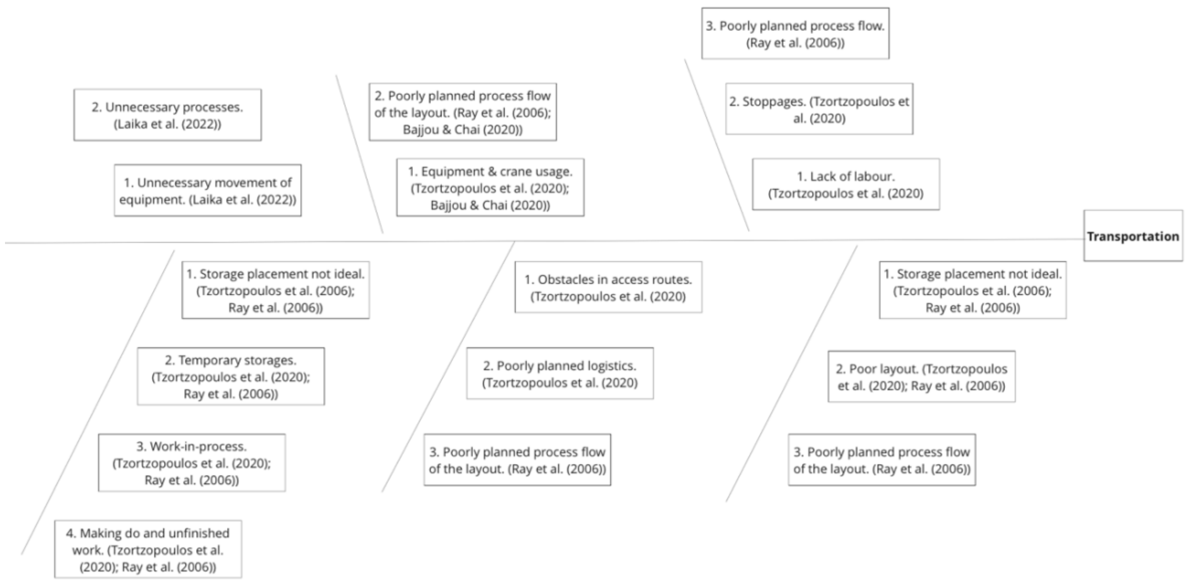


Figure 3.4 An Ishikawa diagram of different causes of transportation.

Quality problems

Quality problems are a substantial and multifaceted cause of waste in the construction industry. The impact of quality defects is big, and Almusharraf and Whyte (2016) present an estimate that they can cause 2-20 percent increase to the completion of a project. Quality deviations can cause risk in form of costs, time and safety. (Almusharraf and Whyte, 2016)

The quality problems can be caused by multitude of reasons, and they can be the causes of many other problems in different parts of the supply chain, such as rework, unfinished work, transportation, work-in-progress, material waste and waiting (Tzortzopoulos et al., 2020). According to Tzortzopoulos et al. (2020), quality problems are often connected to processes with high variability, insufficient problem detection and poorly identified customer requirements (Tzortzopoulos et al., 2020). A collection of different causes of quality problems is presented in figure 3.5.

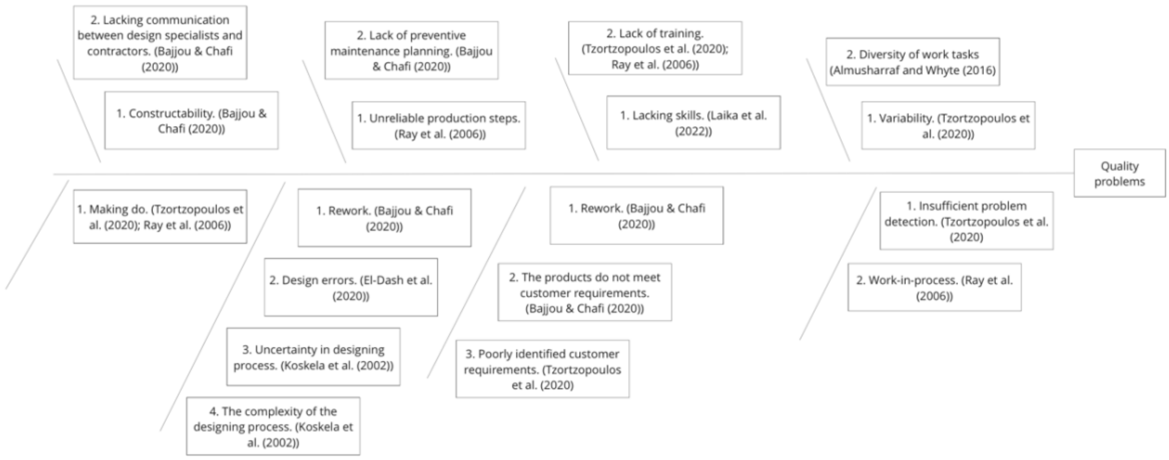


Figure 3.5 An Ishikawa diagram of different causes of quality problems.

Inventory

Inventory is when there is unnecessary storage of materials or products at different stages of the process. Ray et al. (2006) defines inventory as a waste where there is more inventory than needed for the next transforming step. This inventory can contain work-in-process or finished products waiting for the next steps, or more than the needed amount of raw materials. (Ray et al., 2006)

Sometimes inventory is an unwanted consequence of other problems, but sometimes it can be a conscious decision made to boost efficiency. No matter the reason, from the viewpoint of the flow, inventory is always a waste. Inventory can be planned solution to have a buffer to avoid downtime in case of unexpected situations. (Ray et al., 2006) Shown in figure 3.6. is a collection of different causes of inventory found in literature.

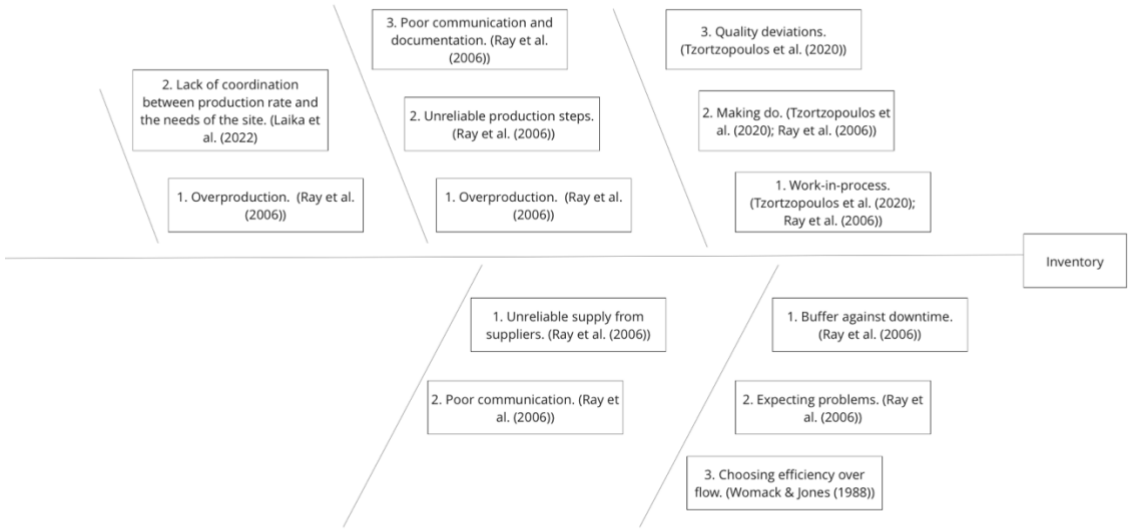


Figure 3.6 An Ishikawa diagram of different causes of inventory.

Waiting

Waiting as a waste means the unplanned idle time spent waiting to be able to proceed to the next step. Waiting can include number of different things such as waiting to access drawings, information, equipment, or materials (Ray et al., 2006). According to Sahran et al. (2017) it is also the most common waste in construction industry along with making-do (Sarhan et al., 2017). Waiting is often connected to how well the activities are planned and scheduled in connection to other activities in the supply chain. Collection of causes of waiting are presented in figure 3.7.

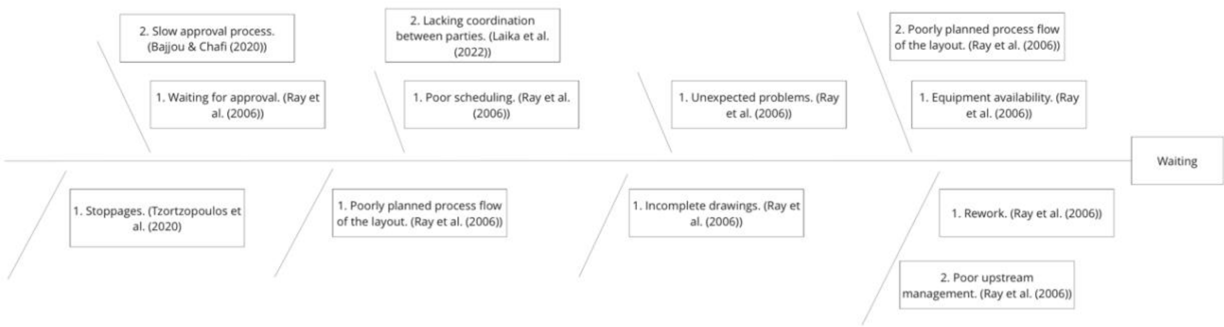


Figure 3.7 An Ishikawa diagram of different causes of waiting.

Overproduction

Overproduction is a waste where production exceeds the amount needed for the next step of the process. Either the products are manufactured at too fast a pace, or the produce is manufactured unnecessarily. If the products are manufactured too early the production is either too fast or the next steps are delayed so that the levels of output and input of successive steps do not meet. Unnecessary production might happen as a result of inadequate management practices (Igwe et al., 2022). A collection of different kinds of causes of overproduction are presented in figure 3.8. Overproduction is an impactful waste as it can lead to other wastes such as inventory and work-in-process (Koskela et al., 2013). Overproduction might also lead to material waste if materials or products are produced unnecessarily, and they cannot be reused in other products.

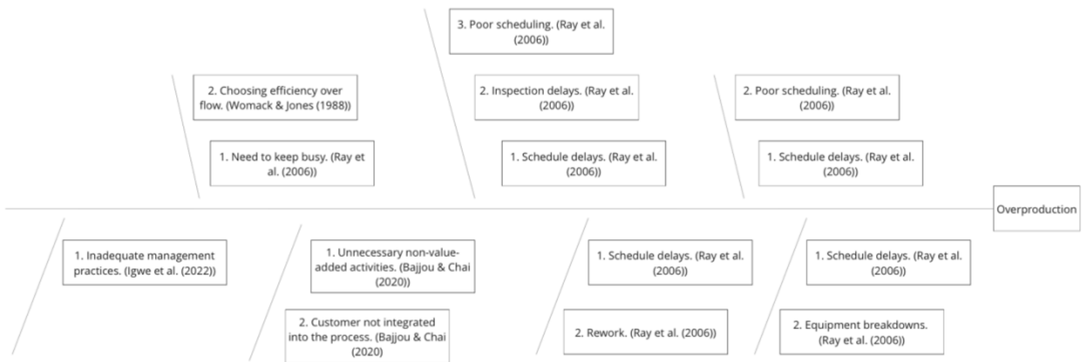


Figure 3.8 An Ishikawa diagram of different causes of overproduction.

Motion

Motion is waste where people or machines move but no value is added. Activities that cause this waste can be looking for something, measuring or checking something or arranging products and materials (Ray et al., 2006). Motion can waste time and unnecessarily wear the equipment. In figure 3.9. is presented some of the causes of motion waste mentioned in the literature.

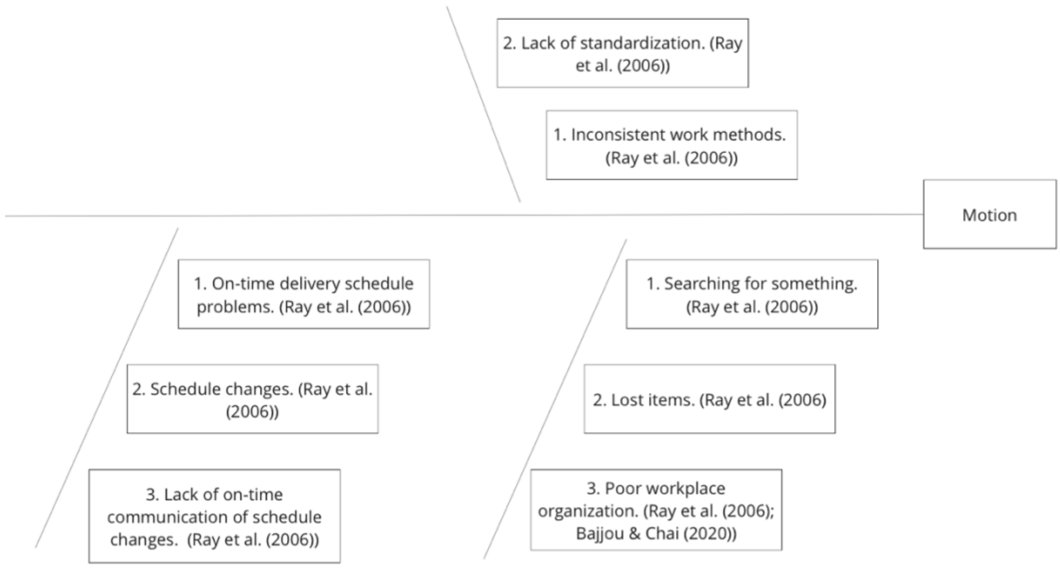


Figure 3.9 An Ishikawa diagram of different causes of motion.

Human potential

Wasting human potential means not using the mental, creative, or physical abilities that the people have. One way to reduce this waste is to utilize the potential by connecting people who might have ideas in the solution finding and planning processes (Ray et al., 2006). Figure 3.10. presents some possible causes that lead to the human potential waste.

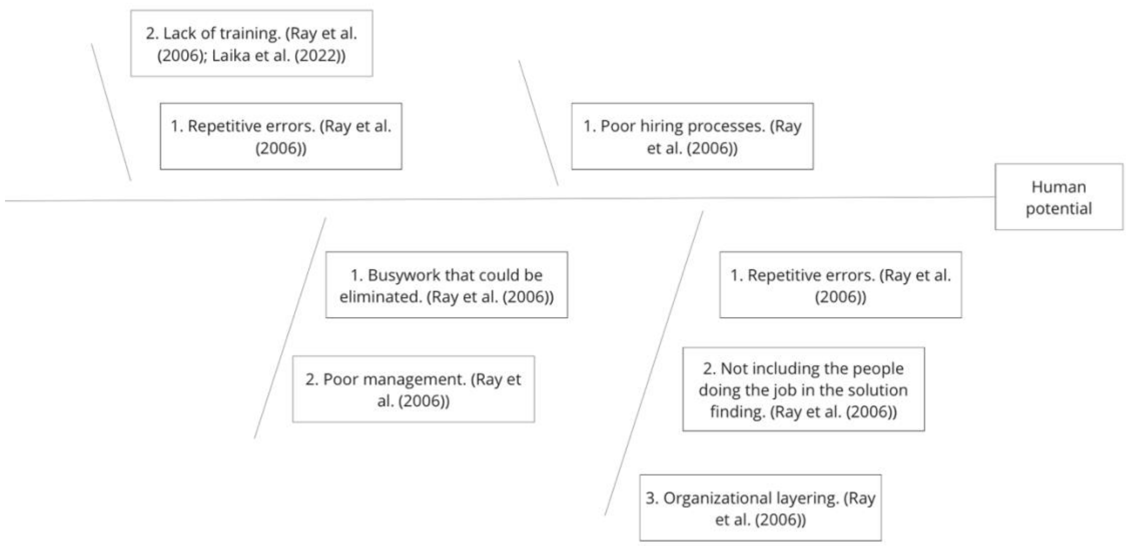


Figure 3.10 An Ishikawa diagram of different causes of wasted human potential.

Making-do

Making-do is improvisation caused by the lack of proper inputs such as information, materials, tools, or other equipment. The reason for making-do is often the apparent need to keep the capacity busy even though the preconditions of the task are not yet met (Emuze and Saurin, 2016). Figure 3.11. presents a collection of causes of making-do. Tzortzopoulos et al. (2020) list lots of different consequences of making-do that include longer lead time, decrease of quality and safety, and material loss (Tzortzopoulos et al., 2020). Emuze and Saurin (2016) add work-in-progress, rework and health and safety hazards as other side effects that are caused by making-do (Emeuze and Saurin, 2016).

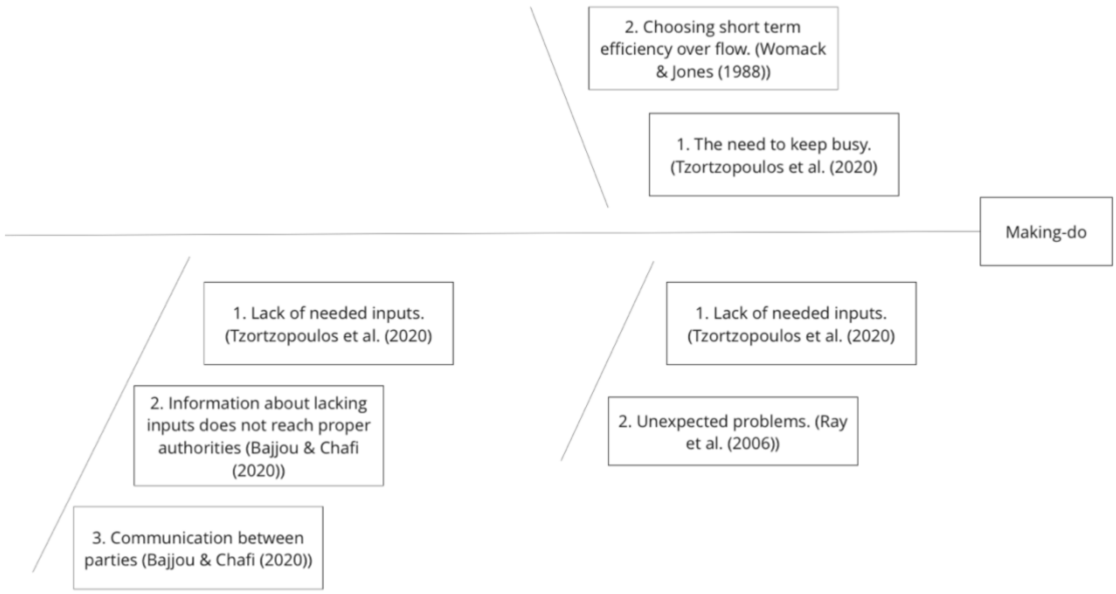


Figure 3.11 An Ishikawa diagram of different causes of making-do.

Extra processing

Extra processing or over-processing means there is more processing in the process than is needed to produce the product. This can include finishing processes that create no new value to the customer, using more materials than is needed, or handling different parts, products, tools, or paperwork more than once. Figure 3.12. presents different causes of extra processing.

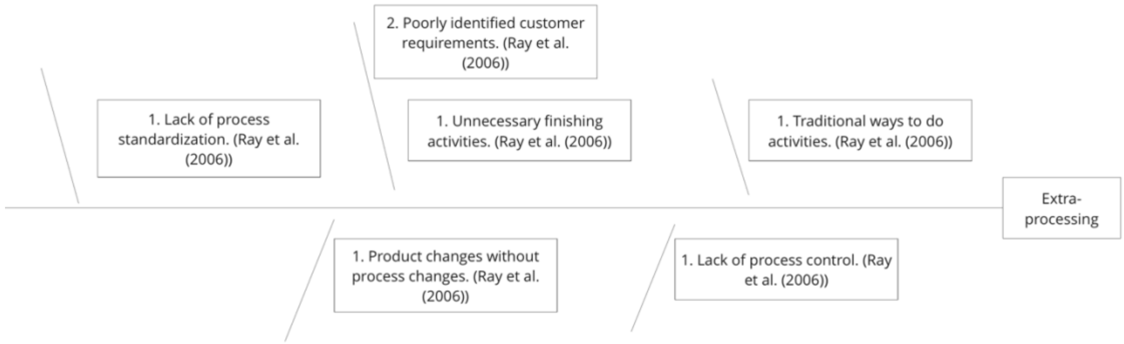


Figure 3.12 An Ishikawa diagram of different causes of extra processing.

Communication and documentation

Communication and documentation are a vital part of every functioning organization (Hicks, 2007). Lacking communication and documentation can lead to other types of wastes or magnify already existing problems. Tzortzopoulos et al. (2020) determine that in construction the systematic waste of miscommunication and misunderstandings in information transferences are caused by the lacking connection between different stakeholders (Tzortzopoulos et al., 2020).

Lean information is its own branch on Lean that according to Hicks (2007) includes the activities of information creation, organization, maintenance, sharing, communication and disposal among other things (Hicks, 2007). Lean information has its own waste categories that Redeker et al. (2018) list to be stock, motion, waiting, processes, defect and overproduction (Redeker et al., 2018). In a combination of Lean information wastes and the causes found in Lean construction literature, figure 3.13. presents a diagram of different causes.

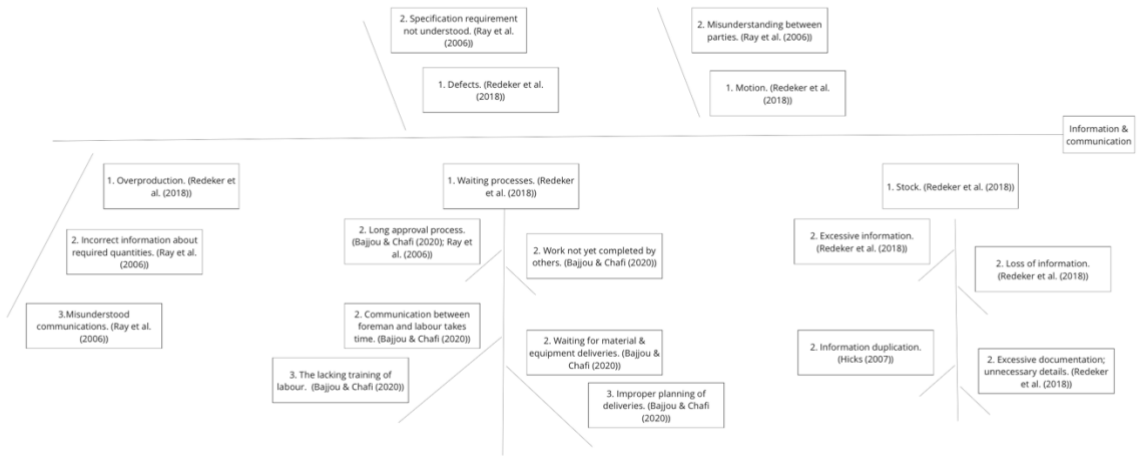


Figure 3.13 An Ishikawa diagram of different causes of communication and documentation problems.

3.2.2 Transaction difficulties in construction projects

In literature there are different ways to categorize the factors causing transaction costs and for clarity this thesis will adopt the term of transaction difficulties. This term is used by Jones and Hill (1988). Jones and Hill (1988) determine transaction costs as the prerequisite costs for an exchange to happen between parties and that they consists of negotiating, monitoring and enforcement costs (Jones and Hill, 1988). In addition to these parent definitions of transaction costs, there are more definitions that also consider the causes of these costs. One such a way, that can be used in construction, is to divide them into three dimensions of transaction costs: asset specificity, frequency of transactions and the uncertainty of the transactions (Hosseinian and Tavakoli, 2023; Speklé, 2001). These dimensions are presented in the figure 3.14. where they are further divided into subcategories.

Li et al. (2015) divide transaction difficulties into four categories which are project management efficiency, the transaction environment, the role of the contractor and the role of the owner (Li et al., 2015). These categories were determined because of a literature review focusing on construction project management. Abdel-Galil et al. (2022) supplement this list of factors by conducting questionnaires and adding three categories regarding the transaction environment that are factors related to bidding, emergency and project characteristic (Abdel-Galil et al., 2022). These categories are shown in the figure 3.15 with the original categories colored red and the additional blue.

Haaskjold et al. (2020) continue the work of determining transaction cost factors done by Li et al. (2015) by empirically testing in Norway which of the transaction factors are the most effective in enabling collaboration and reducing transaction costs. As a result of this research, they determine quality of communication, uncertainty in the project, organizational efficiency, trust, and the changes in orders to be the five most influential factors in the formation of transaction costs. It is important to note that these tests are not concentrated to construction industry as they include results from projects of other industries. However in their research they find that in the construction industry it is significantly more common for contractors to claim extra payment from client, compared to other industries (Haaskjold et al., 2020).

Jones and Hill (1988) list six different factors shown in figure 3.16. (Jones and Hill, 1988). It’s necessary to note that these six factors are not made with connection to construction industry but are more general categories. However there has been some studies in construction industry about some of the transaction difficulties. For example Ikuabe et al. (2020) did a study on how construction professionals perceive the impact of opportunism on transaction costs and as a result they determine that one of the ways opportunism appears in construction process is in the possibility of unwarranted or unmerited claims made by contractors caused by inadequate predicted extent of work (Ikuabe et al., 2020). Also complexity is one of the problem categories in supply chain management on a construction site (Thunberg et al., 2017).

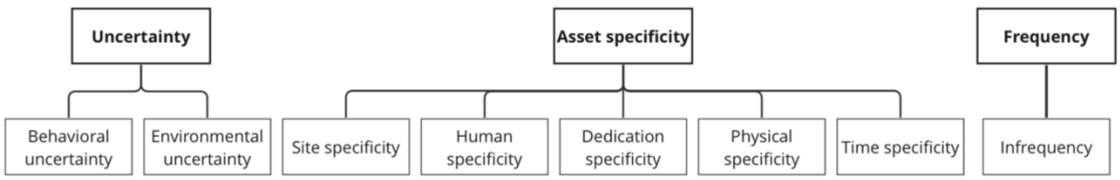


Figure 3.14 Dimensions of transaction cost modified from (Hosseinian and Tavakoli, 2023).

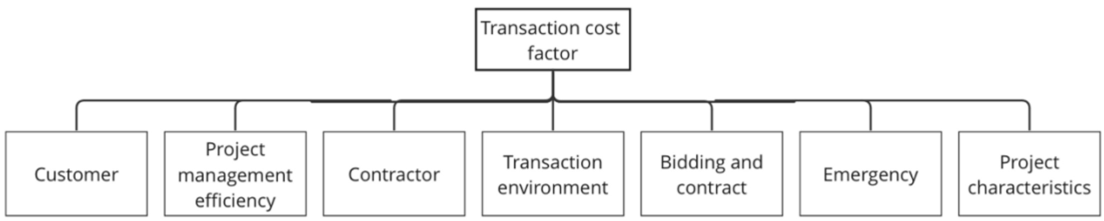


Figure 3.15 The categories of transaction cost factors modified from (Li et al., 2015) and (Abdel-Galil et al., 2022)

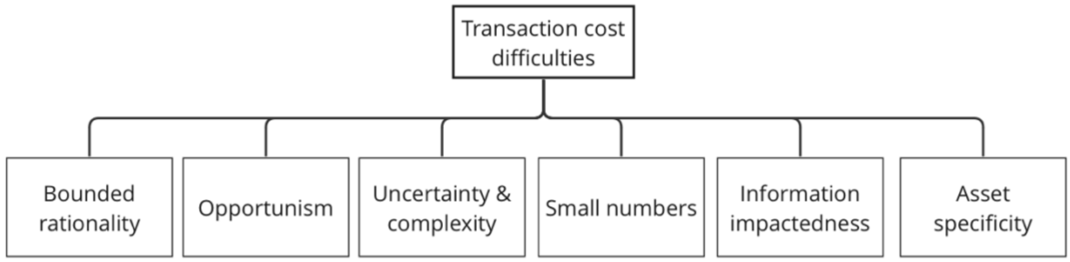


Figure 3.16 Transaction difficulties as determined by Jones and Hill (1988) modified from (Jones and Hill, 1988).

The different categorization shown in figures 3.14. – 3.16. show different viewpoints into the transaction costs. In figure 3.14. the focus is on the conditions of the transactions and which different existing conditions affect the transaction costs. In figure 3.15. the division is done by what causes the transaction costs. In figure 3.16. the division is done based on different phenomena surrounding transaction cost difficulties.

Uncertainty

Uncertainty as a transaction cost difficulty refers to the predictability and how well the transaction and its environment can be specified (Speklé, 2001). Uncertainty from the viewpoint of transaction costs of a construction process can be divided into behavioral and environmental uncertainties. Behavioral uncertainty is the uncertainty around the contracted parties and their abilities and willingness to abide to the contracts. (Hosseinian and Tavakoli, 2023). Sambasivan et al. (2017) state that contractual uncertainty often stems from the estimation of time and cost, as these estimations are usually not exact (Sambasivan et al., 2017).

Environmental uncertainty is related to the scope of the project, technical uncertainties and other external factors (Hosseinian and Tavakoli, 2023). You et al. (2020) state that environmental uncertainty can raise the cost of construction by lowering the productivity and causing opportunism, but by also raising the transaction costs of setup, monitoring and enforcement (You et al., 2020).

Complexity

Complexity is very similar to uncertainty when looking at the consequences in terms of transaction costs (Speklé, 2001). The mechanism of how uncertainties generate transaction costs is by making it challenging to specify and foresee all the possible issues when making contracts, if the projects are complex in nature (Sambasivan et al., 2017).

Gao et al. (2018) divide the complexities in construction industry into three categories of technical complexity, organizational complexity, and environmental complexity. The technical complexity refers to the technological difficulty of the project and how the activities are interconnected. (Gao et al., 2018) Complexity of the tasks and how they should be managed are connected to how they are connected to each other. Different kind of interdependencies between activities are shown in figure 3.17. to illustrate how complexity is connected to them.

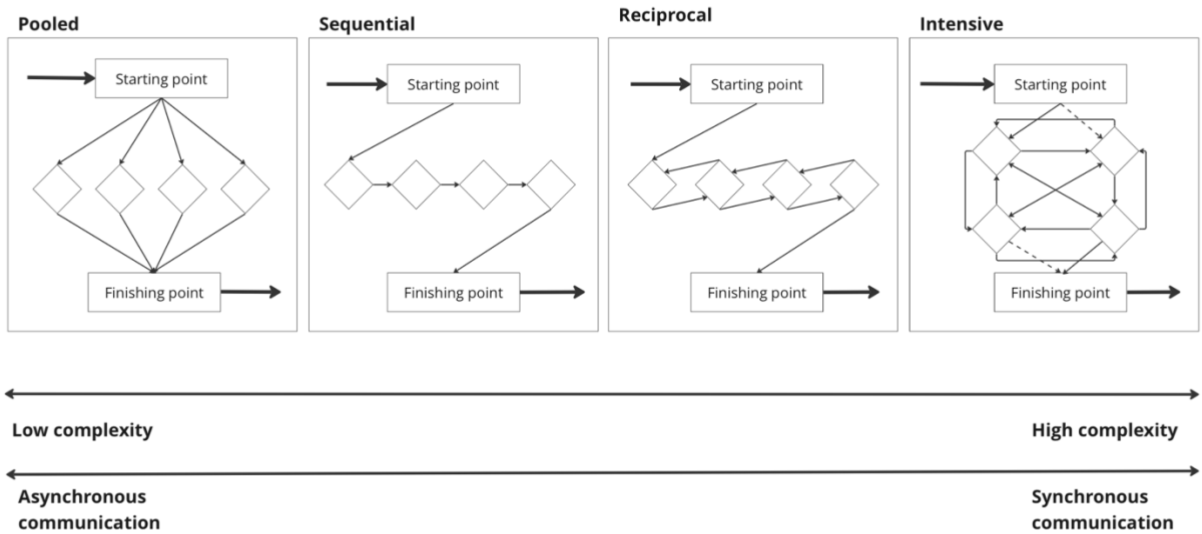


Figure 3.17 The complexity of team tasks modified from (Knotten et al., 2015).

Pooled interdependencies can be integrated with setting standards while sequential tasks need to be broken down into work structures that are then scheduled precisely. Reciprocal tasks are even harder to manage and they require dedication from all parties involved. (Gao et al., 2018)

Organizational complexities reflect the differentiation of teams and individuals connected in the project and the depth of the hierarchies of the organization. Construction projects typically include numerous vertical components which leads to inefficiencies in communication. (Gao et al., 2018)

Environmental complexity refers to the external environmental factors that might cause unpredictable consequences in projects. These external factors include concrete problems like weather conditions, but they also include external structures that surround the project such as political and economic environments. (Gao et al., 2018)

Asset specificity

Asset specificity refers to the limitations placed on the transactions caused by the requirements of specific assets (Jones and Hill, 1988), or the size of the opportunity losses that would incur from the termination of the transaction (Speklé, 2001). This means that the investment of asset would be beneficial for only the transaction in question and that the investment would not be beneficial in transactions in different environment. According to Jones and Hill (1988) this can cause opportunism (Jones and Hill, 1988).

In construction setting, the assets specificities can be divided into categories of site, physical, human, time, and dedication specificities. Site specificity refers to the requirements caused by the construction sites unique characteristics such as unique or unusual location. Physical specificity is connected to the need of specific tools or equipment and human specificity to the specific skills needed for the job. Time specificity refers to the requirements caused by tight or specific schedule. Dedication specificity refers to size of the investment needed to be made in order to execute the transaction (Hosseinian and Tavakoli, 2023).

Frequency

Frequency of transactions refers to how often the transactions are conducted. Frequency is a factor that affects the magnitude of the other transaction difficulties (Speklé, 2001). Frequent transactions build trust between the transaction parties which is a key factor in obtaining advantages from cooperative relationships (Wang et al., 2018).

The level of frequency along with the level of asset specificity has a high impact on which kind of governance method is most suitable for the situation (Erikson and Laan, 2007). The governance method’s dependance to the asset specificity and the frequency of the transactions are presented in the figure 3.18.

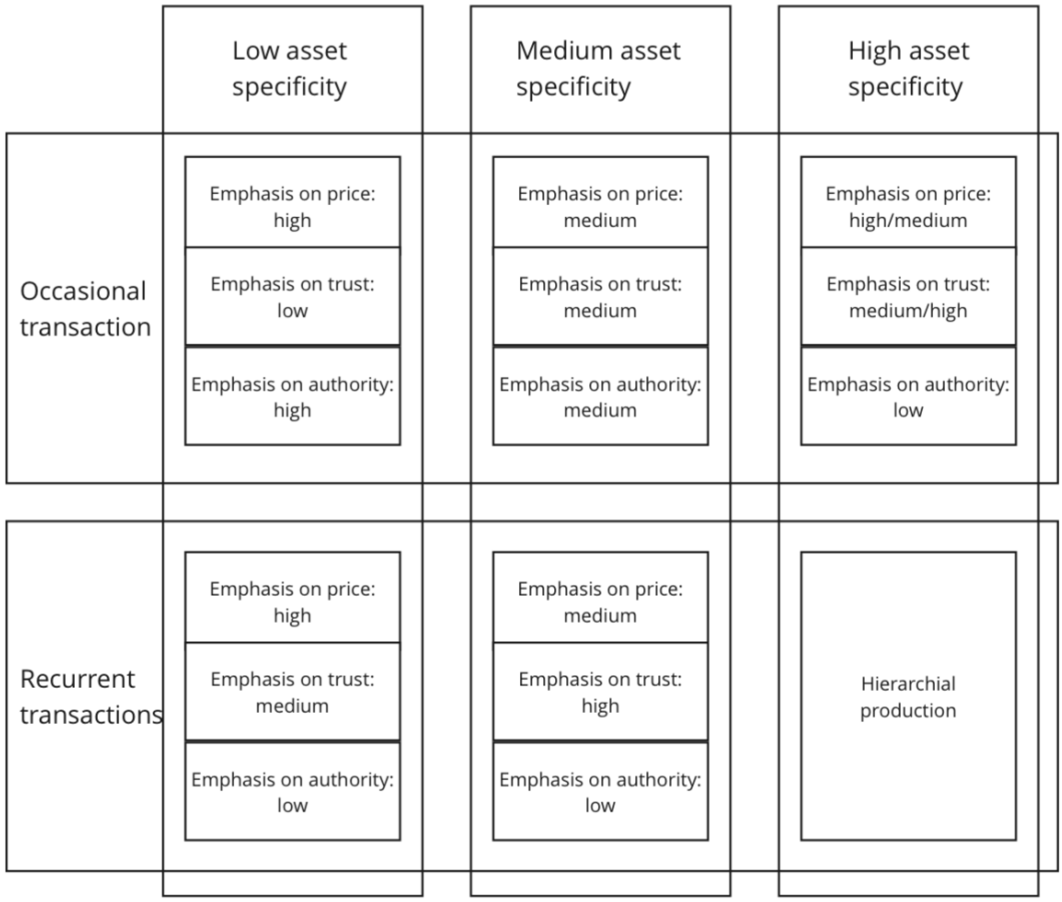


Figure 3.18 Model for choice of governance modified from (Knotten et al., 2015).

Bounded rationality

According to Simon (2000) bounded rationality refers to how the human behavior is bounded by their ability to process information. Decision making is affected by how the people see the world, their capabilities, and priorities. (Simon, 2000) Uncertainty and bounded rationality determine the reasons and timing of the need to adapt (Speklé, 2001).

Opportunism

According to Ikuabe et al. (2020) opportunism can be described as the promotion of self-interest. Symptoms of opportunistic behavior can include actions such as withholding information, stealing, dishonesty, breach of contracts, disguising attributes etc. (Ikuabe et al., 2020).

Opportunism can exist in all kinds of environments, but its scope is influenced by different factors. Some factors that promote opportunism are uncertainty, asset specificity, bounded rationality and contract incompleteness (Hobbs, 1996; You et al., 2020). Figure 3.19. presents things that might enable or cause opportunism in construction projects.

Ikuabe et al. (2020) list four most impactful reasons for opportunism of contractors to be errors in descriptions of contact bills, unclear scope of work, no sanctions for not reporting drawing inconsistencies and the fact that the cost and consequences of delays of written instructions are not addressed (Ikuabe et al., 2020). By limiting these factors, it is possible to reduce the level of opportunity in the project.

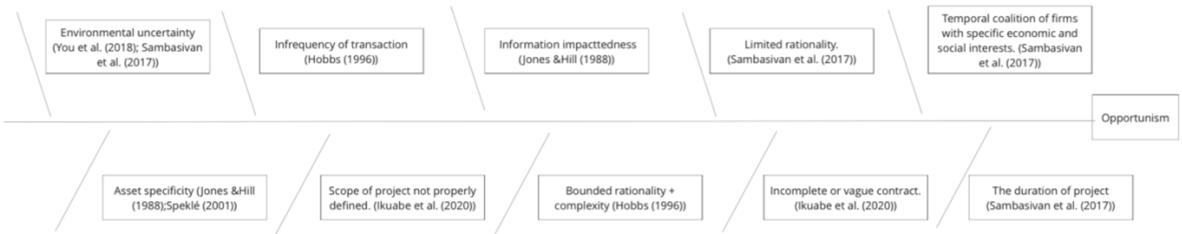


Figure 3.19 Causes of opportunism in construction projects.

Information impactedness

Information impactedness is when the information related to the transaction is divided asymmetrically between the transaction parties. This asymmetricity causes one party to have more information than the other or others. (Jones and Hill, 1988) The main sources of information impactedness are uncertainty and opportunism (Speklé, 2001).

3.3 Supply chain management

Supply chain management (SCM) is a practice of coordinating assortment of different activities performed in the supply chain. The advantage of this practice is that unlike in many of the traditional business models where profits are maximized at the expense of other parties in the supply chain, SCM aims to maximize profits by enhancing competitiveness which will benefit all the partners in supply chain (Sople, 2012). This goes along with the Lean ideology where it is emphasized that optimizations should be done across the whole organization (Lu, 2011). This idea is supported by the statement of Autry and Moon (2016) that locally implemented optimization in different functional parts of an organization, will most likely cause suboptimal results for the organization as a whole (Autry and Moon, 2016).

Supply chain management (SCM) is a key factor in implementing and managing improvements made to the supply chain. The goal of this practice is deeply fused with Lean ideology and the integration of long-term supply chain management into the lean practices will encourage Lean construction (Meng, 2019).

Le and Nguyen (2022) have identified supply chain management, integration, standardization, problem-solving, information sharing, flexibility and sustainability as the seven key trends regarding supply chain management in construction (Le and Nguyen, 2022).

Integration

Integration has a lot of promise as a method of improving the operations of the supply chains. Sople (2012) expresses that integration between supply chain parties will aid with reducing waste, delays, and cost reduction by coordinating activities to enhance the value to customers and help increase customer satisfaction (Sople, 2012). Thunberg et al. (2017) supplement this by stating that the integration of supply chain and construction project process is one way to reduce external communication problems (Thunberg et al., 2017). If integration can be achieved properly it can be a solution to problems caused by fragmentation of the construction production process (Dainty et al., 2001).

There is some variance in the definition of integration and how it is measured. Autry and Moon (2016) propose the following definition for the integration of a supply chain:

”Integration is an ongoing process in which functionally diverse areas of an organization collaborate, coordinate, and communicate to arrive at mutually acceptable outcomes for their organization.” (Autry and Moon, 2016)

This definition needs to be expanded to cover different organizations that exist within the supply chain, but the main idea stays the same with the need to collaborate, coordinate and communicate. These activities and how well they are implemented can be used to determine the level of integration. Table 3.2. present different levels of integration defined by Speak man et al. (1998).

Table 3.2 The level of integration in supply chains. Modified from (Speakman et al., 1998).

The Level of integration	Content
1. Cooperation	Firms use long term contracts and there is some exchange of essential information between parties.
2. Co-ordination	Information and workflow is shared in a way that enables the use of mechanisms used in making the linkages between supply chain parties smooth, such as JIT systems and EDI.
3. Collaboration	High level of trust, commitment and information sharing with common and long-term strategic intentions regarding future designs and product performance shared by the supply chain parties.

Integration is also a key method in controlling the transaction costs. From the viewpoint of transaction costs, the integration can be thought as a spectrum where on the other end is the complete vertical integration and on the other end is a spot market (Hobbs, 1996). Spot market is a situation with little to no supply chain management where price is the sole driver for the transactions (Hobbs, 1996). Hosseinian and Tavakoli (2023) present this same idea where the governance of the spot market is called market and the situation with vertical integration is hierarchy. In market al the activities are out-sourcing based and there is little to no integration. A mixture of these two governance structures is called a hybrid (Hosseinian and Tavakoli, 2023). The governance method is a way to manage opportunism. According to Patnayakuni et al. (2006), the spot market is an applicable solution when asset specificity, the level of uncertainty and the frequency of transactions are low, but when this is not the case, a more hierarchical solution is a better way to lower the risk of opportunism (Patnayakuni et al., 2006). On top of these governance methods, the integration can be a method to lessen the transaction cost difficulties that could lead to the increase of the transaction costs. Integration where the decision making of different functional groups can be a way to lessen uncertainty by bettering the quality of work and strengthening the information sharing (Sople, 2012).

Standardization

According to Sergerstedt and Olofsson (2010) standardization and modularization of semi-manufactured components is a way to lower the costs of production, decrease delivery times, increasing flexibility, and the variety of products, used in the traditional manufacturing. Standardization can also be used as a way to enable different versions of the supply-and-demand chain. (Segerstedt and Olofsson, 2010) The supply-and-demand is connected in the order placement point (OPP) and the value offering point. By moving these points along the chain, value formation can be influenced (Sople, 2012).

Problem-solving

The problem solving is an important aspect of the supply chain management for the purposes of finding solutions to problems found in already existing processes. As Eisner (2021) states, the problem solving can be generalized into 5 steps of stating the problem, establishing key variables and dependencies, identifying alternative solutions and approaches, selecting and implementing the best alternative, and lastly documenting and presenting the results (Eisner, 2021).

Information sharing

Information flow in the supply chain is an important aspect to take into account for the management of planning, implementing and monitoring (Sople, 2012). Autry and Moon (2016) defines the goal of the cross-functional communication inside the supply chain to be the transferring of knowledge with collective understanding of relevance of information (Autry and Moon, 2016).

Patnayakuni et al. (2006) present some of the traditional problems that supply chains face regarding the flow of information to be sparse or imperfect information, lack of suitable software or hardware to conduct the communication and information exchange, and excluded classes of information (Patnayakuni et al., 2006).

Sople (2012) introduces one solution for bettering the information flow to be to connect the supplier’s production schedule to the customer’s schedule. The suppliers’ operations are to be thought as an extension of the firm’s operations instead of completely different entities. The advanced that can be achieved when the electronic data interchange (EDI) is implemented correctly between the supply chain parties, are shorter lead times, elimination of multiple data entries and lowering the costs of the supply chain. (Sople, 2012) Patnayakuni et al. (2006) supplement this way of operating with the idea that transaction risks can be managed with sharing monitoring and control information between different parties. This could mean sharing the production and delivery schedules between all connected parties as well as having shared performance metrics to monitor the activities. (Patnayakuni et al., 2006)

3.4 Synthesis of the literature review

From the viewpoint of the thesis' aim to better the process flow of the frame erection phase, the problems can be defined as things that impair or prevent the flow. As such to answer the first research question of what kind of problems hinder the flow in the supply chain of a construction project, and why do these problems occur, waste can be named as one such a problem. However, waste is deeply connected to the activities within the process, but it does not take a clear stand on how well everything is handled outside of the value creating activities. In the frame erection phase of a building with PCC element frame, the supply chains have a significant effect on how well the project succeeds. As the supply chains are formed from a connection between different facilities and companies, the transactions between the different parties are very important. Thus, the second group of problems that the supply chains face are the transaction cost difficulties.

The most referenced waste types in the construction were defined to be transportation, inventory, quality problems, waiting, overproduction, motion, human potential, making-do, extra processing and problems with communication and documentation. The transaction cost difficulties that can exist within the supply chains in the construction industry were found to be uncertainty, complexity, asset specificity, frequency, bounded rationality, opportunism, and information impactedness.

The waste can be caused by many different things and for the 10 types of waste there were named 54 different branches of causes. Some of the most reoccurring themes in the waste causes were poor planning, lacking communication, work-in-process, making-do, complexity, poor management practices and lacking definition of requirements.

The causes behind the transaction cost difficulties are not straightforward cause and effect relationships and many of the difficulties were deeply connected to each other and the characteristics of the project. Many of the causes for the transaction cost difficulties can be found in the early stages of the project or the decisions made early in the project predisposes to the formation of these problems. Some of the common causes that could be found between causes of waste and causes of transaction cost difficulties were poor planning, complexity, lacking definition of requirements, lacking communication, and unexpected problems.

4. EMPIRICAL FINDINGS

4.1 Current process

4.1.1 Business model

The frame erection phase of the precast concrete typically consists of many different parties, which is also the case in the case project. The main actors in this case are presented in the figure 4.1. These actors are arranged into functional groups to emphasize the importance of different functions in the supply chain.

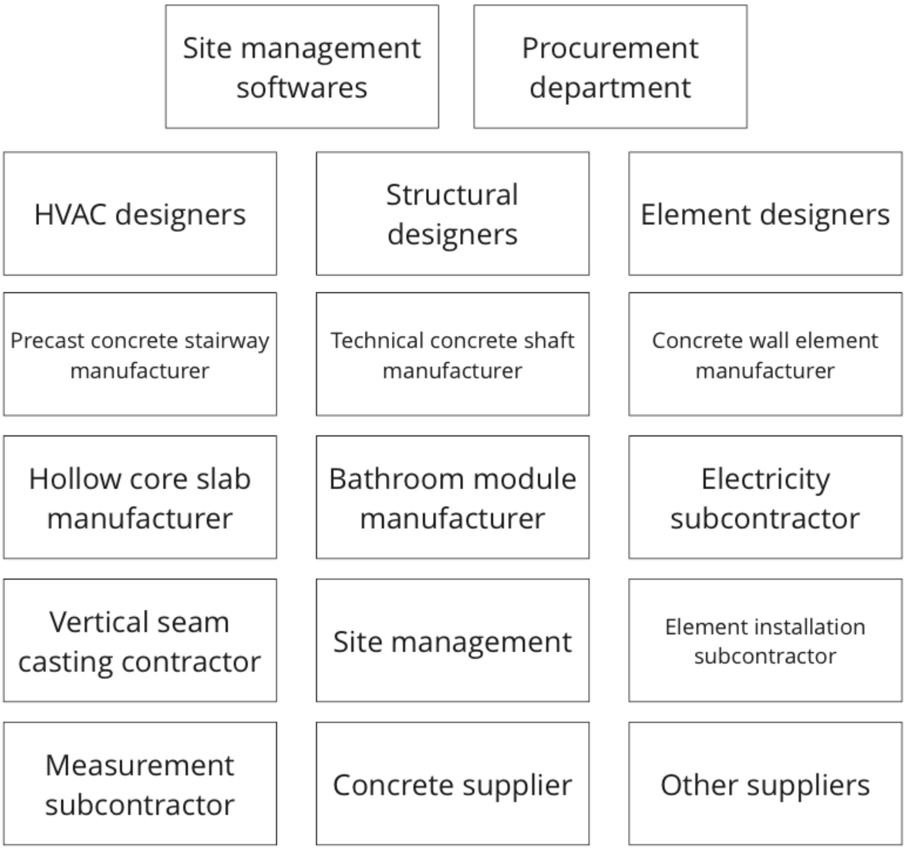


Figure 4.1 The main actors of frame erection phase of the case project.

Each of the actors presented in the figure 4.1. have their own business models with various means of accumulating value with their operations. The business ecosystem of the actors connected to the PCC elements is presented in figure 4.2.

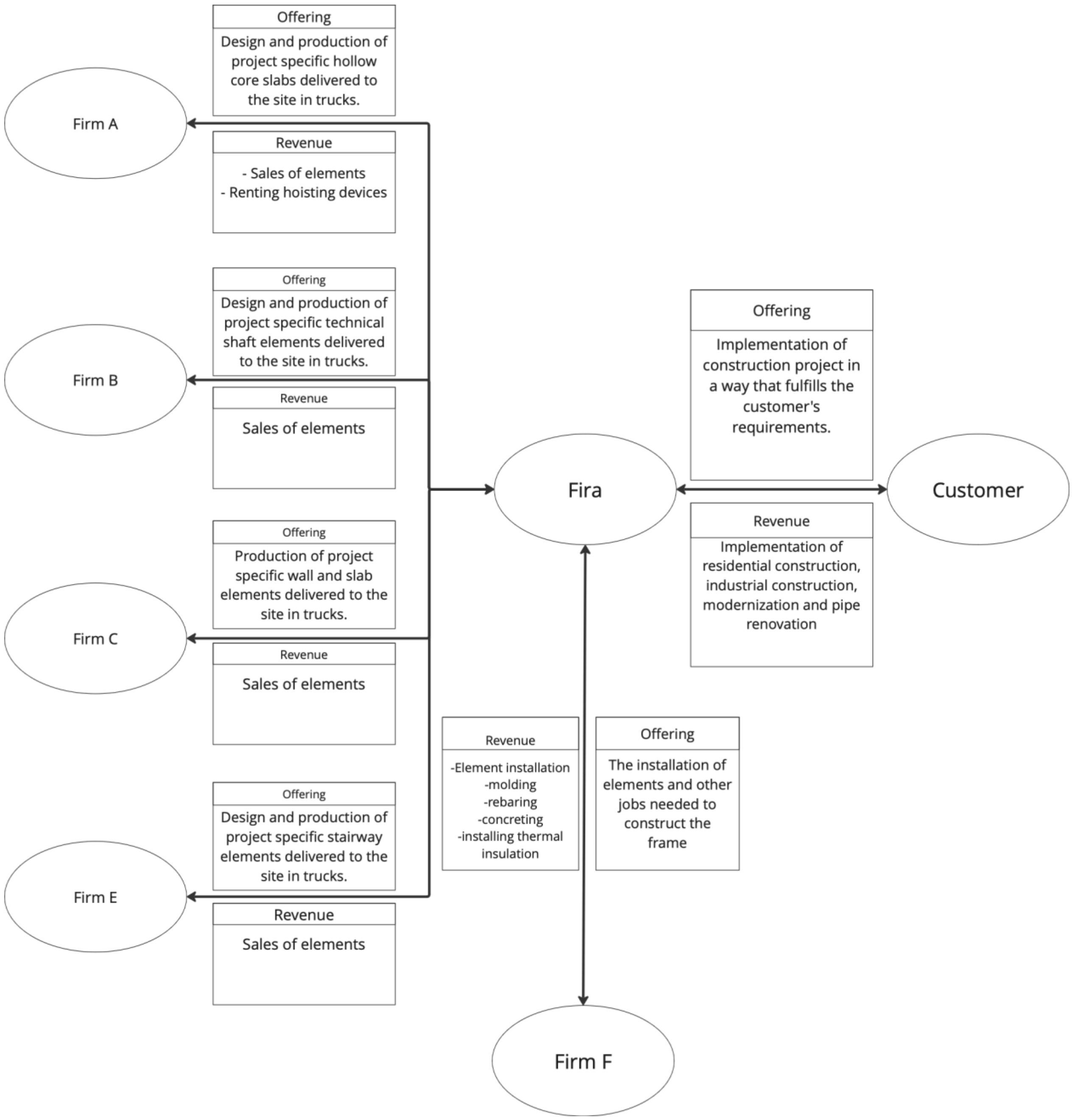


Figure 4.2 A view into the business ecosystem of the supply chains of the PCC elements.

The contract type of the manufacturers has an impact on the transaction costs of the project and the level of integration. The case contract types of the PCC element suppliers are presented in the table 4.1.

Table 4.1 The contract type between Fira and PCC suppliers and installation subcontractors.

Firm	Firms role	Contract type
A	Hollow core slab manufacturer	Project based contract
B	Technical shaft element manufacturer	Seasonal contract
C	Wall and slab element manufacturer	Project based contract
E	Stairway element manufacturer	Project based contract
F	Element installation contractor	Seasonal contract

The project-based contracts are more common in the case project but firms F and B have seasonal contracts.

4.1.2 The products

The number of different types of PCC elements used in the case are presented in table 4.2. The numbers and types presented are the ones that have been used in the procurement contract between the manufacturers and Fira.

Table 4.2 The PCC elements of the case project.

Element	Number of elements	Number of element types	Defined surface/ other specifications	Manufacturer
External walls	551	9	Graphic concrete in some of the elements. Windows pre-installed.	C
Internal walls	531	3	Sewatek installation	C
Balcony slabs	168	2		C
Balcony sides	90	2	Acid wash/painting preliminary treatment.	C
Balcony pillars	115	4		C
Massive slabs	121	3		C
Hollow core slabs	1448	7		A
Elevator shaft elements	26	3		A
Technical shaft element	195	39 lines		B
Stairway element	40	1	Mosaic concrete	E

The pricing of the elements is based on the element types and the numbers of elements. Additional price for some of the parts used in the elements is added according to the pricing of the manufacturer. The element installation is priced based on the number of PCC elements. The materials needed for the installation is not included in the contract, and Fira provides them as needed.

4.1.3 Value creating activities

The value creating activities were identified through interviews and the VSMs of the current model are presented in the appendices D-G. The value creating activities of the PCC element manufacturing are portrayed starting from the invitation for bids to the final financial statement. The value stream follows one element from the start to finish. The activities portrayed in the appendices D, E, F, G are verbally detailed below.

Contracts and Procurement

There are two ways Fira uses to form contracts with element contractors and subcontractors. Either there is an existing seasonal contract, or the contract party is selected on project-by-project basis by sending out invitations for bids. In both cases, the procurement contract is made for the project for each element type.

The procurement starts early in the process. The procurement schedule is determined by a pull method by starting from the date the elements are needed on the site and going backwards the delivery times of the elements. The longer the delivery times are, the earlier the procurement needs to start. The procurement is done based on the designs and if the designs are late, it makes the procurement much harder. The usage of Firas apartment library makes it easier for the procurement to form the invitation for bids as the components are standard.

Element design

The element design when the element designer receives the needed inputs to begin the designing. The needed inputs differ between the element types, but they come from either structural designers, HVAC designers, architectural design or from all of them. The hollow core slabs require input from both structural and HVAC designers as they are a structural part of the frame, the technical shaft element needs only the HVAC input, and the wall elements require all of them.

The design of the hollow core slab, technical shaft, elevator shaft and stairway elements are included in the contracts between Fira and the element manufacturers. For the wall, solid slab and balcony slab elements, the element design is done by a subcontractor of Fira and the designs need to be submitted 8 weeks before the scheduled delivery.

If the element contains special components that need longer than normal delivery time, the element designer might notify the manufacturing department so that they know to order these parts on time. In the case supply chains, this is expected of the element designers who are part of the same company as the manufacturing section, but in the case of the wall and slab elements where the design come from an external source, it depends on the designer if they are willing to do this.

The quality control of the finished element designs is done by designer cross checking each other's designs after which the designs are send to an email chain with all the necessary parties involved. These email recipients include the architect, the structural designers, the HVAC designers, the main contractor's project manager and site manager. They are given a deadline by which any needed changes should be reported. The deadline is usually about 2 weeks from the first email.

Production planning

The production planning includes two different levels of planning: the infinite loading and the finite loading. The first one is a rougher project level schedule that includes the element quantities and project schedules. The finite scheduling is the more accurate production schedule that includes the element dimensions and on which bed they should be manufactured.

The production planning of the hollow core slabs made use of their ERP. The element places on the casting bed are optimized and then the information is usable in the manufacturing process. The hollow core slab loads are determined at this point.

Manufacturing

The manufacturing methods are very specific to each element type. The manufacturing begins from the preparation of the beds and pulling and tension the cables over the bed. The manufacturing of the hollow core slabs makes use of automation in the casting, marking, and cutting of the elements. The machines move over the bed along a track. The quality inspection of the hollow core slabs is done on daily basis by doing a full inspection to 1 element and then the height is inspected from the first, third and last element on each bed.

The technical shaft element begins when the drawings are brought to the workshop floor. The element molds are built on raised movable beds, where the needed rebars and the HVAC components are placed. When it is time to cast the concrete, a foreman calls the concrete mill next door and orders the needed amount of concrete based on the dimensions of the elements. The elements are cast and left overnight to cure after which they are sanded according to the specifications of the element. The quality inspection of the elements is done once before the casting of the concrete and then once after they have been finished.

Inventory of finished elements

The elements are stored as needed either on the manufacturers end or on the construction site. Short time inventory on the manufacturing plant can be an informed choice made to manage the schedule and the efficiency or the PCC production, or it can be caused by the site being behind schedule. The costs of inventory is allocated to the correct party according to the cause of the inventory.

The PCC wall, balcony slab, pillar and side elements are stored in the manufacturing plant as a strategic tactic to allow the elements to be manufactured in a way that allows the same element molds to be used as many times as possible. The number of element inventory can be around 2000 elements. These elements are manufactured around 3 weeks before the shipping date.

On the site, the inventory of all the elements excluding the hollow core slabs is a strategic choice done so that the elements are ready on the site when needed. The hollow core slabs are an exception as they are installed straight from the truck while the others are unloaded from the trucks into interim storage on the site. On the case site there is one crane which is needed in both the installation and the unloading of the elements from truck which means that these tasks cannot be done at the same time.

The elements are stored outside which exposes the elements to the effects of weather conditions. The adverse effects of the weather might cause the need for repair.

Ordering of the elements

The elements are ordered to the site by an email by the site foreman a week before they are needed on the site. The manufacturers define to which email these orders are send to. The needed information is the date, time, and the IDs of the needed elements. Sometimes it is enough to tell which floor the needed elements belong to. The case site foreman uses an excel sheet where there is listed the dates of delivery of all the needed elements, materials, and contractors. When ordering the elements, the foreman send this excel to the manufacturers so that the manufacturers can stay up to date on the situation on site.

Transportation

The transportations are organized by the PCC element manufacturer and implemented by their contractors. In contracts, there are mentioned different kinds of conditions regarding the transportation.

The hoisting equipment of hollow core slab can be borrowed from the manufacturer. The firm A prices this either by the number of days they are being borrowed or by the number of times the hoisting equipment is returned to the manufacturing plant.

The transportation of the technical shaft elements is based on the foreman order and organized by a transportation organizer. The organizer calls the transportation firm and arranges it about a week before.

The truck driver loads the element to the truck and drives to the site. The truck driver works along with the element installers to unload the elements from the trucks by first removing the fastenings used during the transportation and then connecting the elements to the crane.

Scheduling the frame erection and installation

The scheduling of the element installations is based on the number and types of the elements and the installation pace of the installation team contracted to the project. In the contract the installation pace is determined to be 110 elements per 4 workdays. The work activities are divided into smaller categories to get more accurate schedule.

Installation of elements

The installation of elements is element type specific. The installation proceeds by element types as follows: exterior walls, interior walls, balcony sides, elevator shaft, massive slabs, stairway elements, technical shaft element, bathroom module, hollow core slabs and balcony slabs. The elements are either hoisted straight from the truck or from intermediate storage.

The element installation team is contracted to the case project through a seasonal contract. On the case site, the installation team consists of 4 members where one stays on the ground to connect the elements to the crane and the others stay on the floor being built. The communication between different members of the team and the crane operator is done with walkie-talkies and hand signals. The site foreman also has a walkie-talkie that can be used to communicate. Other ways that the installation team uses to communicate with the foreman, is to call by phone, send a WhatsApp message, or walk to the site hut and speak with the foreman.

Vertical seam casting

The vertical seam casting is done by a subcontractor. The cement needed for the vertical seam casting is ordered for three floors at once by the site foreman, but the necessary tools and equipment needed to cast the seams are the responsibility of the subcontractor. The casting begins by hoisting the vertical seam pump and the cement bag to the top floor.

Rebaring and floor casting molding

The floor casting preparations include rebaring and molding. Rebaring can begin when the hollow core slabs have been installed. On the case site it is done partly simultaneously with the hollow core installation so that the floor casting can begin as soon as possible. Floor casting molding can also begin after the hollow core installations are done. Floor casting molding must be done before the vertical seam casting is done.

Floor casting

The floor casting begins by the foreman placing an order for the concrete. The quantity of the concrete is estimated by the size of the floor and how much concrete was needed for the floor below.

The case site uses a concrete pump. The pump’s nozzle is extended to the highest floor and the concrete truck will reverse behind the pump vehicle and pour the concrete into it. As the concrete starts to pour from the nozzle, the installers will sweep the concrete to the channels between hollow core slabs while the pump driver guides the nozzle. If the weather is hot, water will be distributed to the floor to make sure the concrete cures correctly.

Reclamations

The reclamation procedures of the elements with quality defects depend on the type of defection and the type of the element. The simple, quick to fix problems are usually fixed by the element installers. Problems that require an expert to be called to the site are more expensive. The technical shaft elements require a repairer to be called to the site if either the element has quality deviations, or the element installation was not successful. Most of the problems are noticed during the element installation.

4.2 Problems in the current model

4.2.1 Problems in the supply chain

The problems were identified using 3 different methods: using existing data about the problems on site, interviews, and workshops. The data from the site is presented in the appendix A and these problems will be referred to as problem list 1. The problems gathered from interviews are presented in the appendix B and they will be referred to a problem list 2. The problems from the workshop are listed in the appendix C and problem list 3 is referring to it.

The list 1 contains 75 different problems that have been observed on site. They are mostly problems that cause easily observable direct consequences in the PCC installation on site. The list 2 contains 59 problems identified by different individuals form different functional groups of the case supply chains. The list 3 is a collection of problems that the participants have determined to be reoccurring in the PCC supply chains and it contains 36 problems.

Some of the problems can be seen reoccurring between lists. The reoccurring problems are presented in table 4.3. The biggest overlap between the list was with list 2 and 3 which share 13 problems.

Table 4.3 The reoccurring problems from different sources.

Problem	Sources
Errors in the details of the elements	List 1, List 2, List 3
The shipments of the elements are behind schedule.	List 1, List 2, List 3
Problems with crane	List 1, List 2
The element has been installed in the wrong place.	List 1, List 3
Missing elements on site	List 1, List 3
The elements are not loaded in the truck in the order of installation.	List 1, List 3
The problems with electrical component of the element.	List 1, List 3
The element GUID changes because designer makes changes by deleting the old element and adding the new one.	List 2, List 3
The designing schedule is too tight, the designers do not have time to check the designs.	List 2, List 3
The inputs are insufficient for the element design.	List 2, List 3
The information flow between procurement and the design is lacking.	List 2, List 3
The PCC manufacturer might not have accurate up-to-date schedule of the site.	List 2, List 3
The façade materials change after the contract has been done.	List 2, List 3
The changes to the elements come too late.	List 2, List 3
The determination of a responsible party is time consuming.	List 2, List 3
The problems in the design phase affect the manufacturing.	List 2, List 3
The problems caused by improperly implemented or prolonged storage of elements.	List 2, List 3
The site does not document all the problems and sometimes corrective measurements are done without consulting structural or element designers.	List 2, List 3

While there are many overlaps with the lists, there are many more problems that came up only once. All together there are 170 different problems with 18 problems that were named in two or more times.

4.2.2 Analysis of the problems

The problems are analyzed to determine what kinds of problems occur in the supply chains of the PCC elements, and what are the root-causes behind them. The analysis considers the different methods that has been used to collect the problems and compares the results of these different methods with each other.

In the table 4.4. there are presented how the problems are distributed between different categories. The 25 problems categories are defined in the data, and they are determined for the whole investigation that contains information from 4 different sites.

Table 4.4 The problem types on site according to the problems found on the case site.

Accessories (lifting loops, pulleys, cable loops, etc.)	12
Shipment behind schedule	9
Slots and reservations	9
Insulators	6
Element dimensions	5
Deficiencies in deliveries	4
Site visit and deliveries	4
Installation of the element	3
The load was not loaded in the installation order	3
Electrical design	3
Information flow	2
Concrete delivery	2
Element labels	2
S-point holes and s-pin irons	2
Lack of equipment	1
Castings	1
Measurement error	1
Crane driver gone	1
Crane broken	1
The Height level was indicated incorrectly	1
Site area and deliveries	1
Installation accessories	1
Electric pipes, boxes, and other electrical slots in the elements	1
Electrical parts	1

The most common problems on the case site were observed to be the accessories of the PCC elements, the shipments being late, the errors in the slots and reservation in the elements, the insulations in the elements and the dimensions of the elements. From these 25 problem types, 6 are about the PCC elements themselves and 3 about the deliveries. The number of problems related to different parts of the process are presented in the table 4.5.

Table 4.5 The number of problems that affect different parts involved.

Affected part	Number of problems
Elements	41
Shipments	18
Site logistic	5
Information	2
Other	7

Most of the problems listed consist of the errors in the PCC elements and their shipment, however, it needs to be noticed that it only the symptoms and causes of different problems within the supply chain that surface on the site.

While the problem list 1. does not consider the causes for each of the different mistakes but it has an assessment of where in the supply chain the problems were formed. The figure 4.3. shows how the problems are distributed in the supply chain according to the data gathered from the case site.

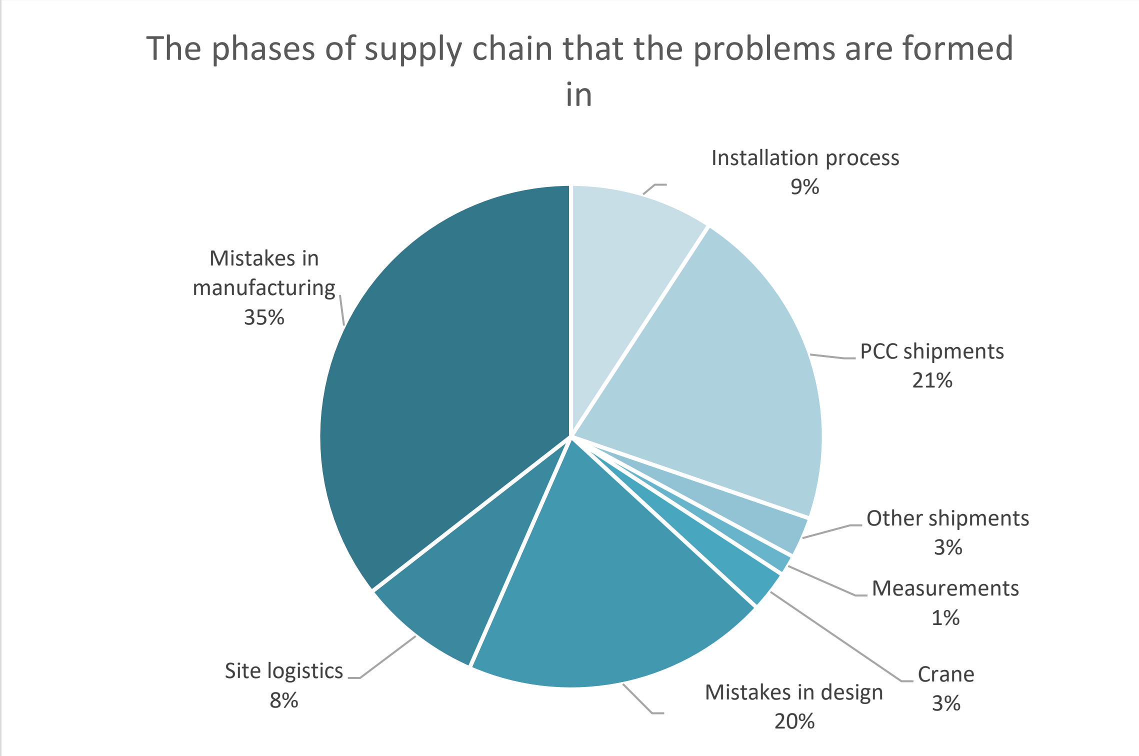


Figure 4.3 The phases of the supply chain that the problems are formed in according to the problems found on the case site.

From the list 1, the biggest categories are the mistakes in manufacturing, mistakes in design and the shipment of the elements. These problems were only noticed at the site even thought they were formed earlier on in the supply chain. The lists 2 and 3 give a better insight on how the problems form.

The problems on the list 2 give an idea on how the people working in different functional groups experience how the supply chain is working. The interviewees gave some insight on what they presume to be the causes of the problems. These causes were supplemented with the information presented in the literature review portion of the thesis and the root causes were categorized according to different reoccurring themes. These categories and the how often they occur within the root-cause analysis are presented in table 4.6.

Table 4.6 The problem root-cause categorization based on the interviews and the literature review.

Category	Number of occurrences
Problems with communication	12
Lacking skills/knowledge	8
Lack of coordination between parties	7
Unexpected problems	6
Poor scheduling	6
Insufficient problem detection	5
Choosing efficiency over flow	4
Variability / lack of standardization	4
Requirements management	3
Information duplication	2

A root-cause analysis was conducted on the problems on list 3 and a classification of different root-causes was made based on them. The classifications and the number of times they appear within the context of the problems on list 3 are presented in table 4.7.

Table 4.7 The problem root-cause categorization from the workshops.

Category	Number of occurrences
Lacking status information about the supply chain	7
Communication and data transfer	6
Error detection	5
Human error	4
Requirements management	4
Scheduling	3
Lack of skills	2
Determination of problem types	2
Element identifiers	2
Information flow	1
Data storage	1
Procedural error	1
The possible accuracy level of inspections	1
Unexpected problems	1
Generating information	1

The root-causes made from both lists 2 and 3 contain many similarities. Themes that are included in only one of the lists are lacking coordination between parties, choosing efficiency over flow, variability, information duplication, determination of problem types, element identifiers, information flow, data storage, procedural errors, the possible accuracy level of the inspections and generating information. However, if all the problem categories that involve communication, documentation and data transfer are grouped together into one category, it leaves out only choosing efficiency over flow, variability, element identifiers, procedural errors and the possible accuracy level of the inspections. The choosing efficiency overflow and variability as root-causes for problems are based on Lean which explains why they might be found in the analysis of list 2 that based on flow and not in the list 3 that was based on workshops.

In the table 4.7. many of the categories can be summarized and combined with some of the other categories as they are very similar. The narrowed down list of the categories is presented in the table 4.8. along with indicative value of how often these themes occur in the root-causes of the inspected problems.

Table 4.8 The final root-cause categories and the number of occurrences in the lists 2 and 3.

Category	Number of occurrences
Communication, documentation, and data transfer	35
Insufficient proactive planning	25
Human resource management and human-oriented problems	21
Lack of classification of errors and error documentation	17
Process information formation	11
Unexpected problems (weather etc.)	9

The contents of the categories vary in scope and effects. Figure 4.4. present the percentage of the root-causes to make an approximation of the frequencies of how often these causes lead to noticeable problems.

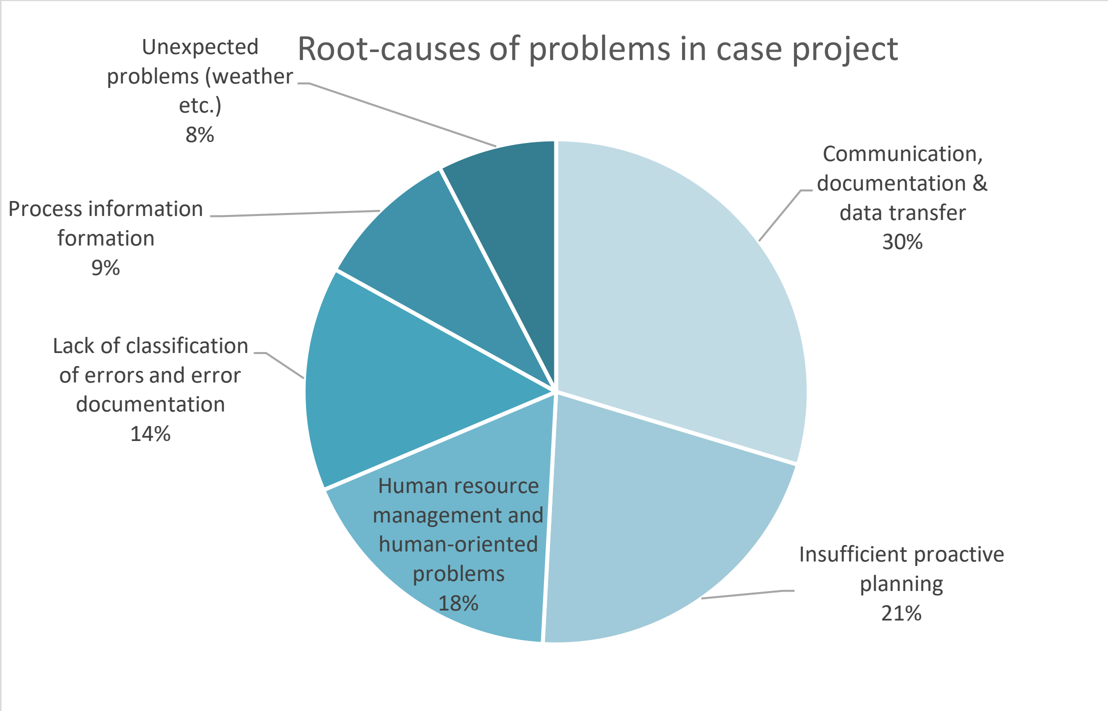


Figure 4.4 The percentages of different root-causes found in lists 2 and 3.

Problems with communication, documentation and data transfer is a broad category that involves many different situations such as lack of coordination, slow information exchange, lack of feedback, information documented in the wrong place or not documented at all etc. These problems are interwoven into the supply chain, and they can either amplify already existing problems or create new ones.

Insufficient proactive planning refers to the problems that could be avoided with more detailed or accurate planning. This category contains for example lacking requirement planning, poor scheduling and lacking maintenance planning. In an ideal situation, where everything goes right these deficiencies might not cause problems, but when combined with unwanted situations, the consequences can be significant.

Human resource management and human-oriented problems refers to the problems that could be reduced with better management of the employees and other problems that are human oriented. This category includes lacking skills, human error, procedural errors etc.

The lack of error classification is connected to how well the problems are recognized in different parts of the supply chains, and how the information of the problems is documented and shared with different parties. With no error classifications, the data processing and comparison is not possible in a way that promotes the development of the supply chain. In the case project this can be seen in the insufficient error detection which refers to how the errors are not detected in time which in turn causes the error to move on to the next step of the process. Different types of errors cumulate along the supply chain which causes problems to grow until they are eventually noticed. This can be seen in figure 4.4. which shows that many of the problems occurring on the construction site originate from upstream of the supply chain.

The process information formation refers to the problems that are cause by the lack of sufficient information regarding the process. The process does not generate information and as such a lot of useful information is lost or inaccessible to the correct parties. It is not possible to form a comprehensive snapshot of the process which complicates the coordination of different functional groups and obstructs development activities. From the viewpoint of Lean and flow, where continuous improvement is one of the key themes, the improvement of process information formation can be named as an important development objective.

An alternative way to divide the problems into categories could be to divide them into things that cause problems, and things that increase the consequences and make the prevention of the problems difficult.

4.3 The challenges in the current model

4.3.1 The waste types in the current model

In the current process, there are many different types of waste. These are presented in table 4.9. displayed by where they occur in the current model. These wastes are either an integral part of the process or the process is the likely cause of these waste according to the empirical portion of the thesis where interviews were used to map out the current process.

Table 4.9 The wastes found in different parts of case the supply chains.

	Transportation	Quality deviations	Inventory	Waiting	Motion	Overproduction	Human potential	Extra-processing	Making-do	Communication & documentation
Contract & procurement		x		x				x	x	x
Element design		x	x	x	x		x	x		x
Production planning										
Manufacturing		x				x		x		
Quality checks										
Storing of finished elements	x	x	x		x					
Ordering elements										
Transportation		x		x						x
Scheduling the frame erection and installation				x				x		x
Installation of elements	x	x		x	x					x
Vertical seam casting	x		x	x	x					
Electrical tubing			x	x	x			x		x
Rebaring and molding	x		x		x					
Floor casting										
Reclamations			x		x					x

The most reoccurring wastes across different functional groups were waiting, motion and communication and documentation. Least common waste types were overproduction, human potential, and making-do. The results vary from the results of the literature review which could indicate that while a waste can be found in many different places it might not have as significant consequences or that there was more waiting, motion and communication and documentation problems that is typical in the case project.

Transportation waste

Transportation can be found in the case project in physical and informational forms. On the construction site, problems caused by poor layout planning or logistics planning can cause the need to transport materials and equipment. Information transportation occurs when information is moved back and forth between parties via email. The information exchange conducted via email could be implemented more effectively. In addition to the transportation waste, email exchange can lead to other wastes such as waiting.

Inventory

Inventory in the supply chain can be the waste itself or the cause of other problems. For example, the long duration of inventory leads to higher inventory costs, and it might also lead to quality problems when an element is damaged due to long inventory times in outdoor storage. Inventory exists in all supply chains connected to the site, and it is done by all parties connected to different extents.

When the inventory is done strategically, as is done, for example, by the wall element manufacturer, it can cause other problems as it is incompatible with the other processes. In the interviews, it was noticed that the window installation was sometimes more complicated than needed when the windows did not arrive on time with the element manufacturing. This was partly caused by the batch production and inventory of the elements that did not follow the flow-based schedule that the construction site follows.

Quality problems

Quality problems are often the culmination of many problems, and determining their causes can be challenging. In the case project, there arose many instances where the problems were only noticed when the next task could not be completed because of the problems that occurred in earlier tasks.

Many quality problems are only noticed on the site when the element cannot be installed. If the problems were to be noticed earlier, the costs of fixing the mistake could be significantly lower. The cost of fixing an element on site can include the repair fee of an outside repairman, the cost of waiting to be able to continue, and the costs caused by possible schedule delays.

Waiting

Problems upstream of the supply chains can cause waiting in the later parts of the chain. Waiting in the case of supply chains is often found when the needed input material, data, or information is being moved between different functional groups, especially if they are moving across company borders. The procurement and element design wait for the design, the manufacturing might have to wait for the materials and components, the site needs to wait for the elements to be made and delivered, and the element installations and electrical tubing might need to wait for the other to be done, vertical seam casting might need to wait for the hollow core slab installation and molding to be done, and floor casting might have to wait for the repairing to be done. In some cases, the waiting time could be reduced by bettering the coordination between different parties by sharing the schedule information better. Also, the better the understanding of the process, the easier it is to make operational plans and schedules beforehand.

Overproduction

Overproduction of the PCC elements is seldom about too many elements being made. More common is the situation where the elements are made too early and stored for a long time either by the manufacturer or on the site. On top of unnecessary inventory, overproduction can lead to other problems, as the interview findings show. When there are elements that are copies of each other, and they are done in a batch, the possible errors will be copied into the other. This can lead to a scenario where repairs need to be done on every floor if the problem is not caught on time.

Motion

Motion, in the case supply chain, can be found in physical work and communication. Motion in communication can happen when information is exchanged between different parties. As the primary form of communication between different functional groups is email or a phone call, there can be much back-and-forth to exchange the needed information. An example of the physical motion of people and machinery in the case process can be found on the site where logistical problems cause the need to move materials out of the way of other contractors working on site. If the material that needs to be moved is heavy and requires the crane to move, it causes the installation to be stopped. Even if the crane is not used, it requires work power to move.

Human potential

Human potential is a more abstract waste than many of the others, and it is not easy to spot just by observing the process. Some indications of potential human waste can be found in the number of problems caused by human error, and there are ways to manage people so that the number of human errors can be reduced. Another instance where the human potential came up in the interview process was in the element design process, where the element designer expressed that better solutions could have been found if the element designer could participate in the planning process earlier.

Making-do

Making-do is a waste that is not seen from the VSM of the supply chains, but it can exist in different activities if there are problems upstream that cause deficiencies in the needed input for the task. In the literature review, making-do was presented concerning the work done on-site. However, there was no indication during the study that this was a central problem on site. Concretely in the case project, making-do can occur if the procurement does not receive the needed information to proceed as planned, but rather, they need to make do with the information they already have.

Extra-processing

Extra-processing in the case project can be caused by making-do; for example, if in the procurement phase, the request for quotations is made with insufficient information about the project, it will increase the workload for the contract negotiations. The same can happen in the element design process if there is a need to make changes to the design after the first version is done. In the manufacturing phase of the exterior walls, if the façade of the element is not defined yet in the contract, it might lead to the finishing of the element being more laborious than would have been needed.

Communication and documentation

One prominent waste found in the empirical portion and given its own category in the problem categories is problems with communication and information exchange. In the VSM of the current process, the problems can be found in long waiting processes and the motion caused by the used means of data transfer. Most information exchange is done by phone or email, and the transferred information is usually not documented. This makes it very challenging to collect data from the project and thus hindering the development of the processes. Information flow problems are also a theme found in the list of collected problems. It occurs in many different forms, such as the lack of coordination between parties, data duplication, poor scheduling, and problems with communication.

4.3.2 The transaction cost difficulties in the current model

Uncertainty

Behavioral uncertainty regarding the fulfillment of the contracts. One cause for the contractual uncertainty is the difficulty of assessing the time and costs of the activities (Sambasivan et al., 2017). This uncertainty could be found in the empirical research as the duration of the design of the element could not be estimated. The estimations that they use to schedule their work are roughly on the week level.

Complexity

The effects of organizational complexity can be seen in the inefficiencies of information transmitting between different vertical teams which lowers the productivity and increases the transactional cost of setup, monitoring and enforcement (You et al., 2020).

The complexity of the tasks varies between the functional groups of the supply chain. The production activities in the manufacturing plants are mostly low-complexity sequential activities where the output of the previous activity is the input of the next activity, and the production activities of the construction site are a mixture of pooled and sequential. This would lead to the conclusion that these sets of activities are relatively low on the complexity spectrum. However, when taking a step back and looking at the whole supply chain, the interdependence between the manufacturing plant activities and the construction site activities is very much reciprocal, and the parties rely on each other to reach the common goal of building a finished frame that meets the customer's requirements. The construction site needs the elements to proceed, and if the site falls behind schedule, it affects the production of PCC elements. This complexity complicates the management and scheduling of the activities and grows the need for working synchronized communication.

While the complexity can have a big impact on the transaction cost in the case projects, it is worth noting that the residential building construction is on the lower end of the complexity spectrum when compared to many other types of projects in the construction industry.

Environmental complexity, in this case, can be seen in the unexpected problems of weather conditions, equipment breakdown, or for example, the material supply problems caused by the war in Ukraine. These are often problems that are difficult to predict, but reducing the possible consequences of this complexity might be a worthwhile endeavor.

Asset specificity

Asset specificity can be challenging when looking for suppliers of PCC elements as the number of alternative manufacturers is limited. Some of the things, that affect the number of suitable manufacturers, are the location and the element types. The location of the case site is not too unique, but as the number of PCC elements is substantial and the elements themselves are large-sized and heavy, the shorter the transportation distance, the better. The types of elements might limit the number of potential manufacturers. One example of this, in the case site, is the exterior wall elements where the windows need to be pre-installed to the elements during the manufacturing. The number of already existing manufacturing plants that can produce this kind of product in Finland is minimal. It would require a bid dedication for a plant without the equipment or skills to start manufacturing these kinds of elements.

Asset specificity might not cause significant transaction costs, but it increases the risk of opportunism which can bring up the costs. To limit the impact of asset specificity, the risk of opportunism must be limited by other means.

Frequency

The frequency of the transactions between different parties varies. Fira has seasonal contracts with some of the parties connected with the frame erection, but most of the contracts are project-based. This leads to lower frequencies of transaction that might lead to lower level of cooperation between the contract parties and it could magnify the other transaction cost difficulties such as opportunism or information impactedness.

In the supply chain, there are some longer-term contracts such as the transportation contracts between the PCC manufacturers and their transportation contractors, and Fira and the PCC element installation contractors which might decrease the risk of opportunism, but the benefits do not accrue to the entire supply chain.

Bounded rationality

Bounded rationality increases the transaction costs in decision-making situations. Decisions are made in many places in the case of supply chains, but the procurement phases are especially risky situations for bounded rationality. From the interviews, it came up that there are many situations where procurement might need to be done without having all the needed information. When procuring the PCC elements, the missing information might be caused by the design being behind schedule or by the site representative accidentally leaving out some critical information. The missing information for procurement of the PCC element parts might be caused by changes made to the element or if the element designer does not inform the production about parts that need longer than standard shipping times.

Opportunism

The empirical study did not find any clear instances of opportunism, but there could be identified some characteristics that could increase the risk of opportunism. For example, the task complexity and bounded rationality combination might leave room for individual opportunism. Additionally, in the element design phases, the records of errors that have occurred in the previous phases are not well cataloged. In some cases, the scope of work is not always clear to the contractor, which raises the enforcement cost because of the need to clarify the scope of the job included in the job.

Information impactedness

Information impactedness can either be intentional or unintentional. In the case study, there was no clear indication that there was any intentional information impactedness. However, what could be seen in the interviews were the problems caused by the lack of access to information. Especially the lack of up-to-date schedule information was brought up as a reason for some of the problems that can cause overproduction and inventory. Slow communication, where information sharing is delayed, causes one party to have more information than the others for a while. If all relevant information were automatically shared in real-time, there would be fewer instances where the information impactedness causes problems in the supply chain.

4.3.3 Interpretation of the results from the standpoint of supply chain management

Integration

From the empirical findings the overall level of integration in the supply chain is currently low between the main contractor and the suppliers. The contracts are mainly project-specific, excluding the technical shaft element where the contract is based on a seasonal contract. From the problems identified in the interviews the exchange of information and workflow between different parties is lacking and the main method of transmitting information between the functional groups in the daily operations is via an email or a phone call.

Standardization

The case project includes many instances where the standardization and modularization has been used as an advantage, such as the use of PCC and prefabricated bathroom elements, the use of Firas apartment library etc. All of which are perceived to be useful. But the standardization of the processes is lacking. Each of the supply chain parties have their own internal knowledge of how the process works but there is no common standardization of the process.

Problem solving

The problem solving starts from recognizing and defining the problem to be solved and as can be seen in the empirical portion of the thesis, the supply chains contain lots of different problems. But as can be seen in the problems identified in the interviews, in normal situations the detection of problems is insufficient in some instances. On top of that, even in the case that the problem is detected, it can take too long for the information about it to travel to the correct parties in time to correct the error in time due to problems with the information flow.

Information sharing

As can be detected from the problems identified in the problem lists and the waste analysis, the problems with information sharing and communication is a recurring theme in different parts of the supply chain. Information sharing is connected to many of the different problems that the supply chains face from lacking feedback and coordination to misunderstandings. In the current model, the information flow of the supply chains is divided into parts and the information movement between these parts is mainly manual which often means that the communication does not leave any marks and the information stays with the correspondents.

4.3.4 The connections between waste, transaction cost and the case problems

The problems that the supply chains face are very deeply rooted in the process and the other problems. The literature review showcased how waste and transaction costs are connected to their surrounding settings, how waste can generate more waste, and how the transaction cost difficulties can amplify other consequences of the other transaction cost difficulties. The literature review did not take a stand on how these problems are connected. Figure 4.5. presents how the wastes and the transaction costs are connected under different root-cause categories based on the study's findings. The existence of one cause does not necessarily indicate that the corresponding consequence must happen but rather that it is a possible outcome. In most of the categories, most of the consequences are waste, and most of the transaction cost difficulties are on the side of the causes. Transaction cost difficulties present the phenomena and the circumstances surrounding the problems rather than being concrete problems themselves.

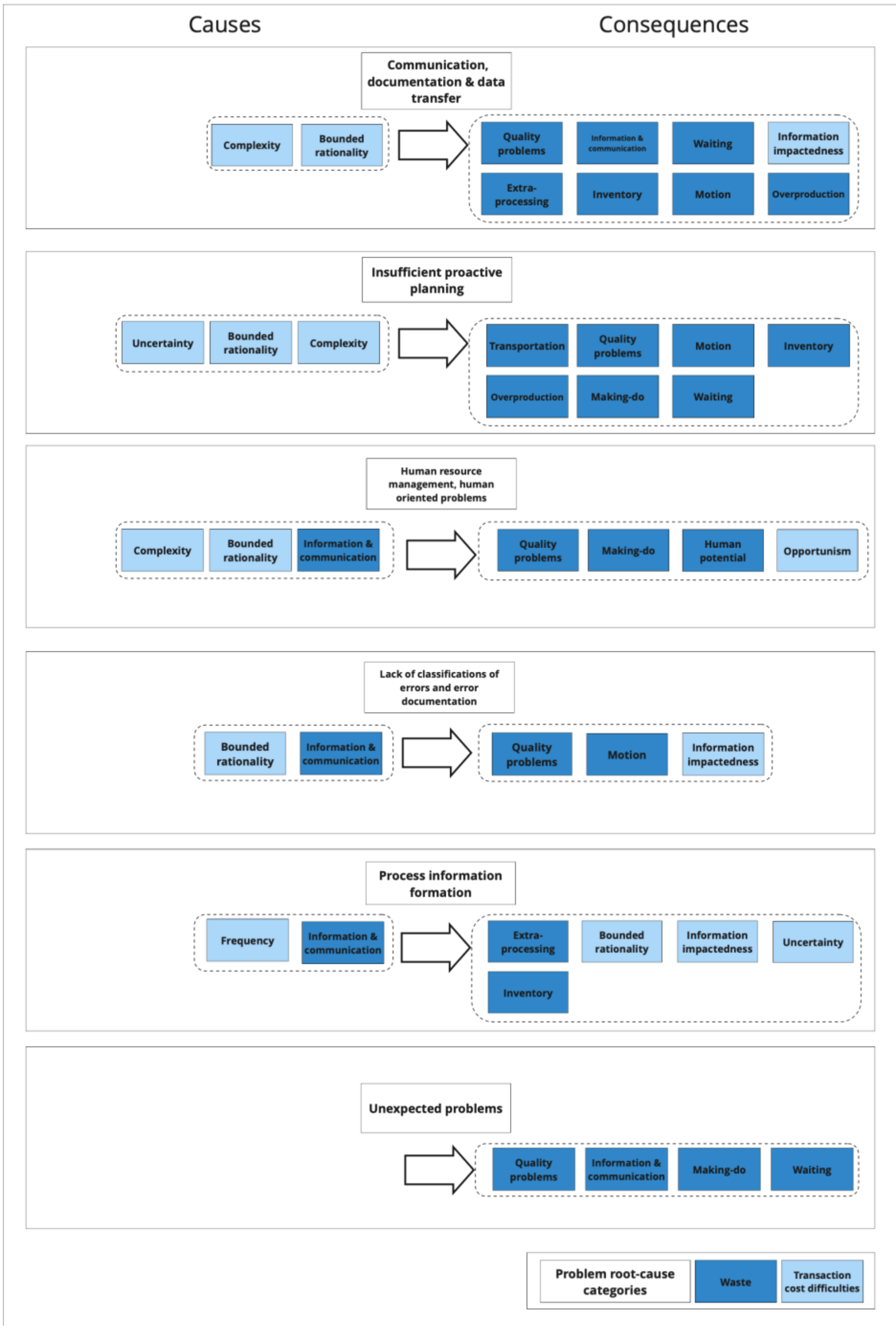


Figure 4.5 The connections between waste, transaction cost difficulties and the root-cause categories.

All the defined PCC supply chain problems' root-cause categories are connected to each other one way or another. Figure 4.6. presents how the categories affect the others with the arrow pointing to the affected category.

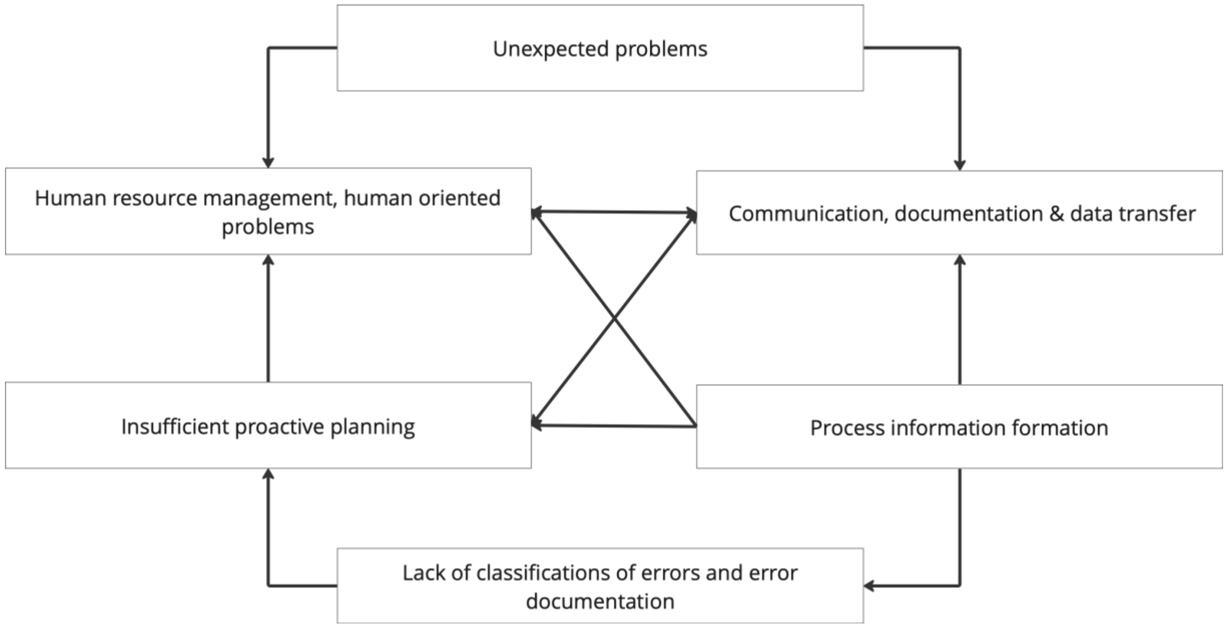


Figure 4.6 The connections between different root-causes.

One notable connection is the lacking knowledge of the supply chain. Currently, it is impossible to form a comprehensive snapshot of the process, which complicates the coordination of different functional groups and obstructs development activities. This lack of process knowledge makes it harder to plan accurately activities and logistics and manage the requirements, which might increase the transaction cost due to the bounded rationality of the decision-making. The lack of process knowledge is also tied to the classification and documentation of errors, as there are no prerequisites to make a comprehensive classification. One of the main reasons why knowledge about the current process is lacking is that the process does not generate information. As such, the logical way to develop the supply chains would be to enable the process to generate information. However, there are many obstacles that make it hard to achieve. One such obstacle is how the construction industry is formed with low maturity levels, high turnover, lack of standardization of procedures, and lack of means to form information automatically. The problems within the process and the industry must be brought to public awareness to change the current situation.

As many of the causes of the problems are deeply rooted in how the construction industry is structured, it would require significant industry-wide changes to fix completely. As such, an important goal would be to raise awareness of these obstacles. While one company cannot change the whole industry, there are other ways to make improvements within the supply chains.

4.4 Proposed actions to better the flow

Many of the problems in the supply chains are deeply rooted into the process and as such are very challenging to take on by just one firm or supply chain. However, some changes can be made to lessen the risks and impacts of the problems. Table 4.10 present the suggested improvement targets and suggested actions based on the problems, waste and transaction difficulties found in the case supply chains.

Table 4.10 The suggestions for improvement.

Development target	Improvement suggestion
Increasing the maturity and integration level, decrease the risk of opportunism by increasing the transaction frequencies.	Longer-term contracts with supply chain parties.
Increasing integration, bettering coordination between different functional groups, decreasing waiting and inventory times.	Common real-time schedule.
Better supply chain management, increasing maturity level.	Common performance monitoring scale.
Improve the process quality, reduce manufacturing errors, improving product quality.	Standardization of process.
Reducing the number of errors caused by human error.	Standardization of job descriptions and orientations.
Continuous improvement	Standardization of error documentation.
Information flow	A more in-depth investigation into how the information flows in the current supply chain.
Information flow	A common plan of how communication, documentation and data transfer should be done.

Communication and other information flow problems were some of the most common problems in all the problem investigations. The fragmentation and the forming of silos in the supply chain can be one explanation for this. To reduce the silo effect, coordination and collaboration between the functional groups is essential. By raising the level of integration, the information will flow more smoothly. The possible courses of action to achieve this could be first to investigate the current situation to understand what needs to change. After the knowledge is gathered, the supply chain parties should come together to figure out common goals for the information flow and the means of implementation that fit into the supply chain. The plan should be made on a concrete level for each work activity, and it should cover how communication is done in different situations, where, how, and what should be documented, and how different parties access any needed information.

For one other method of improving the supply chains, Batista et al. (2019) present that maturity level can be used as a managerial tool to assess the strength, weaknesses, and possible improvement targets. For supply chains, there are five levels of maturity: intra-organizational, inter-organizational, extended inter-organizational, multi-chain, and societal maturity. (Batista et al., 2019) At the moment, the PCC supply chains of the case project are on level 1. intra-organizational maturity where the organizational performance management is handled internally in each different functional group. Achieving higher maturity levels will improve the performance of the supply chain and the next level of maturity is inter-organizational maturity which includes basic partnerships with suppliers and customers and the implementation of performance monitoring tools.

One of the reoccurring themes within the root causes was the problems caused by the lack of skills. To combat this, it is vital to ensure that the person doing the work activities is competent enough to fulfill the job requirements. Inductions and training to make sure the workers have the correct level of skills required for the task help with managing the problems caused by lacking skills. However, if there is no explicit knowledge of what kind of activities the jobs contain, it might be hard to determine what skills are needed. The standardized process could help create standardized jobs and orientations for them. This could also help with the problem of tacit knowledge if the accumulated knowledge could be stored in the process and not left to the employees to remember.

4.5 Synthesis of the empirical findings

The empirical portion of the thesis set out to answer to the second research question about how the current supply network is organized, and what are its main sources of waste, transaction costs and other problems. The structure of the supply network can be viewed from many different perspectives but the value creating activities and the business models were determined to be the most illuminating viewpoints to enable the examination of waste and transaction costs difficulties. To be able to find the waste woven into the process, it is important to know what kind of activities are performed in the supply chain, as waste is defined to be activities that do not form value to the customer. The activities performed in the supply chains were summarized for each of the PCC supply chains in a form of value stream mapping of the current state that are presented in appendices D, E, F ang G. The main structure of the activities in the process was similar between the different manufacturers, but slight variances could be seen in how they manage information, determine the manufacturing schedule, and handle the inventory of the elements.

The business models of the supply chain parties define largely how and why the different activities are carried out inside the process. In the case project, the logic of the offerings and the revenue are similar between the PCC element manufacturers, but some differences can be found in how the contracts are made. The PCC element procurement contracts are mainly short-term project-based contracts where the biggest influencing factor is the price. The transaction costs are connected to the business models in many places, and especially impactful on the transaction costs are the contracts between different parties. In making the contract, the transaction cost difficulties that can cause problems are uncertainty, complexity, asset specificity and bounded rationality. Uncertainty, complexity, and the bounded rationality is a combination where there is not enough knowledge to make effective decisions which cause increasement to the transaction costs.

The short-term contracts used for most of the PCC element manufacturers cause low level frequency of the transactions which might cause problems with opportunism and information impactedness. Without the cooperation between parties, there will be gaps in the information flow along the supply chain.

The different sources of waste, transaction costs and other problems were collected via different means and as a result an analysis of different waste, transaction cost difficulties and root-causes were made. The waste, transaction cost difficulties and the problem categories defined by the empirical study, overlap in many places.

The problem root-cause categories were defined to be communication, documentation and data transfer, insufficient proactive planning, human resource management and human-oriented problems, lack of classification of errors and error documentation, process information formation and unexpected problems. Most reoccurring problem between all the different ways of looking into the problems was found to be the problems with information flow. These problems can be found thorough out the supply chain in many different forms and with many different consequences.

5. CONCLUSIONS

5.1 Review of the main findings

This thesis examines the supply chains of a pre-cast concrete element frame and finds possible problem areas to chart improvement target options. The research was conducted as a qualitative single case study with a literature review of the problem categories to review the current process effectively.

The thesis answers the questions of what kind of wastes and transaction cost sources typically occurs within the supply chain of the pre-cast concrete element frame, how the current supply chain network is organized and what kind of problems it contains, and what changes should be made. The first question was answered through a literature review where lists of the most frequently mentioned wastes and transaction cost difficulties were made. The most commonly referenced wastes were found to be transportation, inventory, quality problems, waiting, overproduction, motion, human potential, making-do, extra processing, and issues with communication and documentation. The transaction cost difficulties that are inspected closer are uncertainty, complexity, asset specificity, frequency, bounded rationality, opportunism, and information impactedness. As a basis for the rest of the thesis, the literature review examined what actions and situations lead to these problems.

The second question was answered through semi-structured theme interviews based on which the current process was mapped in value stream maps, and problems were collected in three different ways, which resulted in comprehensive lists of different kinds of problems that have 170 problems when combined. The list of problems collected on-site points out that many of these problems go through the supply chain unnoticed until they surface somewhere downstream, often only on the construction site. These problems are often not correctly identified, documented, or communicated to the other parties, which leads to the false understanding that the process works better than it does.

The value stream maps, and the interviews were used to find different wastes in the process, and the most commonly occurring waste types across the supply chains were determined to be waiting, motion, communication, and documentation. The transaction cost difficulties were determined to influence the supply chain and should be considered when planning improvements.

The final question was answered based on the compilation of the literature review and the empirical portion of the thesis. The problems were analyzed to find the root causes for each problem so that the improvement measures could be aimed at the correct places. Root-cause categories were summed up into six categories: communication, documentation and data transfer, insufficient proactive planning, human resource management, human-oriented problems, lack of a classification of errors and error documentation, and unexpected problems. The defined categorizations of the root causes were used to determine the suggestions for the development of the supply chains.

5.2 Recommendations for development

The study presents a few useful recommendations for enabling better process flow in the precasted concrete element supply chains. The goals of development targets can be divided into three groups: increasing the integration and the maturity level of the supply chains, the standardization of the process, and better the information flow.

Integration between the supply chain parties will help with the reduction of waste while simultaneously reducing delays and coordinating the activities of the supply chain. To increase the level of integration and the level of maturity, the actions that were suggested were to increase the use of longer-term contracts and use a common schedule and performance monitoring scale. These actions will also positively affect the maturity level of the supply chain, which will improve the performance of the process.

The standardization of the process will help the management of the process, quality control, and continuous improvement, which will improve the process flow. The actions suggested to make steps toward standardizing the process are standardizing the activities, job descriptions, and error documentation.

The information flow is incontestably the most prominent factor in the formation of the problems found in the study. Improving the information flow of the supply chain will have positive impacts on the process flow, and it will aid in achieving the other suggested improvements. The proposed improvement actions are to map out the information flow of the supply chain and then form, together with the different supply chain parties, a transparent plan on how communication, documentation, and data transfer should be implemented in the supply chain. This plan should include how the plan will be implemented and managed.

5.3 Limitations and future research

5.3.1 Evaluation of the study and limitations

The findings of this thesis answers to the three research questions and provides insight into the inner workings of PCC element supply chains. The added value that the study brings forth is the awareness of the current situation and its weaknesses in the scope of the predetermined qualitative research setting. The study also formed a tentative understanding of how waste and transaction costs are formed over the supply chain and the relationship between them and the supply chain.

Due to the nature of the study as an exploratory case study, there are some aspects that might affect the internal and external validity of the research. The inspection of the internal validity must consider the possibility of information, cognitive, and selection bias.

Internal validity

As an exploratory study, the subject matter does not have pre-defined methods and standards for obtaining and analyzing the information in the capacity of this study which might cause informational bias. One possible form of information bias in the case study is recall bias. There is a possibility of recall bias as the information is largely gathered anecdotally, where the observations are based only on what the interviewee or the workshop participants happen to remember during the interview or the workshop. The initial research approach was to study the current supply chains and collect problems of the case supply chains via interviews. However, it was found to be an insufficient method because of the relatively small sample size of the interviews and the possibility of recall bias. The research gave a more comprehensive outlook into the PCC supply chains by supplementing the interviews with the problems found in the workshops and the problems collected on the site. Using multiple sources and methods fits into the nature of qualitative research, giving the results more credibility.

While the interviews were supplemented with other sources, it was still the primary source of information for the VSM, and they had a significant influence on the analysis of the wastes, which should be considered when assessing the reliability of how well they reflect on the general PCC supply chains. The interviewees view the process from certain personal viewpoints due to different motivational, emotional, social influence, and information processing factors, which might affect their reliability and cause cognitive bias to the data.

Cognition bias can also affect the study from the researcher's side. As the interviews were semi-structured, there is a possibility that the previous interviews and preconceptions affected how the interviewers were held. To reduce the number of possible misconceptions and confirmation biases that could affect the interviews, the literature review was compiled before the interviews were held so that the interviews could be held on factual grounds. The complete value stream maps were also checked afterward by the interviews so that they did not contain any factual misinformation.

Selection bias is related to how the participants are chosen for the study. The chosen interviewees were selected to represent the different PCC element manufacturers in the study. However, the final-say on who will participate in the interviews was left to the companies to decide based on availability and willingness to participate. This might cause undercover bias as some members might be underrepresented in the study. There is also the possibility of selection bias in the workshops. The workshops were not planned for this study, and the selection criteria for the participants might differ from what would be ideal for this study. However, the workshop's goals were in line with the study's objectives, and as such, the workshop was accepted as an information source for the study. In the workshops, all the invited parties could not make it to both sessions due to conflicting schedules, which might cause attrition or non-response bias in the collected data as it might not represent the perspectives of all the intended parties.

External validity

The external validity of the chosen case site can be inspected from the viewpoint of transferability or applicability. As a single case study, the representativeness of the study must be questioned. Replicating the exact results from this study could be challenging in other organizations, with different-sized buildings, or at different times. The literature review portion of the study is more generalizable than the empirical portion, as the scope is set to fit around the whole construction industry. The empirical part was originally formed around the frame erection phase of a single case project which left many variables that could make it ungeneralizable to any other case. However, the workshops that were used to supplement the data also made the findings easier to generalize to other precasted concrete element frame erection phases of residential buildings.

Some things that still need to be considered when generalizing the results to other construction projects are the size and complexity of the projects, the structure type of the building, the organizational structures, how the projects are funded, et cetera. The case project was chosen to represent the typical residential building project, and there could be significant differences in the findings if the case study were conducted on a different kind of residential building, for example, a high-rise building. The results of the empirical research cannot be directly generalized to other types of structures as the PCC elements are the main key factor in the study. There might be some similarities in modular construction, but there is no proof of the applicability of the findings between these different situations.

5.3.2 Possibilities for future research

As a qualitative study with multiple different viewpoints, the study opens many other possibilities for future research. The study gave a broad outlook into the PCC supply chain, which could open doors for many more detailed analyses with other research methods and narrower scope. Each problem category determined in this research could prove to be an interesting subject of study, and the classification of the errors could be taken to a functional level so that the standardization of error documentation could be practicable.

The findings of the study conclude that the problems with information flow were the most reoccurring problems in the case project, and as such, the information flow has the most potential for development. The scope of this study was too broad to delve deep into the informational flow, and as such, it would require more research to form a comprehensive understanding of the information flow of the PCC supply chains. Another aspect left on a broader level was the connection between business models and the problems, as it was mainly focused on how the contracts were made. The business model aspect of this study only scratched the surface of the different business models behind the supply chain operations.

The case study concentrated on the vertical aspect of the supply chains, and it dealt with the longitudinal and horizontal aspects only in passing. The longitudinal element could be brought into the study by examining how the operations change over time, for example, by inspecting differences between different floors of the building. Other possible topics that could be investigated in future studies are the improvements that need to be made. Due to the thesis's scope limitations, the supply chain's improvement plan was left vague, leaving an opening for future studies on how these problems should be handled.

As mentioned in the study's limitations, external validity is an aspect that affects how the findings can be applied. The external validity could be tested by replicating the study in different projects and settings.

REFERENCES

Abdel-Galil, E., Ibrahim, A., Alborkan, A., 2022. Assessment of transaction costs for construction projects. International Journal of Construction management 22, 1618–1631.

Ahmad, S., Soetanto, R., Goodier, C., 2019. Lean approach in precast concrete component production. Built Environment Project and asset management 457–470.

Almusharraf, A., Whyte, A., 2016. Task-based defect management: anatomical classification. Built Environment Project and asset management 345–358.

Autry, C., Moon, M., 2016. Achieving Supply Chain integration: Connecting the Supply Chain Inside and Out for Competitive Advantage, 1st ed. Pearson.

Bajjou, M., Chafi, A., 2020. Identifying and Managing Critical Waste factors for Lean Construction Projects. Engineering management journal.

Batista, L., Dora, M., Toth, J., Molnár, A., Malekpoor, H., Kumari, K., 2019. Knowledge management for food supply chain synergies – a maturity level analysis of SME companies. The Management of Operations 995–1004.

Bier, T., Lange, A., Glock, C.H., 2019. Methods for mitigating disruptions in complex supply chain structures: a systematic literature review. International Journal of Production Research 1835–1856.

Costa, S., Carvalho, M., Pimentel, C., Duarte, C., 2023. A systematic Literature Review and Conceptual Framework of Construction Industrialization. ASCE.

Dainty, A., Briscoe, G.H., Millett, S.J., 2001. New perspective on construction supply chain integration. Supply Chain Management 163–173.

Eisner, H., 2021. Problem-Solving: Leaning on the new thinking skills, 1st ed. CRC Press.

Al-Janabi, A. M., Abdel-Monem, M. S., & El-Dash, K. M. (2020). Factors causing rework and their impact on projects' performance in Egypt. Journal of Civil Engineering and Management, 26(7), 666-689.

Emuze, F.A., Saurin, T.A., 2016. Value and waste in lean construction. Taylor & Francis Group, Boca Ration, FL.

Erikson, P.E., Laan, A., 2007. Procurement effects on trust and control in client-contractor relationships. Engineering, construction, and architectural management 387–399.

Gao, N., Chen, Y., Wang, W., Wang, Y., 2018. Addressing Project Complexity: The Role of Contractual Functions. Journal of Management in Engineering.

Godwill, E., 2015. Fundamentals of research methodology: a holistic guide for research completion, management, validation and ethics. Nova Publishers, New York.

Haaskjold, H., Andersen, B., Laedre, O., Aarseth, W., 2020. Factors affecting transaction costs and collaboration in projects. International Journal of Managing Projects in

Business 13, 197–230.

Hall, D., Whyte, J., Lessing, J., 2020. Mirror-breaking strategies to enable digital manufacturing in Silicon Valley construction firms: a comparative case study. Construction Management and Economics. https://doi.org/10.1080/01446193.2019.1656814

Halttula, H., Haapasalo, H., Aapaoja, A., Manninen, S., 2017. Early involvement and Integration in Construction Projects: The Benefits of DfX in Elimination of Wastes. International Journal of Management, Knowledge and Learning 6, 215–237.

Hammersley, M., 2012. What Is Qualitative Research? 1st ed. Bloomsbury Publishing, London.

Hicks, B.J., 2007. Lean information management: Understanding and eliminating waste. International Journal of Information Management 233–249.

Hobbs, J., 1996. A transaction cost approach to supply chain management. Supply chain management 15–27.

Hosseinian, S.M., Tavakoli, M., 2023. Markets, Hierarchies, or Hybrids as Alternative Governance Structures in Construction Contracts: Transaction Cost Economics Analysis. Journal of construction engineering and management 149.

Igwe, C., Hammad, A., Nasiri, F., 2022. Influence of lean construction wastes on the transformation-flow-value process of construction. International Journal of Construction Management 22, 2598–2604. https://doi.org/10.1080/15623599.2020.1812153

Ikuabe, M., Oke, A.E., Aigbavboa, C., 2020. Impact of contractors’ opportunism on construction project transaction costs: Construction professionals’ perception. Journal of financial management of property and construction 125–141.

Jones, G.R., Hill, C.W.L., 1988. Transaction cost analysis of strategy-structure choice. Strategic management journal 159–172.

Kanai, J., Fontanini, P.S.P., 2020. Value Stream map and visilean® for prefabricated concrete panels management, in: Annual Conference of the International Group for Lean Construction (IGLC28). Berkeley, California, USA.

Kinnunen, T., Sahlman, K., Harkonen, J., Haapasalo, H. 2013. Business Ecosystem Perspective to New Product Development. 6–22.

Knotten, V., Svalestuen, F., Hansen, G., Laendre, O., 2015. Design management in the building process – a review of current literature. Procedia economics and finance 120–127.

Koskela, L., Ballard, G., Tommelein, I. 2002. The foundations of Lean construction

Koskela, L., Rooke, J., Bolviken, T., 2013. Which are the wastes of construction?

Laika, M., Heravi, G., Rostami, M., Ahmadi, S., 2022. Improving the Performance of Precast Concrete Production Processes by Simultaneous Implementation of Lean Techniques and Root Cause Analysis. Iranian journal of science and technology. Transaction of civil engineering 2649–2666.

Lavikka, R., Chauhan, K., Peltokorpi, A., Seppänen, O., 2021. Value creation and capture in systemic innovation implementation: case of mechanical, electrical, and plumbing prefabrication in the Finnish construction sector. Construction Innovation 837–856.

Le, P.L., Nguyen, N.T.D., 2022. Prospect of lean practices towards construction supply chain management trends. International journal of lean six sigma 557–593.

Li, H., Arditi, D., Wang, Z., 2015. Determinants of transaction costs in construction projects. Journal of civil engineering and management 548–558.

Lu, D., 2011. Fundamentals of Supply Chain Management. Ventus Publishing ApS.

Martin, K., Osterling, M., 2014. Value Stream Mapping: How to Visualize Work and Align Leadership for Organizational Transformation. McGrw-Hill.

Meng, X., 2019. Lean management in the context of construction supply chains. International Journal of production research 57, 3784–3798.

Ohno, T., 1988. Toyota Production System. Cambridge MA USA.

Ørngreen, R., Levinsen, K., 2017. Workshops as a Research Methodology. Electronic journal of e-Learning 70-.

Patnayakuni, R., Arun, R., Nainika, S., 2006. Relational Antecedents of Information Flow Integration for Supply Chain Coordination. Journal of management information systems 13–49.

Rafique, M.Z., Ab Rahman, M.N., Saibani, N., Arsad, N., 2019. A systematic review of lean implementation approaches: a proposed technology combined lean implementation framework. Total Quality Management 386–421.

Ray, B., Ripley, P., Neal, D., 2006. Lean Manufacturing A Systematic Approach to Improving Productivity in the Precast Concrete Industry. PCI Journal 51, 62–71.

Redeker, G., Kessler, G., Kipper, L., 2018. Lean information for lean communication: Analysis of concepts, tools, T references, and terms. International Journal of Information Management 31–43.

Robson, C., 2002. Real World Research - A Resource For Social Scientists and Practitioners-Researchers, 2nd ed. Blackwell publishing.

Sambasivan, M., Deepak, T.J., Salim, A., Ponniah, V., 2017. Analysis of delays in Tanzanian construction industry: Transaction cost economics (TCE) and structural equation modeling (SEM) approach. Engineering, construction, and architectural management 24, 308–325.

Sarhan, J., Xia, B., Fawzia, S., Karim, A., 2017. Lean Construction Implementation in the Saudi Arabian Construction Industry. Construction Economics and Building 17.

Segerstedt, A., Olofsson, T., 2010. Supply chains in the construction industry. Supply chain management: An international Journal 347–353.

Simon, H.A., 2000. Bounded Rationality in Social Science: Today and Tomorrow. Mind & Society 25–39.

Sisson, J., Elshennawy, A., 2015. Achieving success with Lean: An analysis of key factors in Lean transformation at Toyota and beyond. International journal of lean six sigma 263–280.

Sople, V.V., 2012. Supply chain management. New Delhi.

Speakman, R., Kamauff, J., Myhr, N., 1998. An empirical investigation into supply chain management: a perspective on partnerships. Supply Chain management 53–67.

Speklé, R., 2001. Explaining management control structure variety: a transaction cost economics perspective. Accounting, Organizations and Society.

Talebi, S., Koskela, L., Tzortzopoulos, P., Kagioglou, M., Rausch, C., Elghaish, F., Poshdar, M. 2021. Causes of Defects Associated with Tolerances in Construction: A Case Study. Journal of Management in Engineering. 4.

Teriö, O., Koski, H., Rantanen, E., Ruuhilehto, K., 2003. Runkoprosessin re-engineering. Betonivalmisosarakentamisen suunnittelu-toteutus-prosessin uudistaminen. VTT, Espoo.

Thunberg, M., Rudberg, M., Karrbom Gustavsson, T., 2017. Categorising on-site problems, A supply chain management perspective on construction projects. Construction Innovation 90–111.

Tzortzopoulos, P., Kagioglou, M., Koskela, L., 2020. Lean construction: core concepts and new frontiers.

Wang, W., Chen, Y., Zhang, S., Wang, Y., 2018. Contractual Complexity in Construction Projects: Conceptualization, Operationalization, and Validation. Project Management Journal 46–61.

Williamson, O.E., 1981. The Economics of Organization: The Transaction Cost Approach. The American journal of sociology 548–577.

Womack, J., and Jones. 2003. Lean thinking: banish waste and create wealth in your corporation. Free Press.

You, W., Chen, Y., Gao, Y., You, J., 2020. Understanding the Relationship between Environmental Uncertainty and Transaction Costs in Construction Projects: Moderating Roles of Prior Cooperation Experience and Intragroup Transactions. Journal of Management in Engineering.

Interviews:

Solutions Coordinator. Firm A. 31.1.2023.

Punossuunnittelija. Firm A. 31.1.2023.

Tuotannonsuunnittelija. Firm B. 1.3.2023.

Hankintapäällikkö. Firm D. 9.3.2023.

Runkomestari. Firm D. 9.3.2023.

Tuotantopäällikkö, Firm C. 16.3.2023.

APPENDIX A: PROBLEM LIST 1: A LIST OF OBSERVED PROBLEMS ON CASE SITE

Päivämäärä	Virhetyypin ylätaso	Virhetyyppi	Virhe	Työvaihe	Rakenne	Vakavuus	Hä
2.8.2022	Asennusprosessi	Elementin asennus	Elementti asennettu väärän paikkaan	Elementtiasennus	Sokkelit	3	1.1
8.8.2022	Asennusprosessi	Kalustopuute	Nostokalusto	Elementtiasennus	Kääntökivi	3	
9.8.2022	Asennusprosessi	Valut	Puutteellinen valu	Holvivalu	Holvi	2	
17.8.2022	Asennusprosessi	Elementin asennus	Elementti asennettu liian alas	Elementtiasennus	Ontelolaatta	2	0.0
18.8.2022	Asennusprosessi	Tiedonkulku	Tiedot toimittajalta	Elementtiasennus	Modules	1	
18.8.2022	Asennusprosessi	Tiedonkulku	Tiedot toimittajalta	Elementtiasennus	Modules	1	0.1
18.8.2022	Asennusprosessi	Elementin asennus	Sähköosat	Sähköasennus	Sähköt	2	Jou piik
1.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Elementtiasennus	Ontelolaatta	1	0.3
1.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Elementtiasennus	Ontelolaatta	2	0.4
1.8.2022	Elementtitoimitukset	Puutteet toimituksissa	Nostoelimet puuttuu	Elementtiasennus	Ontelolaatta	2	1.3
2.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Elementtiasennus	Ontelolaatta	1	0.2
2.8.2022	Elementtitoimitukset	Puutteet toimituksissa	Elementti/elementtejä puuttuu	Elementtiasennus	Ontelolaatta	2	On ase har
8.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Kuorman purku	Väliseinä	1	0.1
10.8.2022	Elementtitoimitukset	Puutteet toimituksissa	Nostoelimet puuttuu	Elementtiasennus	Modules	3	1.2
10.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Elementtiasennus	Ontelolaatta	2	0.3
11.8.2022	Elementtitoimitukset	Kuorma ei lastattu asennusjärjestyksessä	Kuorma ei lastattu asennusjärjestyksessä	Elementtiasennus	Ontelolaatta	1	0.0
11.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Elementtiasennus	Ontelolaatta	2	0.1
11.8.2022	Elementtitoimitukset	Kuorma ei lastattu asennusjärjestyksessä	Kuorma ei lastattu asennusjärjestyksessä	Elementtiasennus	Ontelolaatta	2	0.1
11.8.2022	Elementtitoimitukset	Kuorma ei lastattu asennusjärjestyksessä	Kuorma ei lastattu asennusjärjestyksessä	Elementtiasennus	Ontelolaatta	1	0.0
15.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Kuorman purku		1	0.0
16.8.2022	Elementtitoimitukset	Puutteet toimituksissa	Elementti/elementtejä puuttuu	Elementtiasennus	Ulkoseinä	3	As mu
17.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Kuorman purku		1	0.0
18.8.2022	Elementtitoimitukset	Kuorma myöhässä	Kuorma myöhässä	Kuorman purku		3	
16.8.2022	Mittaukset	Mittausvirhe	Mittausvirhe	Mittaus	Ulkoseinä	2	0.2
3.8.2022	Muut toimitukset	Betonitoimitus	Pumppu myöhässä	Holvivalu	Holvi	3	1.4
15.8.2022	Muut toimitukset	Betonitoimitus	Betonitoimitus myöhässä	Holvivalu	Holvi	2	0.2
2.8.2022	Nosturi & sen käyttö	Nosturikuski poissa	Nosturikuski poissa	Elementtiasennus		1	
4.8.2022	Nosturi & sen käyttö	Nosturi rikki	Nosturi rikki	Elementtiasennus		3	0.0
2.8.2022	Suunnitteluvirhe	Elementin mitat	Ontelolaatta liian pitkä	Elementtiasennus	Ontelolaatta	3	1.3
8.8.2022	Suunnitteluvirhe	Korko merkitty väärin	Korko merkitty väärin	Mittaus	Parvekepilari	2	Mit tar kor ase
8.8.2022	Suunnitteluvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym.)	Vemot puuttuu	Elementtiasennus	Ulkoseinä	1	0.0
9.8.2022	Suunnitteluvirhe	Sähkösuunnittelu	Sähkövaraus liian pieni	Sähköasennus	Sähköt	2	Sä jo e ont
11.8.2022	Suunnitteluvirhe	Sähkösuunnittelu	SUR-urat	Elementtiasennus	Ontelolaatta	1	0.0
11.8.2022	Suunnitteluvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym.)	Nostolenkit ei painopisteessä	Elementtiasennus	Ontelolaatta	3	As haa

11.8.2022	Suunnitteluvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym.)	Nostolenkit ei painopisteessä	Elementtiasennus	Ontelolaatta	3	0.0
11.8.2022	Suunnitteluvirhe	Kolot ja varaukset	Kolo tai varaus liian pieni	Elementtiasennus	Porraselementti	3	0.0 0.2
11.8.2022	Suunnitteluvirhe	Sähkösuunnittelu	Sähkövaraus liian pieni	Sähköasennus	Sähköt	1	
15.8.2022	Suunnitteluvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym.)	Teräslenkit liian pitkät	Elementtiasennus	Parvekelaatta	1	0.0
16.8.2022	Suunnitteluvirhe	Kolot ja varaukset	Kolo tai varaus väärässä paikassa	Elementtiasennus	Vemot	2	
17.8.2022	Suunnitteluvirhe	Elementin mitat	Valulipat vääränlaiset	Pystysaumapumppaus	Pystysaumat	2	
17.8.2022	Suunnitteluvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym.)	Vemot väärällä puolella seinää	Elementtiasennus	Vemot	2	0.0
18.8.2022	Suunnitteluvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym.)	Nostolenkkien puutteet	Elementtiasennus	Parvekepilari	2	0.1
18.8.2022	Suunnitteluvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym.)	Vemot väärässä paikassa	Elementtiasennus	Vemot	2	
2.8.2022	Työmaalogistiikka	Työmaa-alue ja toimitukset	Liikaa samanaikaisia toimituksia	Elementtiasennus	Ontelolaatta	2	0.2
2.8.2022	Työmaalogistiikka	Työmaaiikenne ja toimitukset	Työvaiheet toistensa tiellä	Elementtiasennus	Ontelolaatta	2	0.0
9.8.2022	Työmaalogistiikka	Työmaaiikenne ja toimitukset	Työvaiheet toistensa tiellä	Elementtiasennus	Hormielementti	2	0.0
9.8.2022	Työmaalogistiikka	Työmaaiikenne ja toimitukset	Työvaiheet toistensa tiellä	Elementtiasennus	Väliseinä	2	0.2
18.8.2022	Työmaalogistiikka	Työmaaiikenne ja toimitukset	Liikaa samanaikaisia toimituksia	Elementtiasennus	Moduls	1	0.0
18.8.2022	Työmaalogistiikka	Asennustarvikkeet	Nostoliinat	Elementtiasennus	Moduls	2	0.0
1.8.2022	Valmistusvirhe	Eristeet	Eristeiden mitat virheelliset	Elementtiasennus	Sokkelit	1	0.0
2.8.2022	Valmistusvirhe	Elementin mitat	Ontelolaatta liian leveä	Elementtiasennus	Ontelolaatta	2	0.5
2.8.2022	Valmistusvirhe	Kolot ja varaukset	Kolo tai varaus liian pieni	Elementtiasennus	Ontelolaatta	2	0.0
4.8.2022	Valmistusvirhe	Eristeet	Eristeiden mitat virheelliset	Elementtiasennus	Sokkelit	1	0.2
4.8.2022	Valmistusvirhe	Eristeet	Eristeiden mitat virheelliset	Elementtiasennus	Sokkelit	2	0.1
4.8.2022	Valmistusvirhe	Elementin merkinnät	Elementin merkintä virheellinen	Elementtiasennus	Ulkoseinä	3	Se ase
8.8.2022	Valmistusvirhe	Eristeet	Eristeiden mitat virheelliset	Elementtiasennus	Sokkelit	1	0.0
8.8.2022	Valmistusvirhe	Eristeet	Eristeiden mitat virheelliset	Elementtiasennus	Ulkoseinä	2	0.0
8.8.2022	Valmistusvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym)	Vemot puuttuu	Elementtiasennus	Vemot	1	0.0
9.8.2022	Valmistusvirhe	S-pistekolot ja s-tappiraudat	S-tappiraudat liian pitkät	Elementtiasennus	s-tappi	1	0.0
9.8.2022	Valmistusvirhe	Elementin mitat	Elementti liian matala	Elementtiasennus	Väliseinä	3	Pit
10.8.2022	Valmistusvirhe	Elementin mitat	Varaus väärällä puolella	Elementtiasennus	Massiivilaatta	3	0.1
10.8.2022	Valmistusvirhe	Kolot ja varaukset	Kololaatan kolo liian lyhyt	Elementtiasennus	Modules	3	0.0
10.8.2022	Valmistusvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym)	Nostolenkkien urissa betonia	Elementtiasennus	Ontelolaatta	1	0.0
10.8.2022	Valmistusvirhe	Kolot ja varaukset	Kolo tai varaus väärässä paikassa	Sähköasennus	Sähköt	3	Sä ase voi koh
11.8.2022	Valmistusvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym)	Nostolenkkien urissa betonia	Elementtiasennus	Ontelolaatta	1	0.0
11.8.2022	Valmistusvirhe	Elementin merkinnät	Elementin merkintä virheellinen	Elementtiasennus	Ontelolaatta	2	0.0
15.8.2022	Valmistusvirhe	Kolot ja varaukset	Kolo tai varaus liian pieni	Elementtiasennus	Parvekelaatta	2	0.0
15.8.2022	Valmistusvirhe	Kolot ja varaukset	Kolo tai varaus liian pieni	Elementtiasennus	Parvekelaatta	2	0.0

15.8.2022	Valmistusvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym)	Nostoelimessä betonia	Elementtiasennus	Parvekelaatta	1	0.0
16.8.2022	Valmistusvirhe	S-pistekolot ja s-tappiraudat	S-pistekolon sijainti väärä	Elementtiasennus	S-tappi	1	0.0
16.8.2022	Valmistusvirhe	Kolot ja varaukset	Juotosputki tukossa	Elementtiasennus	Ulkoseinä	1	0.0
16.8.2022	Valmistusvirhe	Eristeet	Eristeiden mitat virheelliset	Elementtiasennus	Ulkoseinä	1	
18.8.2022	Valmistusvirhe	Kolot ja varaukset	Kolo tai varaus liian pieni	Elementtiasennus	Ontelolaatta	1	
18.8.2022	Valmistusvirhe	Sähköputket, rasiat ja muut sähkövaraukset	Sähkörasia liian syvällä	Sähköasennus	Sähköt	2	
18.8.2022	Valmistusvirhe	Sähköosat	Sähkörasia liian syvällä	Sähköasennus	Sähköt	2	Jou piik lait uud
27.8.2022	Valmistusvirhe	Tarvikkeet (nostolenkit, vemot, vaijerilenkit ym)	Vemot rikkoutuivat tai irtosivat	Elementtiasennus	Vemot	3	Se har tila voi vaa

APPENDIX B: THE PROBLEM LIST 2: PROBLEMS IDENTIFIED BY INTERVIEWEES

Nro	Havaittu ongelma	Haastateltujen arvioima syy ongelmalle
1.1	Puutteellinen kommunikaatio osapuolten välillä	Osapuolet keskittyvät tekemään omat työnsä, eivätkä huomioi, miten asioiden kommunikaatio helpottaisi muiden työtä.
1.2	Muutokset elementteihin tulevat liian myöhään	Muutostarve huomataan liian myöhään
1.3	Tuotanto myöhästyy, kun erikoisosat, joilla on pitkät toimitusajat huomataan liian myöhään	Erikoisosat huomataan liian myöhään.
1.4	Työmaa ei anna tarpeeksi palautetta tehtaalle. Palautteen avulla voitaisiin korjata virheitä tai parantaa toimintaa.	
1.5	Työmaa ei ilmoita virheistä elementeissä tarpeeksi ajoissa, jotta seuraaviin elemenetteihin ehdittäisiin tehdä korjauksia ennen valmistusta. Virheet voivat toistua eri kerroksissa.	Työmaa ei anna palautetta ajoissa.
1.6	Elementtisuunnittelija tekee muutoksia elementtiin ja poistaa samalla vanhan version ERPistä. Uuden korvaavan elementin GUID on eri kuin aiemman version. Elementti saatetaan valaa kahdesti, jos tuotanto ei huomaa muutosta.	Elementin tiedot kahdesti järjestelmässä.
1.7	Komponenttien nimeäminen eroaa tavallisesta nimeämisestä	Suunnittelijan kokemukseen tai perehdytyksen puute
1.8	Väärin toteutettu tai pitkittynyrt varastointi voi aiheuttaa laatu ongelmia elementtiin	Elementit varastoidaan väärin.
	Ontelolaatat: suunnittelu	
Nro	Havaittu ongelma	Haastateltujen arvioima syy ongelmalle
2.1	Elementtisuunnittelijoille ei kerrota, jos rakennesuunnittelija tekee muutoksia elementteihin.	Suunnitelmiin tehdään muutoksia hiljaisesti.
2.2	Elementtisuunnittelun lähtötiedot eivät ole oikein	Keskeneräinen työ aikaisemmassa työvaiheessa.
2.3	Rakennesuunnittelija ei välttämättä ota kaikkia elementtien ominaisuuksia huomioon	Elementtisuunnittelijat liittyvät mukaan vasta suunnittelun loppuvaiheessa
2.4	Toisiaan vastaavat komponentit, jotka on nimetty eritavalla lisäävät työmäärää.	Komponenttien standardoinnin puute
2.5	Tietomallien tietosisältö on väärä, vaikka kuvana tiedosto näyttää oikealta	Tietomallien käytön ymmärtäminen saattaa olla puutteellista.
2.6	Työmaa kysyy lupaa korjaustoimenpiteisiin vasta korjauksien jälkeen	Aikataulupaineet
	Hormit	
Nro	Havaittu ongelma	Haastateltujen arvioima syy ongelmalle
3.1	Elementtisuunnittelun lähtötiedot eivät tule tarpeeksi ajoissa LVIS suunnittelijoilta, mikä voi lisätä virheitä elementtisuunnittelussa.	
3.2	Elementin asennus epäonnistuu ja välikappaleet menevät ryttyyn	Asentajat eivät seuraa valmistajan asennusohjeita (ei liity tähän case kohteeseen.
3.3	Työmaa on myöhässä aikataulusta, jolloin elementtejä ei voida toimittaa, mikä johtaa varastointiin.	
3.4	Kupariputket joudutaan vaihtamaan, jos elementit ovat liian pitkään varastossa ulkona	Työmaa on aikataulusta jäljessä
3.5	Materiaalin saatavuus ongelmat	Ongelmat toimitusketjuissa. Esim. Ukrainan sota
3.6	Työmaalta voi olla hankala saada paikkaansa pitävää aikataulua	Työmaalta lähetetään vanhentunut aikataulu tai sieltä ei saa vastausta.
3.7	Reklamaatiot tehdään liian myöhään	Reklamaatio tehdään kun kaikki elementit asennettu
3.8	Elementit vaurioituu kuljetuksen aikana	Kuljettaja ei laita tarvittavia kulmasuojia paikoilleen
3.9	Kommentit elementeistä tulevat liian myöhään	
3.10	Joskus reklamaatioissa käytetään asunnon numeroita elementtitunnuksien sijaan.	
3.11	Elementtisuunnittelun virheet ja puutteet	Kiireinen aikataulu
3.12	Reklamaatioita tehdään tarpeettomasti	Kokemuksen puute. Esim kesäharjoittelijat
3.13	Elementtisuunnittelijat eivät aina huomaa, että samassa kohteessa on useampi elementti samalla tunnuksella. Voi aiheuttaa pieniä myöhästyksiä, kun joudutaan selvittämään, mikä elementti pitää kuljettaa.	Kokemuksen puute.
	Työmaa: työnjohto	
Nro	Havaittu ongelma	Haastateltujen arvioima syy ongelmalle
4.1	Tauot nostoissa	Sääolosuhteet, esteet nostojen tiellä
4.2	Toiset urakoitsijat estävät elementtien asennuksen	Toisten urakoitsijoiden tekemisiä ei ole otettu huomioon työn suunnittelussa. Esimerkiksi kaivinkone voi olla elementtirekan tiellä
4.3	Aikataulussa ei ole joustavuutta, jolloin keskeytyksien jälkeen aikataulun kiinni saaminen voi olla hankalaa	Töitä saattaa jäädä kesken vuoron päätteeksi
4.4	Holvivaluun tarvittavan betonin määrä vaihtelee suuresti kerroksien välillä, minkä takia betonia voi olla liian vähän tai sitten sitä jää ylitse (+/-2 tonnia)	Tarvittavan betonin määrä riippuu paljon siitä miten elementit on saatu asennetua
4.5	Nosturia ei voida käyttää	Nosturin kuluvat osat tarvii vaihtoa
4.6	Onnettomuudet pysäyttävät työt useaksi tunniksi ja hidastavat työtä	
4.7	Sääolosuhteiden takia elementtikuljetus saattaa olla myöhässä	Elementtirekka jää jumiin lumeen, mikä voi kestää puolipäivää.

4.8	Holvivalu tai pystysauma pumppaus voi estyä sääolosuhteiden vuoksi.	Sää on liian kylmä tai kostea. Aikataulu voi myöhästyä puolipäivää tai päivän
4.9	Elementtiasentajien kokemattomuus	Elementtiasentajat eivät välttämättä ole asentaneet kyseisiä elementtejä aikaisemmin. Uudenlaisista elementeistä tai moduuleista olisi hyvä järjestää malliasennus. Asennus ohjeet voi olla tehty ideaalitilanteelle, joka ei ota huomioon työmaaolosuhteita. Esimerkiski kylpyhuonemoduulit on hankala asentaa jos niiden alla olevat ontelolaatat on kuperia tai koveria.
4.10	Erilaiset ajatusmallit työnjohdon ja aliurakoitsijoiden välillä hankaloittaa yhteistyötä	
4.11	Elementtien nimeäminen ei ole loogista	Seinäelementtien nimeäminen ei seuraa tavallista logiikkaa. Elementtejä on kopioitu alemmista kerroksista ja niiden tunnukset ovat vastaavanlaisia keskenään, mutta ei muiden kanssa.
4.12	Virhe toistuu kerroksesta toiseen	Kaikki linjan elementit olivat jo valettu kun ensimmäinen elementti asennettiin, koska elementit olivat kopioita toisistaan. Toisena esimerkkinä lepotasolaatta, joka ei sopinut porraselementtiin.
4.13	Turvallisuus ja laatustandardit eivät ole samalla tasolla pääurakoitsijan ja aliurakoitsijoiden välillä	Motivaation puute. Haluttu laatutaso ei ole tarkennettu selkeästi sopimuksissa. Aliurakotisijoilla ei ole muuta ulkoista motivaatiota tehdä laadukasta työtä
4.14	Keskeneräinen työ	Aliurakoitsijoiden motivaation puute.
	Hankinta	
Nro	Havaittu ongelma	Haastateltujen arvioima syy ongelmalle
5.1	Työmaalta saatujen lähtötietojen taso vaihtelee projektikohtaisesti	
5.2	Tarjouspyynnön valmistelu on paljon työläämpää, jos suunnittelu on vielä kesken	Elementtien pitkät toimitusajat vaatii, että tarjouspyynnöt lähetetään hyvin aikaisessa vaiheessa projektia
5.3	Suunnitelmien tarkkuustaso ei ole halutulla tasolla	Tarvittua tarkkuustasoa ei ole vaadittu aikaisemmin
5.4	Sopimusten sisältö saattaa vaihdella sopimusten välillä	Sopimukset on tehty word pohjalle, mikä mahdollistaa vaihtelua
5.5	Jos asuntojen välillä on paljon vaihtelua, hankinta on hankalampaa.	
5.6	Elementtien kustannukset kasvavat ulkoisista syistä	Esimerkiksi covid-19, epävakaa markkinatilanne, tilaajasta aiheutuvat muutokset
	Seinä ja laatta elementit	
Nro	Havaittu ongelma	Haastateltujen arvioima syy ongelmalle
6.1	Rikkoutuneiden elementtien syitä on hankala selvittää jälkikäteen	
6.2	Ikkunat eivät saavu tehtaalle samaan tahtiin kuin elementtejä valmistetaan	Ikkunat toimitetaan kerroksittain, mutta elementtejä valmistetaan linjoittain, koska samoja muotteja halutaan hyötykäyttää mahdollisimman paljon tekemällä samankaltaisia elementtejä peräkkäin. Elementtivalmistajan ja ikkunatoimittajan voisi olla hyvä koordinoida aikataulujaan paremmin
6.3	Tiilitoimittaja ei toimittanut julkisivutiilejä ajallaan. Tiilit joudutaan kiinnittämään työmaalla jälkikäteen.	Tiilitoimittaja ei täyttänyt sopimustaan. Syynä ehkä se, että tiilivalmistaja on myynyt ylikapasiteettinsa.
6.4	Elementtisuunnittelu on keskeneräinen. Esim. puuttuvia mittoja tms.	
6.5	Elementtien tunnukset eivät ole loogisia	Tekla määrittelee elementeille tunnukset
6.6	Suunnittelija ei ilmoita erikoisosista etukäteen.	Suunnittelija ei ole osana elementtien valmistajan firmaa ja tätä ilmoittamista ei ole määritelty sopimuksessa
6.7	Reiät elementeissä ovat liian pieniä suunnitelmissa. Esim. IV-putket eivät mahdu työmaalla paikoilleen	Elementtisuunnittelija ei ota huomioon valmistus toleransseja tai asennus marginaaleja.
6.8	Suunnittelu ei optimoi materiaalin käyttöä	Käytetään liikaa tai liian vahvoja materiaaleja (varmuuden puolella olevia), jotta suunnittelu on helpompaa
6.9	Elementin pinnan käsittely ei ole määritelty sopimuksessa.	Pintamaali ei ole vielä tiedossa, jolloin pinnan käsittely ei ole tiedossa. Voisiko pintamaalit ja muut materiaalit standardoida?
6.10	Elementtien kuvat voivat erota materiaaliluetteloista, mikä hankaloittaa osien tilaamista.	Jos elementtisuunnittelija tekee muutoksia malliin, tiedot eivät välttämättä päivity kaikkiin paikkoihin. Syynä voi olla keskeneräiset teklamallit, jotka eivät sisällä kaikkia tietoja ja vaativat tarkempien detaljien olevan eri paikassa. Teklamallin valmiiksi tekeminen veisi aikaa ja sitä ei ole määritelty sopimuksessa.
6.11	Suunnitelmat ovat joskus tehty hankalammiksi toteuttaa kuin olisi tarpeellista	Elementtisuunnittelijat eivät ymmärrä valmistusprosessia.

APPENDIX C: THE PROBLEM LIST 3: PROBLEMS IDENTIFIED IN WORKSHOPS

Seuraus	Ongelma	Syy
A1.1.Elementti ei mene paikoilleen	A1.1.1. Väärä elementti	A1.1.1.1. Tunnukset ristissä, väärä elementti nosturissa
	A1.1.2 Virheellinen detalji	A1.1.2.1.Monia syitä: suunnitteluvirhe, kommunikaatio virhe, valmistusvirhe,
	A1.1.3. Elementit väärässä kohdassa	A1.1.3.1. Kumuloitunut toleranssi, toleranssi loppu
	A1.1.4. Elementti vaurioitunut	A1.1.4.1. Nostoelin vaurioitunut, elementti vaatii korjausta
A2.1.Elementin asennus keskeytyy	A2.1.1. Elementissä virhe ja ei tiedetä miten elementti tulisi korjata.	A2.1.1.1. Ei osata nimetä vastuuosapuolta, korjaussuunnitelman teko vie aikaa/kommunikaatio suunnittelijan kanssa ohjeiden saamiseksi vie aikaa
A3.1. Elementtiasennetaan väärään paikkaan/väärinpäin	A3.1.1. Ei tietoa, miten elementti tulisi asentaa	A3.1.1.1. Puuttuvat elementtitunnukset, piilossa oleva tunnus, inhimillinen erehdys johtuen symmetrisyydestä
A4.1.Elementtiä ei löydetä työmaalla	A4.1.1. Elementtien fakitusta ei dokumentoida	A4.1.1.1. Työmaalla ei sähköistä tietoa varastoinnista
	A4.1.2. Elementtiä ei tunnisteta (ei tunnistetietoa)	A4.1.2.1. Elementistä puuttuu tunnus / ei päästä tarkistamaan tunnistetietoa tai tunnistetta ei erota
	A4.1.3. Elementti puuttuu (ei saapunut työmaalle)	A4.1.3.1. Väärä toimitusosoite / inhimillinen virhe / väärä elementti toimitettu oikean tilasta
	A4.1.4. Puuttuu elementin saapumistieto	A4.1.4.1. Työmaalla ei sähköistä vastaanottoa eikä varastointia
A5.1. Elementtien varastointi vie työaikaa	A5.1.1. Elementtejä varastoidaan työmaalla	A5.1.1.1. Elementtejä bufferina/elementtejä tuotu liikaa työmaalle
A6.1. Elementille ei ole paikkaa	A6.1.1. Toimitettu ja/tai valmistettu ylimääräisiä elementtejä	A6.1.1.1. Tietomallikohde: muutostilanne, suunnittelija tehnyt muutoksen (kiven id muuttuu), tehdas lukee sisälle ja vanhaa ei poisteta, joten työmaa saa tuplaelementin
A7.1. Elementtien virheitä ei huomata vastaanotossa	A7.1.1. Vastaanottotarkastusta ei tehty kunnolla	A7.1.1.1. Kiireinen aikataulu / Elementti varastoidaan ja virhe huomataan vasta asennusvaiheessa
	A.7.1.2. Virhe huomataan, mutta tietoa ei saada talteen	A7.1.2.1. Vastaanottotarkastusta ei määritelty elementtikohtaisesti / tarkastajalla puuttuu hiljaista tietoa tai tarkastajalla motiivi/inessiivi tarkastukseen / dokumentaatio työlästä
A8.1. Seuraavien työvaiheiden työmäärä kasvaa	A8.1.1. Elementin varaus tukossa	A8.1.1.1.Ei mahdollista todentaa kuin paikalla, Virhe ilmenee vasta asennuksen jälkeen, kun virhe kumuloitunut tai asennettava mittatarkka osa tai tuote paljastaa virheen (toleransseissa, mutta tarvitsee esioikaisun)
A9.1. Elementti joudutaan korjaamaan (aiheuttaa lisääntynyttä piidioksidi altistusta)	A9.1.1. Elementissä on pintavika	A9.1.1.1. Valmistusvirhe (muotinpurku/muottiöljy tms), palautteen puutte virheistä
A10.1. Ei tietoa asennuksista ja korjauksista ja siitä milloin voi siirtyä seuraavaan	A10.1.1. Puutteellinen tilannekuva työmaantilanteesta	
A11.1.	A11.1.1. Vikoja ei saada kiinni kerroksien tarkastuksissa	A11.1.1.1. Tarkastus tehdään paikanpäällä silmämääräisesti ja merkitään spraylla. Tarkistus kaupankäyntiä, jossa maksaja merkitään ja ohjeistetaan spraylla

B1.1. Tieto kuorman myöhästymisestä tulee vasta kun se myöhästyy	B1.1.1. Puuttuva tilannekuva kuljettajan aiheuttamasta viiveestä	B1.1.1.1.Sää, liikenne jne.
B2.1. Kuorma tehdään myöhässä, lähtee liikkeelle myöhässä	B2.1.1. Nosturi tms. kalusterikot	
	B2.1.2. Työmaalla ruuhkaa	B2.1.2.1.Työmaan aikataulutus pettää ((tieto aikataulun myöhästymisestä tulee myöhässä?))
	B2.1.3. Vaillinainen kuorma	
	B2.1.4. Puuttuva kuormajärjestys	
B3.1. Työmaa ei saa elementtiä	B3.1.1. Elementti hukassa; ei mukana kuormassa	B3.1.1.1. Kiire lähteä viemään kuormaa
B4.1. Elementti joudutaan varastoimaan työmaalle, ei mahdollista välittää tietoa varastopaikasta, varastopaikka satunnainen, voi aiheuttaa esteen muille töille	B4.1.1.Kuormassa ylimääräinen kivi	B4.1.1.1. Elementti otettu kyytiin, jotta saadaan täysi kuorma
B5.1. Elementtejä pitää purkaa väliaikaisesti	B5.1.1.Elementit kuormassa asennukseen nähden väärässä järjestyksessä	B5.1.1.1. Elementtien geometria: koko vaikuttaa siihen voidaanko kivet pinota päällekäin

C1.1. Elementtiasennuksessa tulee ilmi ongelmia, jotka aiheutuneet varastoinnista	C1.1.1. Varastoinnin aikana syntyvät ongelmat, kuten taipumat	C1.1.1.1. Työmaa ei noudata varastointi ohjeita, ongelmia ei välttämättä huomata kuormauksessa tai vastaanotossa
C2.1.	C2.1.1. Varastointiongelmien kustannuksia ei tiedetä	C2.1.1.1. Prosessi ei tuota tietoa varastointiongelmista

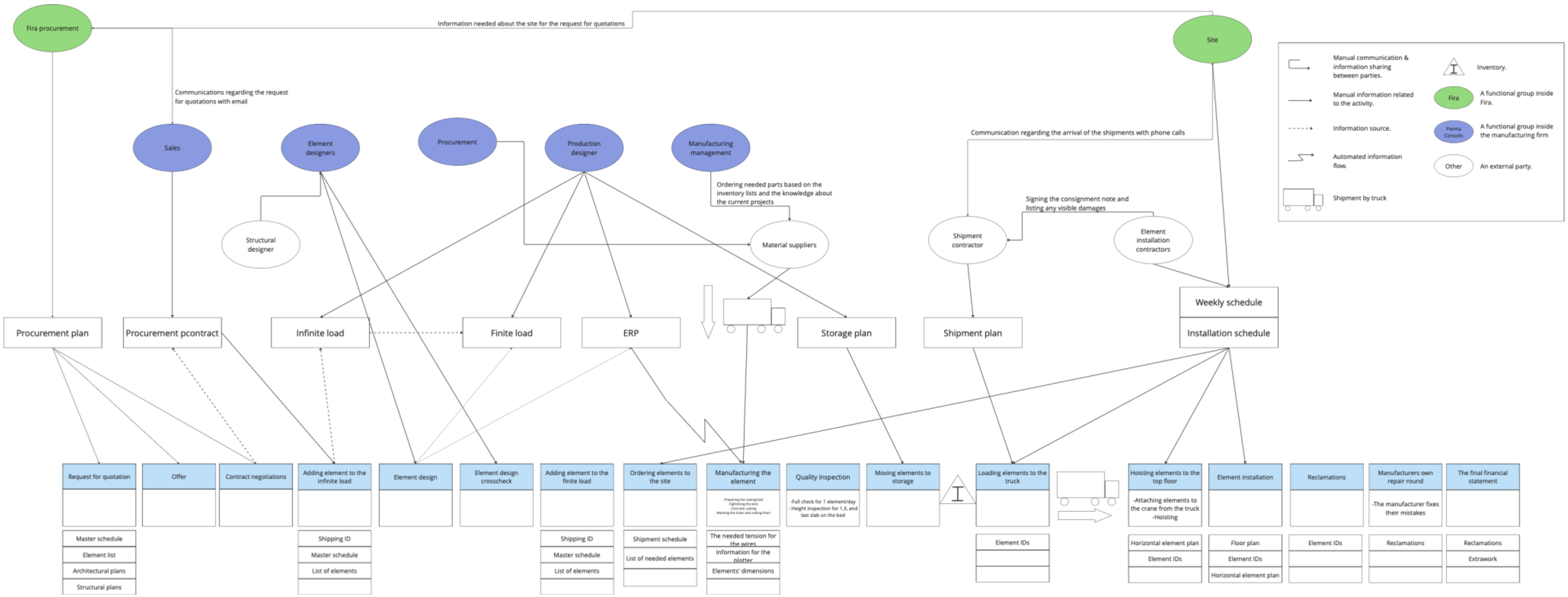
D1.1. Työmaan aikatauluviivästykset eivät tule elementtivalmistajan tietoon, ei voida huomioida myöhästymisiä valmistusaikatauluissa.	D1.1.1.Työmaa tilannekuvan puuttuminen	D1.1.1.1. Ei yhteistä sähköistä tilannekuvaa, työmaa ei ilmoita myöhästymisistä
D2.1.	D2.1.1. Julkisivuelementin julkisivu materiaali muuttuu sopimuksen teon jälkeen	D2.1.1.1.
D3.1. Muutos pitää päivittää moneen eri suunnitelmaan	D3.1.1.Muutokset elementteihin tulevat liian myöhään	D3.1.1.1. Heijastuu muualta. Muutokset huomataan liian myöhään.
Ongelmia tuotannossa. Mahdollisesti elementin tiedot kahteen kertaan järjestelmässä.	D4.1.1.Elementin GUID muuttuu	D4.1.1.1. Kun suunnittelija poistaa ja lisää uuden elementin. Suunnittelija ei ilmoita muutoksista.
D5.1.Värivirheet elementeissä	D5.1.1.	D5.1.1.1. Elementit valettu eripäivinä ja virheet huomataan vasta työmaalla asennuksen yhteydessä.
D6.1. Valmistetaan kuvien mukaisesti virheellinen elementti	D6.1.1. Mittavirhe detaljissa	D6.1.1.1. Alkupään ongelmat heijastuvat tuotantoon. Elementtisuunnittelija voisi olla aikaisemmin osallisena prosessissa ja tarkastaa lähtötiedot
D7.1. Työntekijän osalta oikea ja riittävä tieto puuttuu	D7.1.1. Puuttuu selkeä vaatimusten hallinta, kuten tietosisältö vaatimukset	D7.1.1.1.Ei tiedetä miten prosessi toimii, työntekijän osaaminen?

E1.1. Varaus puuttuu tai on vääränlainen	E1.1.1. Reikäkierto ei toimi	E1.1.1.1. Muutos tilanteet ongelmallisia, kun ei nähdä riippuvaisuuksia
E2.1. Ongelmia tuotannossa. Mahdollisesti elementin tiedot kahteen kertaan järjestelmässä.	E2.1.1. Elementin GUID muuttuu	E2.1.1.1. Kun suunnittelija poistaa ja lisää uuden elementin. Suunnittelija ei ilmoita muutoksista.
E3.1. Ongelmat siirtyvät toimitusketjun loppupäähän, jossa korjaukset ovat kalliimpia ja työläämpiä	E3.1.1. Suunnittelun ja hankinnan ongelmat heijastuvat loppupäähän toimitusketjua	E3.1.1.1. Ongelmia ei havaita ajoissa vaan usein huomataan vasta työmaalla asennusvaiheessa
E4.1. Puutteelliset/virheelliset suunnitelmat siirtyvät eteenpäin kohti tuotantoa	E4.1.1. Suunnitteluaikataulu on liian tiukka, suunnittelijat eivät ehdi tarkistaa kuvia	E4.1.1.1. Puutteellinen vaatimusten hallinta, puuttuu virtautettu suunnittelu, tilannetiedon puute

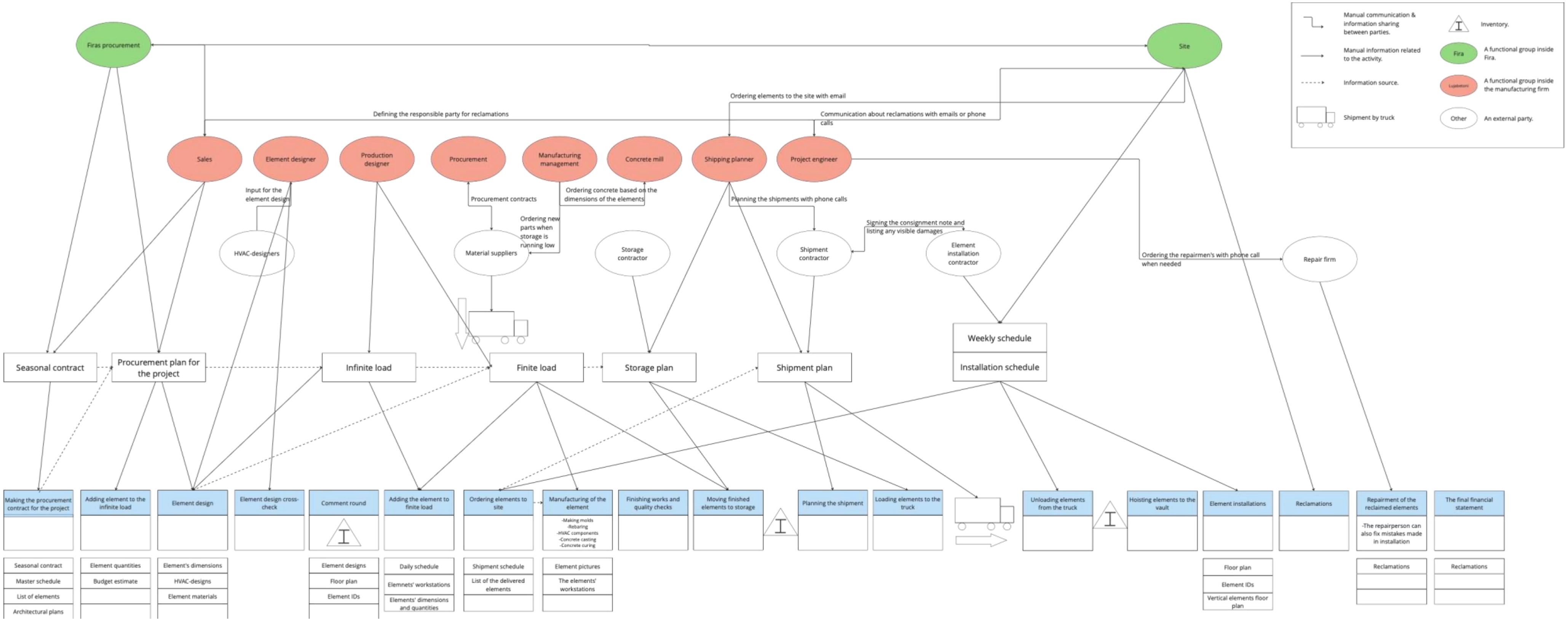
E5.1. Puutteelliset lähtötiedot vaikuttavat muiden tekemisiin ja päätöksiin	E5.1.1. Lähtötiedot uupuvat, ovat puutteelliset	E5.1.1.1. Puutteellinen vaatimusten hallinta, vakio detaljien puute
E6.1.	E6.1.1. Muutokset eivät tule kaikkien tietoon, hankintaan tuotantoon urakoitsijalle.	E6.1.1.1. Ei ole läpinäkyvä prosessi/ puutteellinen tilannekuva
E7.1. Puuttuva tieto voi sijaita eri paikassa, jolloin tietojen muutos ei päivity kaikkialle	E7.1.1. Tietosisältö tietomallissa uupuu.	E7.1.1.1. Puutteellinen vaatimusten hallinta

F1.1.	F1.1.1. Elementtien määrät muuttuvat sopimuksen teon jälkeen	
F2.1.	F2.1.1. Tarjousaineiston määrätiedot heittää / laatu heittää	
F3.1. Hankinta joudutaan tekemään vaillinaisilla tiedoilla	F3.1.1. Hankinnasta tieto/muutokset eivät virtaa suunnitteluun ja suunnittelusta hankintaan.	
	F4.1.1. Suunnittelu ei vielä ole tarpeeksi pitkällä, jotta tarkkoja tietoja voitaisiin tietää	F4.1.1.1.Elementtien pitkien toimitusaikojen takia elementtihankinnat tehtävä ajoissa, suunnittelun aikataulutus ei ehkä huomioi pitkiä toimitusaikoja
F4.1	F5.1.1. KVR urakan haaste tarjouspyynnön ja tarjouksen tekoon on liian vähän, pv/viikko/2.	

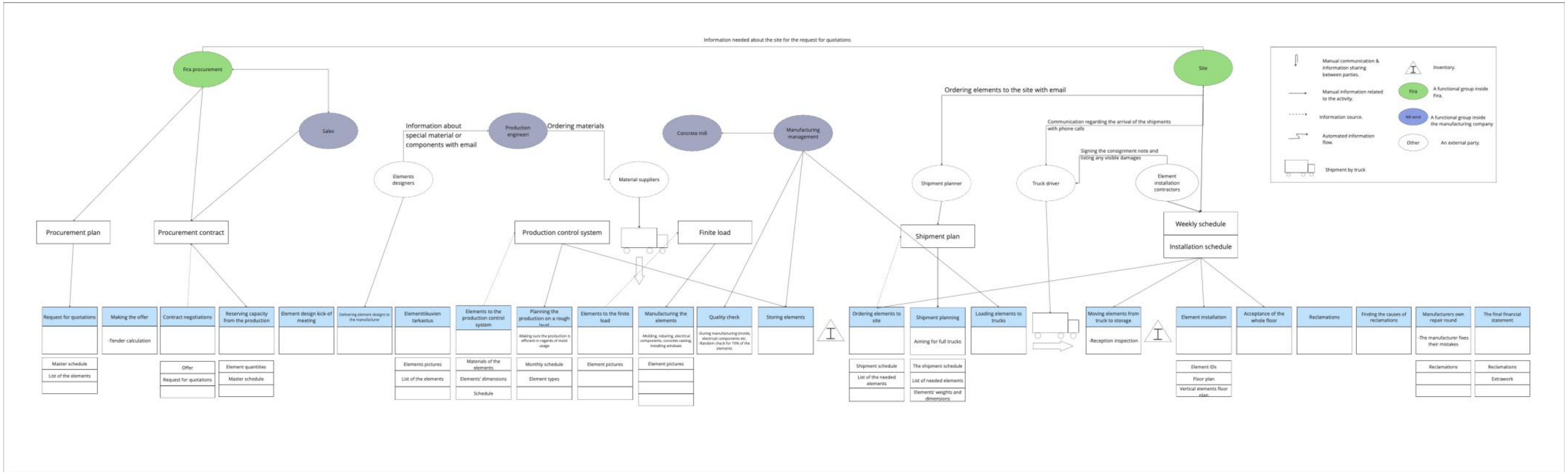
APPENDIX D: A VSM OF HOLLOW CORE SLAB MANUFACTURING



APPENDIX E: A VSM THE TECHNICAL SHAFT ELEMENT



APPENDIX F: A VSM OF THE WALL ELEMENTS



APPENDIX G: A VSM OF CONSTRUCTION OF THE FRAME OF A FLOOR