Systematic technological development in bridge construction

Increased productivity through industrialization of the reinforcement process

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“You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.”

- R. Buckminster Fuller
Preface

In this master thesis of 30 credits the possibilities for industrialization of the reinforcement process in bridge projects are addressed. The master thesis is written within the Civil Engineering and Urban Management program at The Royal Institute of Technology, KTH, and is a combination of two different master tracks; Civil and Architectural Engineering, and Real Estate and Construction Management. The work process has been supervised by adj. professor Lars Pettersson at the department of Civil and Architectural Engineering and associate professor Tina Karrbom Gustavsson at the department of Real Estate and Construction Management, to whom we would like to express many thanks.

The research has been conducted in collaboration with Skanska Sverige AB, at the division of Major Projects, with supervision by Lars Pettersson who also presented the initial idea for the research area. We would like to direct gratitude towards Lars Pettersson for his support, feedback and commitment as well as inspiring thoughts and reflections throughout the process.

We would also like to thank all the respondents for their participation in the interviews. Without their valuable knowledge and input it would not have been possible to map the reinforcement process. We would like to express special gratitude towards Jörgen Johansson at the Nordic Procurement Unit at Skanska AB for the opportunity to visit and attend meetings at a reinforcement supplier in Riga. Furthermore, we would also like to express special thanks to Erkki Törmänen at Skanska Sverige AB Infrastructure for his devotion of time and production knowledge in the process of thinking through the adjustments required to enable for robot prefabrication of an existing reinforcement cage.

Stockholm, June 2015

Johanna Glanzmann and Annika Jönsson
Abstract

The construction industry is characterized by low productivity. Lean is a well-known improvement strategy for an individual company, used in the manufacturing industry to increase productivity. Despite major differences between the construction industry and the manufacturing industry, Lean is an interesting approach for the construction industry as well in order to achieve an increased productivity. Studies have however shown that the low level of Lean implementation in the construction industry is due to deficiencies in knowledge, education and communication.

The main purpose of this thesis is to explore the potentials for increased productivity for bridge project by mapping the reinforcement process in order to identify potentials and obstacles for the implementation of a more industrialized reinforcement process. This has been done through a literature review, interviews, a case study and a study visit.

The Swedish Transport Administration manages 20 600 bridges, the majority of which are reinforced concrete bridges. Roughly 200 bridges are built each year in Sweden to hold the stock. In addition to this, the stock is also expanding. Work dedicated to reinforcement constitutes a large part of bridge projects, almost half of the time in both design and production phase. Furthermore, the reinforcement process has been identified as a process with a number of non-value adding activities. A way to increase the productivity for the reinforcement work is to industrialize the process, for example by implementing BIM and use a high degree of prefabricated reinforcement. Demonstrated advantages of prefabricated reinforcement include shorter construction time, improved health and safety on-site and the possibility for improved quality assurance. These benefits results in lower construction costs and a higher turnover of projects. However, there are some consequences to the use of prefabricated reinforcement and these can be summarized in an increased need for communication and collaboration, reduced flexibility and fewer opportunities for late changes on-site and a need for standardized processes.

The construction industry is a project-based industry that is influenced by weather conditions, fragmented organization and supplier structure, conservative mentality and uniqueness of projects. These factors are reasons to why a transition from craft-based production to mass-customization is hard to achieve unless the construction industry's current organizational structures, production strategies and information structures undergo a change.

Keywords: Bridges, reinforcement, prefabrication, Lean, robotization, industrial construction, BIM
Sammanfattning

Byggbranschen präglas av låg produktivitetsutveckling. Lean är en välkänd förbättringsstrategi för ett enskilt företag som används inom tillverkningsindustrin för att öka produktiviteten. Trots stora skillnader mellan byggbranschen och tillverkningsindustrin är Lean ett intressant tillväggagångssätt för att uppnå en ökad produktivitet även inom byggbranschen. Studier har dock visat att den låga implementeringsgraden av Lean inom byggbranschen beror på brister i kunskap, utbildning och kommunikation.

Det huvudsakliga syftet med detta examensarbete är att undersöka möjligheterna till en ökad produktivitet för broprojekt genom att kartlägga armeringsprocessen och därmed identifiera potentialer och hinder för implementering av en mer industrialiserad armeringsprocess. Detta har gjort genom en litteraturstudie, intervjuer, en fallstudie samt ett studiebesök.


Byggbranschen är en projektbaserad verksamhet som karakteriseras av påverkan från väderförhållande, fragmenterad organisation- och leverantörstruktur, konservativ mentalitet samt projekternas unikhet. Dessa faktorer är orsaker till varför en övergång från hantverksmässig produktion till en masskundanpassad produktion är svåruppnåelig utan att byggbranschens rådande organisationsstrukturer, produktionsstrategier och informationsstrukturer genomgår en förändring.

Nyckelord: Broar, armering, prefabricering, Lean, robotisering, industriellt byggande, BIM
Abbreviations

2D 
Two dimensions

3D 
Three dimensions

BIM 
Building Information Model/Modelling

CM 
Category Manager

BC 
BIM Coordinator

DE 
Design Engineer

DQM 
Design department and Quality system Manager

EM 
Export Manager

IPM 
Implementation and Process Manager

NPU 
Nordic Procurement Unit

PE 
Project Engineer

PdM 
Production Manager

Prof IP 
Professor in Industrial Production

PM 
Project Manager

R&D 
Research and Development

SI 
Superintendent

STA 
Swedish Transport Administration

TA 
Technical Advisor
# Glossary

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1 Introduction

This chapter introduces the background to the research, including productivity in the construction industry, bridge construction in Sweden and industrial construction. Later on in this chapter the problem statement, research questions, purpose, limitations and definitions are presented.

1.1 Background to the research

“If the construction industry was to produce cars the same way as they are building houses the price of cars would be ten times higher. The most prestigious SUV model produced by VOLVO would have cost 550 000 € compared to the market price of 55 000 € and still they would have a much lower profit margin compared to the automotive industry” (Jongeling, et al., 2007).

This comparison, based on statistics from Statistics Sweden¹, of the construction industry and the automotive industry points out a remarkable difference in productivity between the two industries (Jongeling, et al., 2007). Productivity is defined as “an economic measure of output per unit of input” (Investopedia, 2015). The construction industry is characterized by low productivity and this becomes particularly evident when comparing the construction and the manufacturing industry, where the automotive industry is included. According to figures from the National Institute of Technology Research², the construction industry had a productivity growth of 3,5% between 1993 and 2014 while the corresponding figure for the manufacturing industry was 167% (Konjunkturinstitutet, 2015).

The Swedish Transport Administration³ (STA) manage approximately 20 600 bridges all over Sweden. A majority of these bridges are reinforced concrete bridges (Trafikverket, 2015a). Steel reinforcement is used in concrete structures in order to increase the resistance of the structure. The method to reinforce tensioned concrete zones through addition of steel bars was introduced in the 19th century (Ansell, et al., 2012). An assumption that a bridge has a life span of 100 years means that every year, approximately 200 bridges have to be constructed to hold the stock (Pettersson, 2015). In addition to this, the stock is also expanding. The bridge

¹ Statistiska Centralbyrån
² Konjunkturinstitutet
³ Trafikverket
production efficiency is similar to that of the 1970’s since the same manual methods are still used in production, to a great extent. This indicates that there is abundant potential for improvements (SOU, 2012).

In order to address the issue of low productivity within the bridge construction industry, STA has an objective to create conditions for industrial construction and to monitor requirements for industrial construction in early stages, with the aim to increase productivity. In order to achieve this, STA has adopted a new procurement strategy where the share of design-build contracts should increase, and by 2018 constitute half the volume of investment (SOU, 2012). Starting in 2015, STA also demands BIM in all new procurements. STA wants to actively contribute to the introduction of Building Information Modeling (BIM) in the infrastructure industry in order to acquire cost savings, quality improvements and predictability with BIM (Trafikverket, 2015b).

This master thesis is written in collaboration with Skanska Sverige AB and is a continuation of a previous master thesis written by Mattsson and Rodny (2013), in which wasteful activities in a bridge project were identified. Several wasteful activities were acknowledged in the reinforcement process and the reinforcement process was pointed out as an object for improvement. In addition to this, several productivity studies, pointed out by Larsson (2012), indicate large amounts of waste in traditional on-site construction projects. Findings from the case study in this master thesis show that approximately half of the time in design and production phase is dedicated to reinforcement, which indicates a great and lucrative area for minimizing waste through industrialization. Given this starting point, the infrastructure industry, and especially the reinforcement process in bridge projects, is an interesting area for industrialization in order to achieve increased productivity.

Furthermore, in questionnaire surveys done with clients, contractors and consultants within the infrastructure construction, reinforcement has been identified as a component with high potential for prefabrication and standardization (Larsson, et al., 2013). The Development Fund of the Swedish Construction Industry⁴ launched a project in 2008 to map the reinforcement process. Several lacks, difficulties and areas of improvement regarding reinforcement were discovered. These findings raised a willingness among the construction companies to develop a more industrialized reinforcement process (Engström, et al., 2011).

Industrialization is a complex concept. It is not only about technological development, but it also includes fundamental changes in organization and processes (Lindelöw, et al., 2015). Industrialized infrastructure construction includes the following six core elements:

- Prefabrication
- Planning for efficient production
- Cooperation
- Continuous improvements
- Standardization
- Integration of design and production (Larsson, 2012)

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⁴ Svenska Byggbanschens Utvecklingsfond (SBUF)
In this master thesis, the potentials for industrialization through prefabrication of reinforcement in bridge projects are the objective. However, to achieve industrialized prefabrication, all of the listed core elements will be addressed.

The construction industry is often described as a conservative and not an innovative industry in comparison to the manufacturing industry. Studies have shown that investments in Research and Development (R&D) are low in the construction industry (Miozzo & Dewick, 2004) (Reichstein, et al., 2005). According to a nationwide survey conducted by the Civil Engineering Research Foundation in the United States the construction industry only devotes 0.5% of total revenues on R&D (Son, et al., 2010).

Due to this, there is reason to believe that a systematic technological development in the construction industry would result in increased productivity. In order to explain systematic technological development, the components are separately explained with a selection of thesaurus from Oxford Dictionaries (2015).

- **Systematic**: structured, methodical, organized, planned, coherent, orderly
- **Technology**: the application of scientific knowledge for practical purpose, especially in industry, machinery and devices developed from scientific knowledge
- **Development**: evolution, growth, maturing, progress, expansion

Systematic technological development refers to standardized approaches that enable for continuous improvement work regarding technological solutions. Lean is an approach for constantly trying, in the most efficient way; to choose value over waste (Blücher, et al., 2007). One of the fundamental principles of Lean is that standardized approaches are required as a basis for continuous improvement work (Liker, 2004). The philosophy of Lean was developed by Toyota in the 50’s and 60’s and is an established approach in the manufacturing industry (Gao & Low, 2014).

### 1.2 Problem statement

The construction industry is characterized by low productivity. This becomes particularly evident when comparing the construction to the manufacturing industry (Konjunkturinsitutet, 2015).

The reinforcement process in concrete bridges has been appointed as an activity with a lot of waste and is therefore an interesting area for improvement (Mattsson & Rodny, 2013). Lean philosophy is a powerful approach for systematic minimization of wasteful activities. Lean and industrialization are concepts that originate from the manufacturing industry and they are both powerful approaches for systematic minimization of wasteful activities and thereby tools for increased productivity.

Applying industrial methods, such as prefabrication and standardizations, to the reinforcement process is one way of increasing productivity (Larsson, et al., 2013). Unfortunately, there is a lack of knowledge among practitioners and academics about the concept of industrialization in the context of infrastructure projects (Larsson, 2012), but there is a willingness among the construction companies to develop a more industrialized reinforcement process (Engström, et al., 2011). However, the current production strategies, organizational structure and information structure found in the construction industry are not compatible with industrialization.
The research area and research questions were presented by Skanska Sverige AB and further developed in collaboration with the authors.

The research question, derived from the formulated problem statement, is:

*How is systematic technological development achieved in bridge construction?*

In order to answer this question a number of sub questions have been elaborated:

- *What are the benefits and disadvantages with industrial construction in bridge projects and what are the obstacles and potentials for implementation?*
- *How can Lean be used as a tool for increased productivity through elimination of waste in bridge construction?*

This master thesis further aims to investigate the potentials and obstacles for implementation of industrialization of the reinforcement process through prefabrication. The investigation comprises a reinforcement process at a contractor where both the design and production phase are carried out within the company. Furthermore, in this industrialized process, the reinforcement is meant to be robotically prefabricated by the reinforcement supplier, with a high level of automation. The research question stated above is exemplified by the following question:

*What changes have to be made at a contractor in order to implement an industrialized reinforcement process where all reinforcement in a bridge project is automatically prefabricated by robots, directly from a BIM without manual revision?*

In order to answer this question a number of sub questions have been elaborated:

- *How does the reinforcement process in bridge projects, from design to production, look today?*
- *How should the existing reinforcement model, in the BIM software Tekla Structures, of an intermediate support in a studied bridge, be adjusted in order to be compatible with automated prefabrication of reinforcement cages done by robots?*

The key terms that will be analyzed in this master thesis are *BIM, industrial construction, Lean, prefabricated reinforcement, productivity* and *waste*. They are all used to describe the possibilities for industrialization in bridge construction. For explanations of the different terms, see section 1.5.

**1.3 Purpose**

The overall aim is to explore potentials for industrialized processes within bridge construction, in order to increase productivity in a systematic way. The exploration of this research field will mainly be supported by theory within the areas of Lean and industrial construction.

Given the identified waste areas in bridge construction, where reinforcement is one, this master thesis aims to map the reinforcement process in order to explore how it can be industrialized. A case study is conducted in order to map the reinforcement process in a bridge project. This master thesis further aims to examine how to achieve increased produc-
tivity in bridge construction through systematic technological development with respect to the reinforcement process. The final aim is to present a standardized work process that enables for efficient prefabrication of all the reinforcement in bridge projects.

A complete transit to prefabrication of reinforcement is one way to industrialize the reinforcement process. In order to explore the potentials and obstacles for an industrialized reinforcement process, the existing Tekla Structures (BIM software) reinforcement model for the foundation slab in one of the supports in the bridge used in the case study, is revised and adapted to automated prefabrication done by robots. The aim is that the Tekla Structures reinforcement model should include all information necessary for a direct transfer from the design phase to a robot at a reinforcement supplier, without human revision and interference. This would entail a technological development within bridge construction. Within the scope of this thesis, the Tekla Structures reinforcement model will be revised in such a way that the reinforcement design is compatible with robot constructability. This includes well-thought-out mounting order of the reinforcing bars, feasible connections and suitable choice of bar shapes.

In conclusion, prerequisites for implementation of an industrialized reinforcement process, including prefabrication of reinforcement cages done by robots directly from a BIM, at a contractor will be presented.

1.4 Limitations

Since this thesis is written in collaboration with Skanska Sverige AB, the presented prerequisites for implementation of an industrialized reinforcement process are customized for a contractor with the possibility to carry out both design and production within the company. The bridge project in the case study was a design-build project. For this reason, this master thesis is limited to only cover design-build projects.

Due to the limited time frame for this master thesis, one case is studied in order to map the reinforcement process in bridge projects to explore how it can be industrialized. From this case study, general conclusions are drawn. The focus in the case study and the interviews is limited to the reinforcement process.

Within the scope of this thesis, the Tekla Structures reinforcement model of the reinforcement in a foundation slab in a bridge support is revised in such a way that the reinforcement design is compatible with robot constructability. However, additional information required in the BIM software (e.g. Tekla Structures) to enable for direct transfer from design phase to automated prefabrication at a reinforcement supplier done by a robot, without manual revision of the model, is investigated but not included in the revision of the existing Tekla Structures reinforcement model. Sectioning of the reinforcement elements with respect to transport dimension limitations will not be included in the revision either.

Prefabrication only refers to assembled elements of reinforcing bars and does not include cut and bent reinforcement. Focus in this master thesis is on prefabricated cages.
1.5 Definitions

**BIM**

There are many definitions of *BIM* and in this thesis the term refers to both a physical model, (Building Information Model) and the process of modeling (Building Information Modeling). The term includes tools, processes, and technologies that are facilitated by digital machine-readable documentation about performance, planning, construction and operation of a construction (Eastman, et al., 2008). A BIM can also be defined as a shared knowledge resource for information (National Institute of Building Science buildingSMART alliance, 2015). A more detailed explanation of BIM is found in section 4.4.

**Industrial construction**

In this master thesis *industrial construction* and *industrialized construction* equals the same definition. Based on definitions established by Lindelöw et. al. (2015) and Lessing (2006) industrial construction can be described as developed construction process that primarily is organized to be repeatable with a well-suited organization for efficient management, preparation and control of the included activities, flow resources and results for which highly developed components are used in order to create maximum customer value. A more detailed explanation of industrial construction is presented in section 4.3.

**Lean**

*Lean* is sprung from the manufacturing industry and connected to the automobile manufacturing company Toyota. Lean is not a method, but an approach in how to increase the productivity of a customer-driven process by eliminating waste. Continuous improvement is, apart from waste and value, a central concept within Lean. The definition is elaborated around the definitions by Womack and Jones (2003). A more detailed explanation is found in section 4.2.

**Prefabricated reinforcement**

*Prefabricated reinforcement* refers to reinforcement that has been assembled off-site into elements, such as reinforcement cages and carpets, and then transported to construction site. Cut and bent reinforcing bars are also a type of prefabricated reinforcement since the cutting and bending is done off-site before transportation to the construction site. Prefabrication is further described in section 4.3.1.

**Productivity**

The term *productivity* is an economic measurement of the rate of output per unit of input and describes the effectiveness of productive effort (Oxford Dictionaries, 2015). For productivity growth in different industries and further elaboration, see section 3.1.

**Waste**

*Waste*, is a central concept in Lean and the definition used in this research is “any activity that consumes resources but creates no value” (Womack & Jones, 2003). A more detailed description is presented in section 4.2.1.
1.6 Thesis disposition

The thesis comprises of 9 chapters outlining various aspects of the research. Below, a short summary of each chapter follows in order to guide the reader through this master thesis.

**Chapter 1:** This chapter introduces the background to the research, including productivity in the construction industry, bridge construction in Sweden and industrial construction. Later on in this chapter the problem statement, research questions, purpose, limitations and definitions are presented.

**Chapter 2:** Presents the applied research method and why the particular method was chosen. The chosen method’s reliability and validity is discussed in the end of this chapter.

**Chapter 3:** Presents the state of the art in the research field. In the first section, statistics for the productivity growth in the construction industry are presented. In the second section, research within the field of industrialized construction is presented. This section includes prefabrication and research and development within the field of robotics and automation.

**Chapter 4:** Sets the theoretical framework for this master thesis. It will present the concepts of production strategies, differences between the manufacturing and construction industry, Lean, BIM and industrial construction. In addition to this, a section will address the technical facts about reinforcement in concrete bridge structures.

**Chapter 5:** Presents the empirical findings from observations and interviews. Through a case study, it has been possible to map the reinforcement process for several actors in a design-build project, from initial design to execution. In addition, interviews with relevant respondents, not connected to the case study but from academia, have been conducted. To begin with, the case study will be presented by briefly introducing the construction company Skanska Sverige AB, followed by an introduction to the case study. Subsequent to this, data gathered from interviews and observations regarding both the case study and overall efficient bridge construction are presented.

**Chapter 6:** Aims to answer the question of how existing reinforcement model should be adjusted in order to be compatible with automated robot reinforcement prefabrication. To exemplify this, adjustments of the existing 3D model, made in Tekla Structures, of the reinforcement in the foundation slab in the fourth intermediate support in the Slammertorp bridge will be made. Due to the shape and design of the existing reinforcement, focus is on prefabrication of a reinforcement cages.

**Chapter 7:** Combines empirical findings, research within the field of industrial construction and the theoretical framework in order to present an analysis of how to industrialize the reinforcement process. First a more general analysis of obstacles and potentials for implementation of industrialized bridge construction is presented, followed by more specific prerequisites for industrialization of the reinforcement process.
**Chapter 8:** Concludes the general findings and connects them to the research questions. The chapter first answers the question of how systematic technological development can be achieved in bridge construction, followed by the more specific research question of what changes have to be made at a contractor in order to implement an industrialized reinforcement process where all reinforcement in a bridge project is automatically prefabricated by robots, directly from a BIM without manual revision.

**Chapter 9:** Discusses the findings and the conclusion as well as the research quality. Additional insights that have arisen during the process are elaborated. Lastly, suggestions for further research are presented.
2 Method

*This chapter presents the applied research method and why the particular method was chosen. The chosen method’s reliability and validity is discussed in the end of this chapter.*

2.1 Approach

The research area, systematic technological development, was presented by Skanska Sverige AB and the research questions were developed in collaboration between Skanska Sverige AB and the authors.

Logic can be inductive, deductive, or abductive in nature. These differ primarily according to three principles; origin of the hypothesis, the logical structure of the argument and the probability of a truthful conclusion. Generalizations are developed through observations in inductive logic, whereas in deductive logic; specific assertions are generated from known scientific principles or generalizations. For abductive logic, found generalizations serve as explanations for anomalous events (Supino & Borer, 2012). Inductive research is also called theory-building research (Bhattacherjee, 2012).

This master thesis aims, through theory, observations and interviews to explore how an industrialization of the reinforcement process is made possible. General conclusions are based on observations, interviews, literature and theory and an inductive research approach is therefore taken. The approach for this master thesis is to seek explanations of observed phenomena, problems, and behaviors and therefore the research design is also explanatory (Bhattacherjee, 2012).

In qualitative research, information is gathered about how phenomena are experienced by individuals or groups of individuals (and the context of these experiences) (Supino & Borer, 2012). Therefore, this master thesis is of a qualitative research design.
2.2 Research design

The research design of this master thesis includes a literature review in relevant areas, a case study of a concrete bridge project and interviews with people involved in the case study, as well as interviews with external respondents. In addition to this, a study visit at a reinforcement supplier has been included. The master thesis also includes adjustments of a reinforcement model, used in the bridge that was studied in the case study, in order to show possible changes that enable for an industrialized reinforcement process. The changes are modelled in Tekla Structures, a BIM software.

2.2.1 Population and sampling

The sampling, which sets the frame and strategy for the data collection, is selected from a population (Bhattacherjee, 2012). In this master thesis the population target is the construction industry, especially the infrastructure industry and further on concrete bridges.

The sampling frame for the case study will limit concrete bridge projects to bridge projects performed by Skanska Sverige AB. The sample will not be randomly picked but chosen based on availability and relevance.

2.2.2 Literature review

According to Bhattacherjee (2012) the purpose of a literature review is to survey the current state of knowledge in the research area; identify key authors, articles, theories, and findings in that area, and last to identify gaps in knowledge in that research area.

In the beginning, the literature review in this master thesis focused on Lean, automation and prefabrication. Later on, as the research questions developed, literature on industrial construction and production strategies were also reviewed. The variety of the literature included books, peer review articles and reports.

The literature review sets the theoretical framework for this master thesis. The literature review has, to the utmost, tried to derive back to the original authors.

2.2.3 Interviews

Interviews are objective to collect mostly qualitative data. However, the potential and value of collecting quantitative data, like figures and numbers, should not be ignored (Bhattacherjee, 2012).

Semi-structured interviews have been carried out since it was assessed to be the most appropriate for this kind of qualitative research. Semi-structured interviews have a set of pre-determined open questions, which provide the opportunity for discussion and new ways of seeing and understanding the research area addressed.
Interviews with employees at Skanska Sverige AB, connected to the case study, have been conducted in order to map the reinforcement process. For insight in the design phase of the process, the project manager, design engineer and the BIM coordinator have been interviewed. For insight into the construction phase of the reinforcement process, interviews with the production manager, the superintendent and the project engineer have been conducted. In total, six interviews with respondents connected to the case study have been carried out. The following abbreviations have been used for the respondents:

- Project Manager (PM), 25 years of experience in the construction industry
- Production Manager (PdM), 30 years of experience in the construction industry
- Superintendent (SI), 45 years of experience in the construction industry
- Project Engineer (PE), 3 years of experience in the construction industry
- Design Engineer (DE1), 13 years of experience in the construction industry
- BIM Coordinator (BC), 7 years of experience in the construction industry

In addition to the respondents involved in the Slammertorp bridge project, interviews with seven other relevant respondents have been carried out to get a wider perspective of the obstacles and potential improvements regarding construction productivity. These interviews have been conducted with:

- Design Engineer at Skanska Sverige AB (DE2), 20 years of experience in the construction industry
- Category Manager for reinforcement at the Nordic Procurement Unit at Skanska AB (CM), 34 years of experience in the construction industry
- Technical Advisor for reinforcement at the Nordic Procurement Unit at Skanska AB (TA), 10 years of experience in the construction industry
- Professor in Industrial Production at the Royal Institute of Technology (Prof IP), 40 years of experience in the field of industrial production
- Implementation and Process Manager at the technical consultancy firm Tyréns AB (IPM), 11 years of experience in the construction industry
- Export Manager at the reinforcement supplier VMS Group (EM), 1 year of experience in the construction industry
- Design department and Quality system Manager at the reinforcement supplier VMS Group (DQM), 15 years of experience in the construction industry

In order to grasp the field of bridge construction and reinforcement, discussions with Lars Pettersson, Technical Manager for Bridge Projects at Skanska Sverige AB, were also held during the process of writing this master thesis.

Each respondent was e-mailed the interview questionnaire a few days in advance. The interviews were scheduled for 1,5 hour and were conducted face to face or via Lync5 by both authors. The respondents were informed of the purpose with the interview and the objectives for the master thesis in the beginning of the interview. All interviews, except from those with the reinforcement supplier, were conducted in Swedish. Some of the interviews were recorded with admission from the respondent. The respondents’ answers were transcribed by both authors shortly after the interviews were conducted. The answers have been translated to

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5 A communication platform for audio and video calls with possibilities to share documents, desktop etcetera.
English, which means that the choice of words and phrasing are affected by the authors’ ability to translate. All interviews have been kept anonymous and the authors are of the opinion that this has not affected the credibility of the answers.

In total, 13 interviews were carried out. For the interview questionnaire, see appendix A.1.

2.2.4 Case study

A case study gives the possibility to study a phenomenon over time within its natural setting. It is therefore possible to discover of wide varieties of social, cultural and political factors of interest that may not have been known in advance. Case studies belong to the explanatory research, which aims to seek explanations and answers questions like why and how (Bhattacherjee, 2012).

The case study in this master thesis was conducted during spring 2015 and aimed to map the reinforcement process in a concrete bridge. The studied bridge has already been built and the bridge has been in use since 2014. The studied bridge project was relevant since enabled for a possibility to map the whole reinforcement process, from start to end, but also because 3D models and prefabricated reinforcement cages were used to a limited extent. The aim with the case study was to answer how the mapped reinforcement process should change in order to apply a more industrialized way of working.

2.2.5 Study visit

For greater understanding of the process for prefabricated reinforcement cages, a study visit to VMS Group in Riga, a reinforcement supplier that prefabricates cages, was conducted. The Nordic Procurement Unit at Skanska Sverige AB has an established relationship with the visited reinforcement supplier. The study visit was carried out in April 2015.

2.2.6 Tekla Structures

Tekla Structures is a Building Information Modeling software for actors in the construction and infrastructure industry, for example steel detailers, concrete contractors and structural engineers. Functionalities of Tekla Structures are structure and component design in 3D, 2D drawings generation and building information accessibility (Tekla, 2015).

In order to answer the research question that concerns automated prefabrication of reinforcement cages done by robots, a foundation slab in an intermediate support in the studied bridge has been selected as an example. The intermediate support was modelled in Tekla Structures and the model was used in the studied bridge project. The reinforcement cage in the foundation slab has been adjusted in Tekla Structures, with respect to the found requirements for automated prefabrication of reinforcement done by robots.

In order for reinforcement cages to be automatically prefabricated by robots, constructability is essential and has to be considered in the design phase. Mounting order of the reinforcing bars and choice of reinforcing bar shapes have to be chosen with respect to the limitations with robot prefabrication.
In collaboration with the production manager and superintendent in the case study, a detailed mounting order and choices of reinforcing bar shapes have been elaborated. Pipe cleaners, symbolizing the reinforcing bars, were used as a pedagogical tool for visualization of the cage fabrication. The resulting adjustments in the design of the cages were communicated to and approved by the design engineer in the bridge project. The Tekla Structures reinforcement model for the foundation slab intermediate support was adjusted in accordance with the elaborated changes.

Figure 1. Discussions and collaboration regarding constructability, mounting and reinforcement bending shapes for the prefabricated reinforcement cage in the intermediate support. Pipe cleaners were used to illustrate the reinforcing bars (Jönsson, 2015).

2.3 Discussion of the research design

Arguments that are derived from inductive research contain multiple premises that provide grounds for a conclusion but do not necessitate it. The strength of an inductive generalization is determined by the number of observations supporting it and the extent to which the observations reflect all observations that could be made (Supino & Borer, 2012). Only one case study has been conducted but on the other hand, complementary observations like interviews and a study visit exist. The reliability of the general conclusion in inductive research is very much depending on the representativeness of the observations and the literature.

Bias is often an issue, and a weakness for interviews and other qualitative methods. For interviews, there are also risks that the respondents aren’t completely honest and that the interviewer asking questions in a leading way and by that affecting the answers. Another weakness is that interviews are rather time consuming which might be a disadvantage in case large amount of data is needed (Bhattacherjee, 2012).

A strength with interviews is the possibility to reach groups or persons that are not easily accessed with surveys or similar. A second advantage is that misunderstanding and misinterpretation is lowered since the questions can be explained and directly answered when asked (Bhattacherjee, 2012). There is a risk that conclusions are drawn based on findings from interviews where the respondent expresses opinions without enough competent within the research field. However, the majority of the respondents in this master thesis have had a lot of experience.
3 Previous research

This chapter presents the state of the art in the research field. In the first section, statistics for the productivity growth in the construction industry are presented. In the second section, research within the field of industrialized construction is presented. This section includes prefabrication and research and development within the field of robotics and automation.

3.1 Productivity

In order to grasp the term productivity, two definitions are introduced:

“The effectiveness of productive effort, especially in industry, as measured in terms of the rate of output per unit of input.” (Oxford Dictionaries, 2015)

and

“An economic measure of output per unit of input. Accomplish more with less.” (Investopedia, 2015)

The construction industry is characterized by low productivity. This becomes particularly evident when comparing the construction and the manufacturing industry. According to figures from the National Institute of Technology Research\(^6\), the construction industry had a productivity growth of 3.5% between 1993 and 2014 while the corresponding figure for the manufacturing industry is 167%. The productivity growth in the construction industry, the manufacturing industry and the service industry between 1993 and 2014 are presented in Figure 2\(^7\).

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\(^6\) Konjunkturinstitutet

\(^7\) The figures are based on productivity per hour for the economic situation in March 2015 and were developed through collaboration between NIER and Statistics Sweden (Konjunkturinstitutet, 2015)
The productivity growth of 3.5% in the construction industry is exceptionally low. The low productivity figure in the construction industry have been discussed by Lind and Song (2012), whether they are accurate or a result of measurement errors. It was found that it is justified to believe that the productivity growth is low but not as low as presented. It is explained by how the index [doesn’t] handles changes in technology, material costs and quality (Lind & Song, 2012).

In a 30-year (1977-2007) retrospective comparison of productivity and produced drawings within the bridge design phase, it was found that there was no significant difference over the years in terms of effective bridge surface area produced per hour or in unit times for various tasks (Bröchner & Olofsson, 2012). The low productivity in the construction industry is not only incident to the production phase of the construction process, but is also relevant for the design phase.

### 3.2 Industrial construction

Industrialization has been implemented successfully in the manufacturing industry, but the fundamental principles are general and can be applied to all kinds of firms that are producing. The aim with industrialization is to increase the efficiency of the production process, hence the productivity, and thereby increase the competitiveness of the company (Blücher, et al., 2007).

In order to industrialize the construction industry; using prefabrication, product standardization, automation or robot driven development, an expansion scope from the single project to the entire construction firm is required. By broadening the scope, from project to firm, a payoff is reached (Gerth, 2013). However, discussions on the subject industrialization in
Prefabrication is a way to industrialize the reinforcement process. One reinforcing bar takes approximately 10-15 minutes to mount, which corresponds to approximately 20 hours for mounting per 1,000 kg reinforcement (Pettersson, 2015). A study done by Caster and Deuschl (2007) found that approximately 5% of the reinforcement in a project are spacer bars, and not included in the reinforcement specifications done in the design phase. If 20 hours per 1,000 kg is applied to the studied bridge in this master thesis, it means that if all the 300,000 kg reinforcement was mounted on-site, 6,000 hours would have been dedicated to mounting. In order to illustrate this, 6,000 hours corresponds to four people working full time for a whole year (Pettersson, 2015). The time for mounting reinforcing bars per useful bridge surface area takes more time now than 30 years ago according to a 30-year retrospective study (Bröchner & Olofsson, 2012).

Research has shown that in the production phase of office and house construction projects, 22% of the total work is dedicated to the reinforcement (Löfgren & Gylltoft, 2001). A case study on a Swedish in-situ cast concrete bridge has shown that prefabricated reinforcement cages reduced the on-site production time for the reinforcement in the foundation from 80 man-hours to 2 man-hours (Simonsson & Emborg, 2007). Further on, another case study (Larsson & Simonsson, 2012) of a bridge constructed in 2011 in Sweden showed that by using prefabricated beams and slabs the lead time in the project decreased with approximately 75%.

Apart from the time saving, benefits like less physical load for the construction workers, increased safety and less stressful working environment were achieved by using prefabricated reinforcement cages. Similar benefit, like improved work environment, shorten construction time and by this lowered construction costs was also found in case studies by Caster and Deuschl (2007). Further, the chance of errors occurring was also minimized due the fact that the production settings for the prefabricated reinforcement cages could be controlled and the tools used were accurate manufacturing tools (Simonsson & Emborg, 2007). However, the use of prefabricated elements caused some problems that can be summarized in three areas:

1. Increased need of communication and cooperation.
2. Less flexibility and late change difficulties at construction site.
3. Lack of standardized processes. (Larsson & Simonsson, 2012)

Also, wasteful activities, such as uncertainty in how to mount the reinforcing bars were identified. This could easily have been avoided if the design engineer had provided assembly instructions. It was also found that all parties involved must take their responsibility to check the validity of drawings and other information before construction can begin (Simonsson & Emborg, 2007). It was also highlighted that standardized products, e.g. prefabricated elements, need standardized process in order to achieve efficiency and maximal outcome (Larsson & Simonsson, 2012). In all observed cases in the study by Caster and Deuschl (2007), the most important factor when using prefabricated reinforcement was careful planning.

However, it was also found that the prevailing economic situation affect the decision of using prefabricated or not. At a recession, it was found that the construction companies often opt out prefabrication in favor for keeping the construction workers occupied at the construction site. On the other hand, during a boom, when it is shortage of staff, prefabrication was chosen...
since it did not require as much staff compared to non-prefabricated reinforcement (Caster & Deuschl, 2007).

### 3.3 Research and development

Despite the complete technologically change in the construction industry in the 20\(^\text{th}\) century, the construction industry struggles with high costs, low productivity growth and poor quality (Koskela, 2000).

The profit in today’s construction projects is largely anchored in a narrow thinking of the individual project's financial performance as the main driver, instead of a long-term strategic thinking. Implementation of new technique in the construction industry is countered by many different things, e.g. the bigger construction companies’ decentralized organizational structure, short term economic incentives and the site manager work situation. Since responsibility of a project’s economical outcome rests on the site manager, these site managers get responsible for the application and implementation of new techniques. This responsibility ends up in a situation where a company’s R&D strategy depends on the site manager’s willingness and time (Claeson-Jonsson, et al., 2006).

In today’s project based construction, development costs are avoided. Instead, every project has to meet the unique and specific requirements of the client, which means that all development lies within the projects and is paid for by the client (Lindelöw, et al., 2015). Characteristic for project based industries are issues dedicating time for general activities, like product development and innovations, because of the project’s budget constraints (Lind, 2011b).

In the late quarter of the 20\(^\text{th}\) century, the importance of development in automation and robotics technology in the construction industry was received to fall behind compared to other industries. Many studies have shown that the construction industry is reluctant to apply robotics and automation technology and that a lower level of technology than in other industries is employed. This can be related to the fact that the design and construction industry only devotes less than 1% of total revenues on R&D, based on a United States nationwide survey. Studies also show that the low investment in R&D has resulted in higher than necessary construction costs (Son, et al., 2009). An analysis of costs for innovating shows that people using technology tend to innovate when a technology is easy to modify and when the costs to innovate are decreased (Slaughter, 1993). A study, examining productivity trends for varying construction tasks over a 30-year period, found that new technology is a primary factor for improving productivity in the construction industry (Goodrum & Haas, 2002).

However, the industry is becoming more complex and is facing new challenges, which is why attention to the potential benefits with automation and robotics has been growing in recent years. In addition to this, the globalization of the market introduces a high level of competitiveness which urges companies to adopt more automated and efficient means. (Son, et al., 2009).
3.3.1 Robotics and automation

The first construction robots were designed in the beginning of the 70’s in order to increase the quality in prefabrication of modular homes in Japan. In the late 70’s, robots for construction sites started to be developed (Bock, 2007).

Great progress has been made in Japan in the development of automation and robotics for building construction. The SMART system, a Japanese project developed by Shimizu\(^8\) was used the first time in 1991 and is an automation and robotization of a complete building erection. It consists of an all-weather, fully automated factory on the top of a building with a lift-up mechanism that automatically raises the construction plant and the on-site factory when one story has been constructed. More than 30 story-buildings have successfully been built this way (Balaguer & Abderrahim, 2008). Since automated construction requires standardized components, many components used in the SMART system were prefabricated. As a result of this, the material waste was reduced by 70%. In addition, man-hours were reduced due to computerized control systems, prefabrication and unitization of components. This resulted in a labor saving of 50% which corresponded to an overall saving of approximately 30% (Cousineau & Miura, 1998). The SMART system is illustrated in Figure 3.

![Figure 3. The SMART system. Automation of a full-scale building erection (Cousineau & Miura, 1998).](image)

Further on, within the construction industry, there are robots that are able to perform for example brick laying of masonry, interior-finishing, column-to-column welding, column-to-beam welding, semi-autonomous road pavers, asphalt compactors, climbing robots and drones for inspections and maintenance of civil infrastructures (Balaguer & Abderrahim, 2008).

\(^8\) A Japan and Singapore based construction company.
In “Trend Analysis of Research and Development on Automation and Robotics Technology in the Construction Industry” (Son, et al., 2009), an analysis of global trends in R&D within the field of automation and robotics in construction is carried out based on papers published in the proceedings of the International Symposium on Automation and Robotics in Construction (ISARC). Results from the analysis show that Japan, with 23%, is the country that has contributed the most to all the ISARC papers. For the top contributing countries to ISARC papers on automation and robotics are listed below.

1. Japan 23%
2. USA 17%
3. Taiwan 11%
4. UK 7%
5. Germany 6%
6. Poland 4%
7. Spain 3%
8. Netherlands and India 2% (Son, et al., 2009)

A further analysis shows that of all the research contributions on automation and robotics in construction from Japan, about 90% was performed in the field of construction robotics. (Son, et al., 2009). Based on publications of ISARC papers of the total R&D, there has been a relative decrease of research on Construction Robotics, from 71% in 1990-1992 to 33% in 2006-2008 (Son, et al., 2009).

There are existing machines for manufacturing reinforcement cages, but the generated cages are for standard structures and therefore rely heavily on fixtures for exactly these types of shapes. Cortsen et. al. (2014) have studied how to fabricate complex reinforcement structures using robotic automation in order to reduce costs. The research team behind this study has competence within computer systems engineering, robotics and applied mathematics. Cortsen et. al. (2014) have presented a complete integrated system for automatic bending and binding of double curved single layer reinforcing grids using two industrial robots working in parallel. See Figure 4.

![Figure 4. System for fabrication of complex double curved single layer reinforcing grids using robots. The reinforcement fabrication station consists of two robots with specialized grasping and binding tools, a mesh fixture and a rebar bending station (Cortsen, et al., 2013) (Cortsen, et al., 2014).](image)
In the design step, the final assembly of the mesh, e.g. how the individual reinforcing bars are curved and how they should be positioned in the final reinforcement mesh, is defined in a CAD model. The main tasks in the planning step are to calculate, using the CAD model, robot trajectories for bending, transporting and binding the reinforcing bars into the final mesh. Robots, grippers, binding tools, etc. comprise the reinforcement fabrication station that fabricates the reinforcement grids (Cortsen, et al., 2014).

A part from the issue with the reinforcing bars’ elasticity, combined with their considerable length that caused large deflections, there were uncertainties in the actual intersection points. Experiments however show acceptable deviations in binding, repetition of bending in different directions, precision of bend, precision of turn and precision of length. Thus, Cortsen et. al. (2014) have designed and programmed a complete sensor based binding tool that handles inaccuracies in the reinforcing bars’ positions at the binding location, presenting a complete robotic system for automatic manufacturing of complex reinforcement structures. The system involves automatic bending and binding in collision free paths.
4 Theory

This chapter sets the theoretical framework for this master thesis. It will present the concepts of production strategies, differences between the manufacturing and construction industry, Lean, BIM and industrial construction. In addition to this, a section will address the technical facts about reinforcement in concrete bridge structures.

4.1 Reinforcement in bridge construction

Reinforcement is mainly used because of the relatively low tensile strength of concrete, which only is a fraction of the compression strength. Reinforced concrete can however be equipped with both tensile and compression reinforcement. The tensile reinforcement is placed in areas where the concrete is exposed to large tensile stresses, taking up the concrete tensile stresses when the concrete has cracked. This way, the brittle concrete structure becomes more ductile. The reinforcement should be designed and inserted in such a way that the serviceability of the structure is retained even when cracks appear (Ansell, et al., 2012).

Tensile reinforcement is usually used to take up forces caused by bending moments or eccentric normal forces, i.e. due to bending. The compression reinforcement has the task of taking up some of the compressive force in concrete and thereby strengthening compressed concrete, however, in bending, compression reinforcement is only used when there is special reason. Reinforcement can also be used to take up forces in the concrete caused by shear and torsion (Ansell, et al., 2009).

In order to reduce the material consumption of steel, optimization is to strive for. A 30-year retrospective comparison study (1977-2007) reveals that newly constructed bridges consistently have more reinforcement per square meter of useful surface area. A comparison of similar bridges showed that in general, approximately 50% more concrete and reinforcement is used in bridges constructed after 1987 compared to before 1987. However, new regulations and a higher quality in the life-cycle perspective might justify these figures (Bröchner & Olofsson, 2012).

4.2 Lean

The philosophy of Lean stems from the Japanese car manufacturing company Toyota and their successful production philosophy The Toyota Production System (TPS), developed in the 50’s and 60’s (Liker, 2004). The term “Lean” was introduced in The machine that changed the world by Womack et.al. in 1991 and the principles of Lean (and TPS) are
nowadays a well-established production approach in the manufacturing industry (Gao & Low, 2014) (Liker, 2004).

Lean theory contains concepts and tools that can be used in order to increase the productivity of a process. In the manufacturing industry, as a rule of thumb, the productivity is doubled for the whole system at a transition from traditional mass production to Lean production. At the same time the production throughput and inventory levels can be decreased with 90% (Blücher, et al., 2007).

In the following sections the concept and principles of Lean are described, as well as an action plan for Lean implementation.

### 4.2.1 Principles of Lean

The aim with Lean is to increase the productivity of a process by the elimination wasteful activities. Lean is not just an antidote to waste, but also to stagnation (Womack & Jones, 2003).

Waste is a central concept in Lean and is defined as “any activity that consumes resources but creates no value” (Womack & Jones, 2003). Originally there were seven sources of waste, identified by Taiichi Ohno, the production manager at Toyota. An eighth source has been added in retrospect (Liker, 2004).

1. **Overproduction.** Refers to production of more than what has been ordered. This results in overstaffing and unnecessary costs for inventory and transportation.

2. **Waiting.** To wait for equipment, tools or the next step in the process due to delays, lack of material or bottlenecks is a non-value adding activity.

3. **Excessive transportation.** This refers to transportation of material, components or processed parts between processes or in and out of an inventory, inefficient transportation or long transportation distances.

4. **Over processing or defective processing.** Undertaking non-value adding activity by unnecessary or defective processing. Inefficient processing due to use of inappropriate tools or production of products with higher quality than necessary generates waste.

5. **Unnecessary inventory.** Refers to more raw materials, work-in-progress or finished products than required, causing delays, longer throughput times, obsolescence and damaged goods. Unnecessary inventory also hides late deliveries from suppliers, stagnation and defective products.

6. **Unnecessary motion.** Refers to all unnecessary motions the employees perform during an operation. This involves searing for, reaching for or laying aside components, tools etc.

7. **Products of defects.** Refers to product with defective components that need reparation, revision or scrapping (Womack & Jones, 2003).

8. **Untapped creativity of the employees.** Unless there is engagement and attention is paid to the employees, competence, improvements, ideas and opportunities to learn are lost (Liker, 2004).
Another important concept in Lean is value. Value is defined as “a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer”. The first, and critical, step in Lean thinking is to accurately specify value. This concept is connected to two other important concepts; value stream and value stream mapping”. Value stream is defined as “the specific activities required to design, order and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer”. Value stream mapping is defined as “identification of all the specific activities occurring along a value stream for a product or product family” (Womack & Jones, 2003).

Within Lean, perfection is the aim since it is “the complete elimination of waste so that all activities along a value stream create value”. (Womack & Jones, 2003).

In the concept of Lean, the “pull” principle is to strive for as a production strategy. Pull is defined as “a system of cascading production and delivery instructions from downstream to upstream activities in which nothing is produced by the upstream supplier until the downstream customer signals a need. It is the opposite of push” (Womack & Jones, 2003). Production strategies are further described in section 4.5.

With Lean thinking and by implementing a more standardized customer-driven production process, waste can be reduced both in the design phase and production phase by elimination the eight sources of waste (Blücher, et al., 2007).

Moreover, stable, repetitive methods ought to be used everywhere in order to maintain predictability, timing and a regularly flow in the process. When a standardization of the best currently known methods is implemented, the starting position is made visible which is a prerequisite for continuous improvements and development of the process (Liker, 2004).

### 4.2.2 Implementation of Lean

Once value is distinguished from waste, the implementation of Lean can be made. No organization has ever undergone dramatic and comprehensive change without someone somewhere taking the lead (Womack & Jones, 2003). An action plan for Lean implementation, developed by Womack and Jones (2003), is presented below.

**Getting started (first six months)**

1. Find a change agent
2. Get the knowledge
3. Find a lever by seizing the crisis, or by creating one
4. Forget grand strategy for the moment
5. Map your value streams
6. Begin as soon as possible with an important and visible activity
7. Demand immediate results
8. As soon as possible as you’ve got momentum, expand your scope

**Creating an organization to channel your streams (six months through year two)**

1. Reorganize your firm by product family and value stream
2. Create a lean promotion function
3. Deal with excess people at the outset
4. Devise a growth strategy
5. Remote the anchor-draggers
6. When you’ve fixed something, fix it again
7. “Two steps forward and one step backward is OK; no steps forward is not OK”.

Install business systems to encourage Lean thinking (years three and four)

1. Utilize policy deployment
2. Create a Lean accounting system
3. Pay your people in relation to the performance of your firm
4. Make everything transparent
5. Teach Lean thinking and skills to everyone
6. Right-size your tools

Completing the transformation (by end of year five)

1. Convince your suppliers and customers to take the steps just described
2. Develop a Lean global strategy
3. Convert from top-down leadership to bottom-up initiatives (Womack & Jones, 2003)

4.2.3 Lean enterprise

When all inventories and waste are taken out of the internal value stream, an awareness of the costs and performance problems connected to the supply chain, including suppliers’ suppliers and distributors’ retailers, will arise. Technical assistance will be necessary, but not sufficient (Womack & Jones, 2003).

Lean enterprise, developed by Womack and Jones (2003), is an organizational leap that addresses the problems mentioned in above paragraph. It is a leap that not even Toyota has taken and includes working with all participants in a value stream in a new way. The objectives for Lean enterprise are stated below.

- Correctly specify value for customer.
- Avoiding the normal tendency for each firm along the stream to define value differently to favor its own role in providing it (for example: the manufacturer who thinks the physical product itself is the customer’s primary interest, the independent sales and service company that believes responsive customer relations account for most of the value perceived by the customer, etcetera).
- Identify all the actions required to bring product from concept to launch, from order to delivery, and from raw material into the hands of the customer and on through its useful life.
- Remove any actions which do not create value and make those actions which do create value proceed in continuous flow as pulled by the customer.
- Analyze the results and start the evaluation process over again. (Womack & Jones, 2003)

All participants must treat each other as equals, with waste as the joint enemy. Just like Lean, Lean enterprise require a change agent, or a leader and it is proposed to be the firm; bringing all of the designers and components together into a complete product. (Womack & Jones, 2003).
4.3 Industrial construction

What the concept of industrialization involves is debatable. If one refers to the development of new, modern methods based on new technologies, the construction industry has been industrialized several times before. However, the current industrialization of the construction industry is not only about technological development, but it also involves a more fundamental change in approach and a whole new way of thinking. This industrial thinking implies an ambition to constantly improve, but also a separation of product development from the projects the product is used in (Lindelöw, et al., 2015). Hence, industrialization is a wide concept including both implementation of new products and processes, innovations and changes in attitude and culture (Liker, 2004).

Lessing (2006) has tried to encapsulate the term industrialized construction and defines it as:

“...a developed building process with a well-suited organization for efficient management, preparation and control of the included activities, flow resources and results for which highly developed components are used in order to create maximum customer value.” (Lessing, 2006)

Lindelöw et. al. (2015) describes construction as a complex concept that includes technological, organizational and process related aspects. Industrial construction is further described as construction that primarily is organized to be repeatable, leading to a stronger process focus and a reduced project focus. It is however emphasized that the core of industrial construction is to see the whole picture and not to sub-optimize (Lindelöw, et al., 2015). The view is that every project is unique and therefore requires a unique approach (Lindelöw, et al., 2015). Since every project is regarded as unique, a prototype is constructed in every new project. This is, to an even greater extent than for buildings, applicable in infrastructure projects such as bridges (Larsson, 2012). Industrialization requires similarities between projects. For similar projects, the content differs but most of the activities are the same (Lindelöw, et al., 2015).

There is an identified lack of knowledge among both practitioners and academics about the concept of industrialization in the context of infrastructure projects (Larsson, 2012). The research on industrialization in the context of infrastructure is scarce which could be an explanation to why the knowledge about the concept is lacking and widely varying among both practitioners as academics (Larsson, et al., 2013).

Five core elements of industrialized infrastructure construction have been identified, three of them related to the process, one to the product and one related to both the process and product, see Table 1 (Larsson, et al., 2013).
Table 1. The five core elements of industrialized infrastructure construction (Larsson, et al., 2013).

<table>
<thead>
<tr>
<th>Core element</th>
<th>Related to</th>
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</thead>
<tbody>
<tr>
<td>Planning for efficient production</td>
<td>Process</td>
</tr>
<tr>
<td>Integrated design and production</td>
<td>Process</td>
</tr>
<tr>
<td>Continuous improvement</td>
<td>Process</td>
</tr>
<tr>
<td>Standardization</td>
<td>Process and product</td>
</tr>
<tr>
<td>Prefabrication and automation</td>
<td>Product</td>
</tr>
</tbody>
</table>

Prefabrication, standardization and automation will be explained in this chapter. In additions, Lean construction, sprung from Lean will be explained as a part of industrial construction.

A step towards industrialization is to identify the similarities among projects rather than focusing on the uniqueness (Larsson, et al., 2013). Barriers hindering industrialization of the infrastructure construction is lack of large-scale and repetition possibilities, norms and rules from STA, procurement of design-bid-build contracts based on lowest price, conservative industry culture and governmental regulations and laws regarding planning process of infrastructure and complexity (Larsson, et al., 2013) (Bertelsen, 2004). Also, the lack of on-site management control and that the product design often is excluded from the production control is also considered as a barrier (Winch, 2003).

The idea of industrialization has received much attention, the share of prefabricated components has gradually risen, but a breakthrough for industrialized construction has still not occurred (Koskela, 2000). In “Industrialized house building in Sweden: A stress test approach for understanding success and failure”, Lind (2011a) comes to the conclusion that it is difficult to industrialize the construction industry through revolutionary changes, which is why more industrialized production processes on-site are more interesting than dreaming of large quick changes in what is produced off-site.

### 4.3.1 Prefabrication

Prefabrication, pre-assembly and off-site manufacturing are all describing the concept of moving the production from on-site to off-site (Larsson, et al., 2013). The concept means that a product is partly or completely manufactured off-site and transported to the construction site for mounting (Lindelöw, et al., 2015).

Prefabrication has been identified with benefits concerning time, quality, cost, health and safety (Blismas, et al., 2006) (Gibb & Isack, 2003). Obstacles to increase the usage of prefabrication are related to process, value, conservatism and knowledge (Blismas, et al., 2005). Another hindrance with prefabrications is the early establishment of the structure design in the project lifecycle due to the long supply chain (Larsson, et al., 2013).

According to Lindelöw et al. (2015), the advantage with traditional on-site construction, a production strategy based on norms and standards, is the high ability to be flexible. Anything
can be constructed to anyone. However, with a greater degree of prefabrication, problems regarding coordination of the work at the construction site will decrease.

One concern that is specific for bridge construction and not a general concern for construction is traffic disruption, which is reduced by prefabrication (National Cooperative Highway Research Program, 2003).

Even though the benefits and complications with prefabrication are well-documented (Blismas, et al., 2006) they are poorly understood by many practitioners, which lead to an unwillingness to use the technology (Pasquire & Gibb, 2002) (Larsson, et al., 2013).

4.3.2 Standardization

Standardization is a core element within the concept of industrialized infrastructure construction (Larsson, et al., 2013). Standardization means actively reducing the number of variants of an activity or a product with the aim to optimize the economic and technical properties. Standardization involves creating systematic and structure of processes, but also of technical solutions. By establishing systematics and structure, advantages can be obtained with respect to reoccurring problems. Standardization is a prerequisite for structure and documentation as well as for continuous improvements and development, since the starting point is made visible (Lindelöw, et al., 2015). The continuous improvement of standardized processes is assisted by standardized products which imply that it is important to be able to switch focus from products to processes (Larsson, et al., 2013) (Höök & Stehn, 2008). A higher focus should be on information flow rather than material flow, which is the common priority in the construction industry (Larsson, et al., 2013).

When a process is standardized, it will be performed the same way regardless of who performs it. This entails a repetitive and stable process. A standardization of technical solutions such as interfaces, geometry and dimensions creates the conditions for compatibility and interchangeability (Lindelöw, et al., 2015).

The key to success is balance between standardization and flexibility (Gann, 1996). For products, a standardization of interfaces, geometry and dimensions creates conditions for compatibility and interchangeability (Lindelöw, et al., 2015). Standardized products or processes have also been identified as a strategy for decreasing complexity in construction (Bertelsen, 2004).

4.3.3 Automation and robotics

Sakichi Toyoda, founder of Toyota Industries and inventor of automated power looms, defined automation as transferring human intelligence to automated machinery so machines are able to detect the production of a single defective part and immediately stop themselves while asking for help. The automated power looms invented by Sakichi Toyoda stopped instantly when a thread broke, enabled for one operator to oversee many machines with no risk of producing vast amounts of defective cloth (Womack & Jones, 2003).
The term automation and robotics technology refers to generation, development, and implementation of innovative ideas. It also refers to adoption and implementation of products or processes developed outside the industry in order to enhance the efficiency standard operations and in some cases to yield a better product (Son, et al., 2009).

In the construction industry, there is a constant demand for increase in quality and reduction of construction time. Higher quality can be guaranteed with standardized processes since there is a reduced probability of defective workmanship. This results in more satisfied clients and invitations for additional projects. The implementation of automation and robotics in construction is a way to standardize processes and thereby improve the quality, but it also increases the productivity since robots work faster than humans and are more reliable. The use of construction robots will also, through a reduction in manual labor through savings in skilled manual labor on-site, improve the contractor’s ability to compete (Kumar, et al., 2008).

Another advantage with the implementation of construction robotics is that hazards to human workers can be reduced. In addition to an improvement in safety and a reduction of health risks, there is a reduced need for investment in personal protective equipment and safety management, from which reduced costs for safety follows (Kumar, et al., 2008).

### 4.3.4 Lean construction

Lean construction is an approach based on the principles of Lean; more can be produced with less when providing customers with exactly what they want when they want it. This means that production occurs in processes that consume as little resources as possible, comprising a reduction in time, human effort, equipment, surfaces and waste (Blücher, et al., 2007). Lean construction, sprung from the manufacturing industry, is a new way to manage construction in order to reach perfection in performance with the goal to maximize value and minimize waste. (Ballard & Howell, 1998b)

Lean construction should not be seen as application of techniques from manufacturing to construction but as a managerial way of handling dynamic projects. With this approach the application of Lean to construction is possible. (Ballard & Howell, 1998b)

A Danish questionnaire with 485 respondents from the construction industry (60% of the respondents were contractors) shows that 6% know and use Lean in construction (17% know but do not use and 77% don’t know or use). However, some of the 77% respondents that claim that they neither know nor use Lean say that they use techniques and methods that are seen as Lean. With these respondents taken into account, the actual use of Lean principles in the construction industry increases from 6% to 14%. Findings also showed that miss-conceptualize and miss-implementation of Lean Construction was a main issue, due to lack of knowledge, education and communication at right level. Because of this, the full effect will most likely not occur when implemented partly or wrongly (Wandahl, 2014).

The principles, concepts and methods of Lean construction are powerful tools for systematic improvements, where the aim is to increase the value adding time of the total process time. Traditionally, the improvement work has been done with focus on reducing the time of the value adding activities, however, greater effect on the total process time is obtained if there instead is a strive to eliminate the wasteful activities. This can be achieved by considering the complete value stream of the production (Blücher, et al., 2007).
The goals of Lean construction redefine performance against three dimensions of perfection:

- A uniquely custom product.
- Delivery instantly.
- No buffers. (Ballard & Howell, 1998b)

According to Ballard and Howell (1998b), buffers or wasted capacity are the natural consequence of unreliable flow.

However, field observations done on structural steel frames erection process testing three hypotheses; Lean principles will improve project performance, Lean principles will make construction processes more volatile, and managing construction buffers is a key to moving to leaner processes, showed that zero buffer at construction site caused high volatility to the process and made it sensitive to variance in reliability. Conclusions drawn from this are that managing buffer size is a critical component for implementing Lean principles in construction processes (Al-Sudairi, et al., 1999).

Lean forces attention on how value is generated rather than how any one activity is managed. The design phase is the place to “stop the line” by assuring no defective assignments are released downstream (Ballard & Howard, 1998a).

Lean Forum Bygg has since 2010 handed out an award named Lean construction of the Year. The three nominees for the Lean construction of Year 2015 have collected their tips on how to become Leaner. for example bringing the design team together and put them all in the same room, daily meetings and decentralized planning The benefits from Lean for these three construction companies are many, such as improved quality, shorter lead times and decreased reclams (Melin Lundgren, 2015).

4.4 BIM

BIM can be used for preservation and product development of the construction system, which are important activities for industrial construction (Lindelöw, et al., 2015). Building Information Modelling (BIM) have many definitions, here follows two that the authors have found to be representative:

“Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder.” (National Institute of Building Science buildingSMART alliance, 2015)

9 Årets Lean-byggare
“A verb or an adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation.” (Eastman, et al., 2008)

BIM can represent different things depending on the perspective taken. The National Institute of Building Science buildingSMART alliance (2015) presents three different perspectives and what BIM represents when it is applied in each perspective.

- **Project**: Information management where the right information should be transferred to the right person at the right time. The information and data is contributed to and shared by all project participants
- **Project participants**: BIM defines how a team, or many teams, work together to conceive, design, build and operate a facility. BIM can be seen as an inoperable process for project delivery.
- **Design team**: BIM leverages the technology, solutions, encouraging creativity, providing feedback and empowering teams. BIM represents integrated design from this perspective.

By facilitating communication between design team and production team through visualization, BIM can be used as a tool to increase constructability. In order to reach constructability, integration between design and production is accomplished by integrating production competences in the early design phase of the project. A downstream flow of design information to production is complemented with an upstream flow of constraints from production to design (Jensen, et al., 2012).

In a 30-year (1977-2007) retrospective comparison of productivity in the bridge design phase, it was found that the number of drawings clearly increased over time and bridges constructed in the 1990’s and 2000’s were represented in CAD files rather than manual drawings. There was however no significant difference over the years in terms of useful bridge surface area produced per hour or in unit times for various tasks, but more drawings of the same bridge could be produced in the same time when CAD files were used instead of manual drawings (Bröchner & Olofsson, 2012).

A problem regarding BIM in the current situation which needs to be addressed is the lack of interface between different software, since the different BIM software are not built around the same databases as the other software used within the company. There would be great benefits if information from the BIM model could be reused for production preparation and costing establishment (Lindelöw, et al., 2015).

A rigorous analysis has showed that the combination of BIM and Lean construction, despite their quite different initiatives, has synergy effects. The two can be used separately and are not dependent on each other, but combined, the outcome of both Lean and BIM is enhanced. Implementation and usage of BIM technology can be seen as a catalyst or enabler for transformation into Lean (Dave, et al., 2010).
4.5 Production strategies

A strategy how to produce something is found in all industries that produce something. The strategies describe the corporate plans and policies regarding production (Gerth, 2008). The four main production strategies are presented in Figure 5 and below:

- **Engineer-to-order**: the customer is involved in the design phase and all design and engineering work is done after an order has been made.
- **Make-to-order**: the customer is involved after the design phase and products are configured based on predetermined selections but produced after customer has made an order.
- **Assembly-to-order**: elements are fabricated and these prefabricated elements are mounted together into products after the customer has made an order.
- **Make-to-stock**: mass-produced products are put on stocks. (Lindelöw, et al., 2015)

The construction industry is considered to belong to the production strategy engineer-to-order (Lindelöw, et al., 2015). Also, project-based approaches and “pull” dominate the construction industry (Vrijhoef & Koskela, 2005a).

![Figure 5. A visualization of the four production strategies engineer-to-order (ETO), make-to-order (MTO), assembly-to-order (ATO) and make-to-stock (MTS), based on where the order point hits the product process (Gerth, 2013).](image)

In the automotive industry, a part of the manufacturing industry, the production has, between the mid-19th century and the early 20th century, developed from craft based production (engineer-to-order) to mass production (make-to-stock). In the late 20th century a transition from mass production to mass-customization took place. Mass-customization corresponds to the make-to-order strategy, which is the strategy used by the automotive industry today. Mass customization means that the customer has the opportunity to make personal choices among some alternatives to mass production prices (Lindelöw, et al., 2015). The production development in the automotive industry is presented in Figure 6.
Figure 6. The development in the automotive sector from craftbased production, to mass production and mass customization. Each colored area represents a specific production strategy (Gerth, 2013).

Further, production can be divided into three types: craft, mass and lean. They differ in worker’s skills and applied technology, see Table 2. Construction is most similar to the craft production type (Al-Sudairi, et al., 1999).

Table 2. Different production types (Al-Sudairi, et al., 1999).

<table>
<thead>
<tr>
<th>Production type</th>
<th>Worker’s skill</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craft</td>
<td>High</td>
<td>Simple</td>
</tr>
<tr>
<td>Mass</td>
<td>Unskilled/semiskilled</td>
<td>High-rigid</td>
</tr>
<tr>
<td>Lean</td>
<td>Multi-skilled</td>
<td>High and flexible</td>
</tr>
</tbody>
</table>

When comparing the production strategy in the construction industry with one in the automotive industry, the construction industry use the same production strategy as the automotive industry used during the 19th century (Gerth, 2013).

In contrast to most other production industries, craft based production prevailed largely in the construction industry for the first part of the 20th century and do still characterize the construction industry to a remarkable extent. The evolution of construction has not been similar to that of manufacturing, where the productivity steadily increases. The cause of the manufacturing industry’s growing productivity curve is considered to be the changes made in templates of production (Koskela, 2000).

Craft based production is considered to be inefficient, since the craftsperson is wasting motion by moving around and working on lowly and challenging tasks alone. In mass production the higher-level thinking tasks are assigned to managers and professionals, the work is separated
into parts, each scientifically optimized, and defined in detail by an expert. The work is then taught to an unskilled worker and performed repetitively throughout the day (Liker & Franz, 2011).

Mass production is efficient and provides lower-cost products in mass quantities to customers. However, something is lost in the transition from craft production to mass production. In craft production, the worker is thinking about how the work could be done better, e.g. save materials, improve the quality of the product for the customer. In short, innovate in the product and the process. There are ways to balance the efficiency of mass production and with the benefits of craft production, which has been applied by Toyota. Responsibility for control and continuous improvements of products and processes, are put on work groups that do and study the work. In parallel, teach and learn activities, like plan-do-check-act/adjust, are undertaken. The duality between process improvement and skill development is inseparable and if split between the staff thinkers and the line doers, the hope of continuous improvement is destroyed (Liker & Franz, 2011).

Industrialization of processes in the construction industry requires new production strategies, which entails changes in management, organization and production systems (Gerth, 2013).

### 4.6 Differences between manufacturing and construction industry

Industrialization and Lean principles have been successfully implemented in the manufacturing industry, but the fundamental principles are general and can be applied in all kinds of production where the aim is to increase the efficiency of the production process, hence the productivity, and thereby increase the competitiveness of the company. However, the construction industry and the manufacturing industry differ in many aspects (Blücher, et al., 2007). In the following section some of these differences are highlighted.

The construction industry is dominated by project-based production including temporary organizations and is sometimes seen as a “loosely coupled system” of projects (Vrijhoef & Koskela, 2005a). A project is defined as a temporary organization consisting of a coalition of firms, with distinctive properties, chartered by a client. A project moves through a predetermined life cycle, with a termination date and limited resources for the temporary organization. Projects are embedded in contexts that are both organizational and institutional, simultaneously shaping and being shaped by these contexts (Winch, 2010). Every project is usually different and delivered to a different client (Vrijhoef & Koskela, 2005a).

It is common that these new organizations in each project consist of new people, making it difficult to systematically learn from the production. In addition to this, the construction industry is often lacking a well standardized production process, resulting in difficulties with perusing improvements (Blücher, et al., 2007).
As said before, the characteristics of a project are temporary organizations. The five stages of the development of temporary organization, working as a team, are described in Tuckman’s Team Development Model (Tuckman & Jensen, 1977):

- **Forming**: Uncertainty about roles and tasks, team members look for guidance and direction.
- **Storming**: Growing confidence in team, concerns about team hierarchy. Denial and resistance to perform tasks.
- **Norming**: Acceptance and open view about the team’s individual differences. Procedures for task performance are dealt with.
- **Performing**: Resources are allocated efficiently. The team is able to solve problems, communicate effectively and share final objectives.
- **Adjourning**: Disengagement of relationships between team members and a short period of recognition for the team’s achievements. (Tuckman & Jensen, 1977)

Tuckman highlights some important observations of the team development lifecycle:

- A team will not be fully effective unless it reaches the stage of performing.
- Many teams accept storming as a normal way of operating, while a number of teams may never get beyond forming.
- Unless the process of norming is fully finalized, teams may degenerate into storming.
- The required time to complete the cycle will vary tremendously between teams. (Tuckman & Jensen, 1977)

Vrijhoef and Koskela (2005b) have also presented a comparison of the culture, structure and management in the construction industry to other industries, see Table 3.

<table>
<thead>
<tr>
<th></th>
<th>Construction</th>
<th>Other technology-driven industries</th>
<th>Non-technology industries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culture</td>
<td>Informal</td>
<td>Formal</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Structure</td>
<td>Fragmented</td>
<td>Consolidated</td>
<td>Integrated</td>
</tr>
<tr>
<td>Management</td>
<td>Project driven</td>
<td>Process driven</td>
<td>Customer driven</td>
</tr>
</tbody>
</table>

The construction industry structure has been rather fragmented and oriented towards getting the work done on time and within budget. The fragmented structure of the industry has been criticized for not being efficient. However, fragmentation does not have to mean low efficiency in the post contract period. In this particular period, the fragmentation may lead to increased efficiency of resource allocation and speed of information exchange between parties (Vrijhoef & Koskela, 2005a).
Three major peculiarities of production in construction have been discussed by Vrijhoef and Koskela (2005b):

- Site production (i.e. organizing the production around the product dependent on outdoor conditions)
- Temporary production organization (e.g. fragmented supply chain)
- One-of-a kind product (e.g. engineer-to-order project-based production).

Many times, particularly within the realms of Lean construction, the basic hypothesis is that the three peculiarities presented lead to variability, and thus to waste, and low performance levels in terms of productivity and value delivery to clients (Vrijhoef & Koskela, 2005b). These peculiarities are also highlighted in Blücher, et al. (2007), where it is stated that the production conditions in the manufacturing industry are the same for every product that is manufactured, whereas parameters such as temperature, weather conditions, location, supplier and organization changes from one project to another in the construction industry.

There is also a difference regarding the flows, which are more complex in the construction industry where resources such as skilled labor, equipment and materials are moved between workstations, in contrast to the manufacturing industry where only material and components are moved from one workstation to another (Blücher, et al., 2007).

In Table 4, Gao and Low (2014) summarize differences between the construction and manufacturing industry, with support from previous research.
Table 4. Differences between the construction industry and the manufacturing industry (Gao & Low, 2014).

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Construction industry</th>
<th>Manufacturing industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (life cycle)</td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>Nature</td>
<td>One-of-a-kind nature</td>
<td>Repetitive</td>
</tr>
<tr>
<td>Work station</td>
<td>Transient</td>
<td>Stable</td>
</tr>
<tr>
<td>Material components</td>
<td>Non-standardized</td>
<td>Standardized</td>
</tr>
<tr>
<td>Material supply</td>
<td>Schedule-driven</td>
<td>Order-driven</td>
</tr>
<tr>
<td>Safety provision</td>
<td>Less enforced</td>
<td>Highly enforced</td>
</tr>
<tr>
<td>Labor force</td>
<td>Seasonal, low job security</td>
<td>Not seasonal, higher employment security</td>
</tr>
<tr>
<td>Wages</td>
<td>Vary depending on skill, experience and employment</td>
<td>More stable wage policies</td>
</tr>
<tr>
<td>Environment</td>
<td>Productivity influenced by the change in environment</td>
<td>Productivity less influenced by the change in environment</td>
</tr>
<tr>
<td>Assembly and production</td>
<td>Final production is assembled in situ</td>
<td>Within the factory</td>
</tr>
<tr>
<td>Technology</td>
<td>Low level of automation, prefer not to use</td>
<td>Better and advanced</td>
</tr>
<tr>
<td>Quality</td>
<td>Related to production conformance, rework is common</td>
<td>More closely to process control, rework is generally avoided</td>
</tr>
<tr>
<td>Owner involvement</td>
<td>Highly involved</td>
<td>Less involved</td>
</tr>
<tr>
<td>Culture</td>
<td>Ill-defined, site personnel know nothing of company’s management philosophy</td>
<td>Clearly defined so that staff are conscious of it</td>
</tr>
<tr>
<td>Regulatory intervention</td>
<td>Design solution and many work phases in a construction project are subject to checks and approvals by regulatory authorities</td>
<td>Less subject to checks and approvals</td>
</tr>
</tbody>
</table>
In order to emulate the Lean approach of the manufacturing industry and thereby allow for a more efficient production, the construction process has to be more standardized from which it follows that construction ought to be less conducted as projects. There also has to be more fixed organizations that don’t change between each new construction project (Blücher, et al., 2007). A step towards more repetitiveness in the construction industry would influence the supply chain considerable. The level of integration would increase and probably generate long term team collaboration which would strengthen some suppliers’ position (Vrijhoef & Koskela, 2005a).

The fact that the production is usually driven as projects in the construction industry is one of the reasons why production costs often are high. An industry operating in projects has generally high product development costs, a low degree of standardization, high overhead costs and lost knowledge capital (Blücher, et al., 2007).
5 Findings

This chapter presents the empirical findings from observations and interviews. Through a case study, it has been possible to map the reinforcement process for several actors in a design-build project, from initial design to execution. In addition, interviews with relevant respondents, not connected to the case study but from academia, have been conducted. To begin with, the case study will be presented by briefly introducing the construction company Skanska AB followed by an introduction to the case study. Subsequent to this, data gathered from interviews and observations regarding both the case study and overall efficient bridge construction are presented.

5.1 Presentation of the case study

The aim with the case study is to map the reinforcement process, its current obstacles and potentials for improvements, in a bridge project. Findings originate from interviews, observations and documents and are presented in the section 5.3.

5.1.1 Presentation of Skanska AB

Skanska Sverige AB is an affiliated company to Skanska AB and is one of Sweden’s largest construction companies with 11 000 employees in Sweden, more than 2 500 projects yearly and a revenue of 33 billion SEK. Globally Skanska AB has 57 000 employees, 136 billion SEK in revenue and the company completed more than 10 000 projects in 2013. The company was founded in 1887 in the southern part of Sweden as a concrete product manufacturing company and has developed tremendously since then. Today, the focus is on profitability rather than growth and the goal is to be the developer of the future of tomorrow (Skanska AB, 2013).

Construction, residential development, commercial property development and infrastructure development are Skanska AB’s main operations. Skanska AB has domestic markets in both Europe and America (Skanska AB, 2013).

5.1.2 The Slammertorp bridge project

The project under study is a roadway bridge project. The bridge is called the Slammertorp bridge and is part of the Mälarbanan project in which 20 km of the Mälarbanan is expanded from two tracks to four tracks between Tomteboda and Kallhäll in Järfälla municipality in the area of Stockholm. The aim with the project is to increase the capacity of the Mälarbanan by
separating the commuter trains from the rest of the rail bound traffic. In order to accommodate for the expansion of the tracks the old bridge over the tracks had to be demolished and a new one, the Slammertorp bridge, was built over the widened railway tracks south of the old bridge.

The construction of the bridge started in 2012 and was completed in 2014. The bridge was a design-build contract where STA was the client. This means that Skanska Sverige AB had the responsibility for both design and construction. However, the Mälarbanan project as a whole is a design-bid-build project.

The overall length of the bridge is 135 meters and it has a slight horizontal and vertical curvature. It is a concrete bridge that consists of four mid piers which carry two cross beams on which the bridge deck rests. Due to difficult ground conditions one of the abutments and some of the bridge piers are founded on piles. The Slammertorp bridge is shown in Figure 7.

![Figure 7. The Slammertorp bridge (Trafikverket, 2014)](image)

### 5.2 The reinforcement process

The total amount of reinforcement used in the Slammertorp bridge was approximately 300,000 kg. According to SI, approximately 5% of the reinforcement in the Slammertorp bridge project was prefabricated.

In the production phase of the project, approximately half of the total work was dedicated to the reinforcement (PE). PE estimates that 80% of the reinforcement work consisted of mounting. Also in the design phase, approximately half of the total time is generally dedicated to the reinforcement, according to DE2.

In the Slammertorp bridge project, both design and production were carried out by Skanska Sverige AB. The production was involved early in the design phase of the project which resulted in improved constructability. The project manager decided that design meetings were to be held every other week during the design phase at which the project manager, the production manager, the superintendent, the design manager, design engineers and representa-
atives from STA were present. The production manager and the superintendent requested prefabricated reinforcement for shortened construction time and improved site conditions. Regular design meetings were held on a weekly basis.

In the design phase, structural calculations were made and the bridge was designed. Calculations and 2D drawings were sent to STA for review, after which the design engineer made calculations for the reinforcement and 2D reinforcement drawings were made. Two of the intermediate supports and the superstructure were 3D modelled by the BIM coordinator, but due to lack of time, these were only used in production and not sent to the reinforcement supplier.

Reinforcement documents and 2D drawings were sent to the reinforcement supplier where prefabricated reinforcement elements were made for some parts of the foundation slabs. The reinforcement supplier made 3D models of the prefabricated reinforcement elements to facilitate fabrication. The reinforcement elements and cut and bent reinforcement were then transported to the construction site where they were mounted. A flow chart of the reinforcement process is presented in Figure 8.

<table>
<thead>
<tr>
<th>Client</th>
<th>Enquiry documentation</th>
<th>Review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Structural design drawings 2D</td>
<td>Structural design with reinforcement drawings 2D</td>
</tr>
<tr>
<td>Contractor</td>
<td>Structural design drawings 2D</td>
<td>Structural design with reinforcement drawings 2D</td>
</tr>
<tr>
<td>Production</td>
<td>Requirements</td>
<td>Requirements</td>
</tr>
<tr>
<td>Supplier</td>
<td>Revision and fabrication (Cut and bent and prefabricated elements)</td>
<td>Receive and mounting</td>
</tr>
</tbody>
</table>

Figure 8. Mapped reinforcement process in the Slammertorp bridge project. Information flow is symbolized by arrows. Green represents digital transfer (dwg, xml, tbp). Red represents “dead” format (pdf, mail, paper, verbal).

### 5.3 Mapping obstacles and potentials

Findings that concern both the case study and general reinforcement process are presented in this section. The aim is to map obstacles and potentials for increased productivity in bridge construction through implementation of Lean methods and industrialization of the reinforcement process. Findings from the following areas will be elaborated: communication, Lean, industrial construction, prefabrication, BIM and visualization, differences between the manufacturing and construction industry, as well as organization and corporate culture. Abbreviations are found in the method chapter, section 2.2.3.
5.3.1 Communication

Meetings

BC implies that communication between actors is an important factor for success. If the inspector from the client, who possesses great knowledge, and the production are involved in the early phase of a project, the outcome is excessively better (PM). If there are many actors involved in a project, it is important with transparency (SI). The frequency of meetings depends on the size of projects. Big projects prioritize meetings in a greater extent than smaller projects (DE1). The weekly design meetings that were held during the design phase of the Slammertorp bridge project were appreciated. The continuity of the meetings and the close collaboration with the production facilitated the design process (BC). The meetings in the Slammertorp bridge project were videoconference and face to face but it would have been ideal if you as a design engineer could sit on-site since that is where the knowledge about reinforcement mounting is (DE1). PM and SI agrees with this and believe that generally, it would be desirable if the design engineer could be physically located at the construction site during production. In the production phase it is important with quick answers and feedback (SI).

Production involvement in design phase

The project manager in the Slammertorp bridge project decided that collaboration between design and production was to be initiated early in the design phase (PdM). The early production involvement in the design phase enabled adjustments of the reinforcement regarding constructability which decreased change feedback in the production phase since the problems had already been solved in the design phase (DE1). The adjustments regarding increased constructability were for example reduction of joints, change of reinforcing bar dimensions and bending types. These changes improved the work conditions on-site (PdM). PdM also recognize that many production problems were solved already in the design phase due to early involvement.

Furthermore, DE1 states that the extraordinarily high engagement from both production and design management was an important factor in the Slammertorp bridge project. There is a difference if both the design and production phase are carried out by the contractor in contrast to having external consultancies involved in the design phase. It is easier to engage the production in the design phase if the whole process is done within the same company (SI). According to BC, the reinforcement design process for the Slammertorp project is recurring, however, the requests from the production regarding the degree of prefabrication and constructability varies from one project to another. The exchange of reinforcement document in the design phase of the Slammertorp bridge project did not differ from other similar large projects (BC). One difference could be that in smaller projects, the drawings are sometimes made by the design engineer instead of the BIM coordinator (DE1).

DE1 believes that more time and money have to be invested in the design phase to accomplish time savings in the production phase. SI is of the same opinion and says that early involvement of the production in the design phase means time savings in the production phase. An example is that requests from the production of prefabricated elements can be made (SI). Errors will decrease if the production is involved in the design phase, but “errors cannot be
fully eliminated since the reality always differ a bit from theory”, according to PE. It is therefore essential to develop a process that quickly handles errors.

**Knowledge transfer**

The knowledge follows those who have been involved in the project and is not documented. Asking is the only way to access the knowledge (PE). BC agrees and says that “reports about lessons learned can always be written but you will never know if they are read and by whom”. Talking about experiences and lessons learned face to face is therefore a more efficient communication way than reports (BC). The knowledge is transferred with the person carrying it and not put down in any document (TA). PdM shares this view and says that lessons learned and experiences are carried on to the next projects by people and are not documented. There exists no process for knowledge sharing today, CM says. Also, information about lessons learned is not searched for until it is needed which prevents the “think ahead” (CM). PdM thinks it hard to find desirable information from previous projects on the intranet. PdM suggests a database where you can find projects, involved people and encountered problems in order to avoid repeating mistakes. According to SI there exists no system for knowledge transfer today. This means that the same mistakes are repeated.

Today there is no standardized way for knowledge transfer and this is demanded. The knowledge transfer is today done from person to person. This is a drawback when experienced employees retire or quit and the knowledge thereby leaves the company. There exists a group with those of us who work with bridges, the climate is friendly and open minded to new ideas and innovations (PM). For the design engineers it is possible to look at previously executed projects and solutions. The benefits with this are that you avoid repeating errors made earlier and can take advantage of previous experience (DE1). The 3D model/BIM also carries some knowledge which it accessible for subsequent projects (PdM).

Pulse meetings are often an important part of knowledge transfer in the manufacturing industry. They are often held once a week and during the meetings current status, improvements and required resources are discussed. A problem with meetings is that they require attendance and attendants’ engagement. Preparation documents are established in the manufacturing industry, including information about how and why the operator should assembly and perform a task in a certain way. Preparation documents ensure that the latest knowledge is distributed to and exercised by every operator (Prof IP).

**Reinforcement supplier**

DQM, as a reinforcement supplier, states that “communication is a part of our business and it is extremely important that we are good in communicating otherwise we will lose customers”. Information about state of production, delivery time and type of delivery is communicated to the client. The communication with the client increase if prefabricated reinforcement cages is chosen over cut and bent since more questions arise regarding e.g. shapes, element sectioning and spacer bars. Further on it is important that the final reinforcement documents from the client are communicated and used as order documents. If the order documents are revised by the client it entails extra work for the reinforcement supplier (DQM).
As for the internal organization within the reinforcement supplier company, EM says that the roles in each step are very clear. It is always the same person that is responsible for one task (EM). EM says that all orders follow the same flow: sales – design – production – logistics. Both DQM and EM do however agree that there is room for improvements concerning the workflow.

5.3.2 Lean

IPM defines Lean as a system for continuous improvements. Prof IP fills in that Lean is above all about management and not only about waste. Prof IP names Lean as leadership structure. The actual meaning of Lean is knowledge in basic production management. If Lean is supposed to be understood within the construction industry this expression is more explanatory than the word Lean (IPM).

IPM says that Lean is not equal to industrial construction, and adds that implementation of Lean is possible without implementation of industrial construction but not reverse. Further on, Lean cannot be applied to individual projects but has to be applied and implemented to the whole company. Today knowledge is not shared to new projects, but every project start on a blank paper. Lean construction therefore works in individual projects in the construction industry but not between projects (IPM). Lean implementation has to be supported by the management and further, the management must engage the whole organization in the improvement work (Prof IP).

There are great potential for Lean in the whole construction chain (Prof IP). Both IPM and Prof IP say that if the companies within the construction industry were aware of the potential benefits of Lean, the implementation of Lean would be more visible than it is today and the organizational structures would be different. By this, Lean is not compatible with the current construction industry mentality and culture (IPM), and it is the construction corporate culture and the mentality that are the greatest obstacles for Lean implementation (Prof IP).

5.3.3 Industrialized construction

Industrial construction is about connecting organizational, information and production strategies and the first step towards industrial construction is process mapping (Prof IP). The concept of industrial construction is an efficiency improvement strategy for an individual company. It is about creating value for the client in every step in the delivery. It is not possible to partly industrialize a process, since a sincere attempt to industrialize will affect everything (IPM). IPM says that there are potential for industrialization for all actors in all phases. However, IPM continues, it is only possible to industrialize the processes and products a company owns and controls. Therefore, those who possess the whole construction process, e.g. contractors that holds both design and production, are those who have the greatest potential for financial gains due to implementation of industrial construction. CM says that today, there is much focus on sub optimization. Prof IP states that in order to implement industrial construction, the client has to set requires on suppliers and subcontractors.
Due to low productivity in the construction industry, implementation of industrial construction is necessary in order to be competitive (Prof IP). Opinions whether the construction industry is aware of the potential gains with industrial construction differs between the respondents. For example, Prof IP says that there is an awareness of the potential benefits with industrial construction in the construction industry, but the knowledge in how to address the current productivity problems does not exist and according to IPM, the construction industry is not aware of the potential gains with industrial construction.

The responsiveness for ideas and innovations is much higher today than it was several years ago (PM). However, the construction industry still indulges in handicraft – customization, but not mass-customizationas in the manufacturing industry. Mass customization should be the aim for the construction industry, and this is not possible without implementation of industrial construction (IPM). The industrial production methods and processes from the manufacturing industry cannot be mimicked entirely, since the corporate culture in the construction industry is different, according to Prof IP. Prof IP thinks that processes concerning production engineering can be transferred to the construction industry whereas other areas have to be developed by the construction industry itself. So, in order to incorporate industrial construction, the organizational structure has to change and also new and different roles have to be implemented (Prof IP).

Beside quality improvements, IPM also thinks that there is a potential of 60-70% increased efficiency due to implementation of industrial construction. In order to implement industrial construction investments are needed (IPM). Today, industrial construction does not exist in large construction companies but can be found in single smaller building construction firms, e.g. the small company called Tomoku Hus that specializes in wooden modules, produced in Sweden and shipped to Japan (Prof IP). IPM predicts that the industrialization of the whole construction industry will take time, approximately 20 years.

**Standardization**

The standardization potential for the reinforcement process is huge (SI). By going towards a more standardized design and higher usage of prefabricated elements you get “more bridge for the money” (PdM). Today every bridge is unique even though it is possible to design and construct more standardized bridges. Standardization and prefabrication is therefore part of the future (PdM). The foundation of standardization is however standardized processes (Prof IP). Standardization gives routines and thereby less errors and quicker processes (PM).

Industrial construction often mean standardization in design to some extent, from which limitations in customization follows; the client cannot get exactly what is desired but only the closest offered solution. However, an advantage is that the solution offered is much cheaper (IPM). Mass customization in the manufacturing industry allows for flexibility. Mass customization should be the aim for the construction industry as well (IPM).

When working with standardized modules, i.e. standardized geometries, the physical connection between the modules is often the most difficult part (Prof IP). Furthermore, PM says that it would be appreciated if there were standards in design regarding architectural guidelines for bridges (PM). A limitation for standardization of design is that, sometimes, the client’s request for architectural design counteracts the standardization (SI). The architectural aspects are more common in the building construction than in the infrastructure construction which would make infrastructure constructions favorable for prefabrication and standardization. The architectural aspects could limit the use of prefabrication and standards. It is up to the client to
consider the cost savings connected to prefabrication and standardized geometries and measures that limits the desired architecture compared to the gains of a desired architecture that is incompatible with standards. Often, a company’s awareness of how their products are optimized is low. The benefits with prefabrication will be even bigger if the concept fully extends to both industrial construction and standardization (IPM).

BC believes that there are great potential for improvement regarding standardization and development of the reinforcement process in the construction industry. People working within the construction industry do things the same way as they have always done. The construction industry has not development in the same speed as other industries (BC). When it comes to reinforcement, standardization of processes is preferable to standardization of design and geometry. A standard prefabricated reinforcement design complicates for optimization of the amount of reinforcement (TA). From the current situation, the amount of reinforcement can be decreased with 10-20% by optimization in the design phase. This can be achieved if every bar is optimized instead of calculating a critical section. Standardization of geometry would counteract with this aim. Due to this, standardization of dimensions and design regarding reinforcement is not preferable from a material consuming and an environmental perspective (CM).

Working with 3D automatically gives a standardized process (BC). It is easy to extract the reinforcement specification from the BIM, which means that the specification does not have to be made manually. This saves time but also reduces the risk for human errors since the specification generated fully correlates to the model (BC). This is supported by CM who says that 3D models give a standardized expression which is a benefit. However, CM adds that standardizing geometry and design is not to optimize. The focus for the future should mainly be in how to simplify for optimization and not only in standardization (CM).

Skanska Sverige AB is currently working with the concept “normalläge”10, which means that lessons learned from many projects has formed a standardized way of working with a specific task. The benefits with this are that good ideas and solutions are shared and that you don’t have to “reinvent the wheel” (BC). Working with “normalläge” ensures a current solution for a specific part that is well-tried and optimized. However, it do not exist “normalläge” for every task. Many are experiencing that their project is too unique for solutions in accordance with “normalläge” (PE). Since every bridge is a prototype, “normalläge” cannot be used for the entire bridge. The benefit with “normalläge” is that errors can be eliminated. A drawback could be that “normalläge” hinders the development and new initiative. There is a risk that “normalläge” does not encourage thinking for oneself (SI).

**Parametric platforms**

At the technical consultancy firm where IPM works, a team that works with development and implementation of parametric platforms and modules has been appointed. Their task is to be a technical support for the design engineers in their work with parametric platforms for calculations and drawings in order to automate and industrialize consultancy services in the design phase of construction projects. This way, repetitiveness is decreased and most of the engineering work is done before an order is received. Experiences have shown that the time

10 Directly translated into ”normal mode” in English
for the bridge design phase in a project can be reduced by 70% when parametric platforms are used (IPM).

Bridge design is advantageous to industrialize and standardize in comparison to buildings since bridges in a wider extent are controlled by rules and regulations and require more calculations. Rules and regulations differ in every country so parametric platforms and modules have to be modified if they are going to be used outside the Swedish borders (IPM). Standardized processes and formalized activities are prerequisites for all kinds of efficiency improvements. Without a standardized process it is not possible to work in a Lean way. Standardization is a general structure for a process. Modules and parametric platforms are ways of working in a standardized matter in the design phase (IPM).

Towards automation and robotization

It is believed, by BC and DE1, that it is possible to create a BIM that can be sent directly to a robot for automated fabrication of reinforcement cages. However, BC thinks that an automated reinforcement process might demand software development. DE1 adds that it is possible that extra work might be needed for preparation of robot readable documents, e.g. mark welding points that nowadays are not specified. Furthermore, DE1 believes that he will need someone from the production to discuss mounting with. Today the design team lacks the necessary knowledge regarding reinforcement mounting needed to enable for robot involvement. BC says that this kind of knowledge is within the production and therefore they should be involved in the design team. Also, the time plan has to allow for the extra work 3D modelling demands in the design phase and for the productions to be involved in an early stage to share their competence regarding mounting and construction of the reinforcement cage since this knowledge has to be utilized in the design phase (DE1).

The big potential for automation and robotization regarding reinforcement lies with the reinforcement suppliers (PdM). DQM says that with more machinery and robots their business (as reinforcement suppliers) can be more industrialized and thereby more efficient, but this requires financing and new technology. However, on-site prefabrication of the reinforcement cages done by robots could be profitable for projects with a large amount of reinforcement (PdM).

5.3.4 Prefabrication

Prefabrication of reinforcement mainly comprises moving the mounting, assembling and processing of reinforcing bars to a weatherproof area off-site. Generally, receiving and sorting deliveries of cut and bent reinforcement takes time at the construction site, especially if it’s poorly packed. The reinforcing bars have to be sorted and put in inventory. Normally one reinforcing bar at the time is manually mounted and tied or welded. The ergonomics for this kind of labor is poor since the accessibility to binding and welding points is sometimes so bad that crawling is necessary. Due to this, prefabricated elements are preferable in the production phase (PE). A good overall solution is often a combination of several different prefabricated elements, e.g. cages, mesh and roll mesh. The best result is achieved when the cut and bent reinforcement represent a low percentage of an order (DQM). In order for prefabrication to be profitable the prefabricated share has to be relatively large (SI). DQM says that the price for prefabricated cages are higher than for cut and bent but reinforcing bars, but the total cost for a project when using prefabricated cages is lower since the on-site work is reduced and the
overall project time is thereby shortened. If the reinforcement supplier knows the on-site disposition and how the site manager wants to work it is easier for them to come up with good prefabrication solutions, says DQM. DQM further adds that delivery scheduling is an important task of their job. It is extremely important for the flow on the construction site that the reinforcement is delivered on time, and not before or after.

The reinforcement represents 10-15% of the total cost in infrastructural projects, which can be compared to building construction projects where the reinforcement stands for approximately 1% of the total [design and production, eds.] cost (CM). It is rare in bridge projects that the level of prefabricated reinforcement exceeds 30%. The prefabricated cages are often split into sections in order to fit the transport limitations (CM). Prefabrication is used to a greater extent within building construction compared to the infrastructure construction (IPM). Today, approximately 30-70% of the reinforcement in [Skanska Sverige AB’s, eds.] bridge projects are prefabricated. The total reinforcement content increases with approximately 5% if elements are prefabricated due to additional spacer bars (TA). The awareness of the benefits of prefabrication is relatively low in the construction industry, but prefabrication is necessary in order to address the massive issues regarding optimization and efficiency in the construction industry (SI). Incentives for using prefabricated reinforcement cages decreases if the work force is foreign instead of Swedish. Therefore, prefabrication of reinforcement cages does not pay off if cheap labor is accessible (PdM). PE is of the same opinion and says that if foreign manpower is available it is not cost favorably to decide for prefabricated reinforcement cages (PE).

According to BC and SI, in the Slammertorp bridge project the production requested for the reinforcement cages to be prefabricated. This was done during the design phase. There was also a demand from the production that the characteristics/serial letters¹¹ for the cut and bent reinforcing bars should be organized in the right order for mounting (BC). If the project is run completely by Skanska Sverige AB, the involvement regarding prefabrication design is in an earlier phase compared to if external consultants are involved (TA). A request for prefabrication of reinforcement cages demand adjustments regarding the design of the reinforcement to enable for transportation, e.g. where is it possible to weld stabilizing spacer bars and how should the reinforcement be sectioned into elements (DE1)?

The Nordic Procurement Unit

TA says that if prefabricated elements are used, the Nordic Procurement Unit (NPU) team develops a reinforcement concept. They look into where in the structure it is suitable to use prefabricated elements, how they should be designed and how the elements should be mounted on-site. A delivery schedule is developed together with the reinforcement supplier. For all projects where prefabrication is used the working process is similar. First a concept is developed together with the production; sometimes the design engineer is involved. Then, the reinforcement is modelled in 3D and drawings of the elements aimed to be prefabricated are extracted as well as other information needed for manufacturing. An order is then placed at the reinforcement supplier (TA). TA suggests that in the future, the work done by the NPU regarding design of prefabricated elements could be done by the design engineer instead. The

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¹¹ Littera
suggestion to prefabricate often comes from the project (the production) but is sometimes proposed by the Nordic Procurement Unit (TA).

A criterion for decision on prefabrication is that it has to be taken in an early stage, hence time is an important factor (SI). Time is always critical and of great importance when working with prefabrication. It is common that the prefabricated reinforcement elements are designed from the review documents and not from the final construction documents and therefore there is a risk that the reinforcement changes in design and if so, this results in additional work. It would be preferable to wait until the final construction documents are completed. The reason for designing the prefabricated elements from the review documents and not the final construction documents is the lack of time (TA). In the Slammertorp bridge project, the reinforcement supplier required 2-3 weeks delivery time. During the delivery time, changes were made to the drawings which affected the amount of needed reinforcing bars. Due to this, approximately 5% of the ordered reinforcement bars were wasted in the Slammertorp bridge project. Generally, a buffer of 1-2% is ordered to cover spacer bars and any design changes (SI).

**Manufacturing of prefabricated reinforcement cages**

In the existing process, the limitations for the suppliers regarding prefabrication are: transportation, BIM competence, time and software licenses (CM).

At the reinforcement supplier, the prefabrication is for the most parts done manually by humans but in some cases by robots and the information for prefabrication given from the client to the reinforcement supplier is often revised by the reinforcement supplier. The manufacturing of the prefabricated reinforcement elements is approximately to 95% done by humans and the remaining 5% by robots (CM). Observations from the study visit at the reinforcement supplier showed that the mounting and binding of the cages were performed manually. The cut and bending of reinforcing bars were however automated but with manual receiving and sorting of the cut and bent bars.

![Automated cut and bending of reinforcing bar at VMS Group's reinforcement factory in Jelgava, Latvia (Jönsson, 2015).](image)

**Figure 9.** Automated cut and bending of reinforcing bar at VMS Group's reinforcement factory in Jelgava, Latvia (Jönsson, 2015).
If instead, the manufacturing of the prefabricated reinforcement elements was to be made completely by robots without the supplier revising the BIM sent from the contractor, the preparation documents included in the BIM would become extremely important. Positions, grasp area and gripping tools are some of the things that would have to be defined (Prof IP & BC). Robots in production demand fixed positions and have to be built into the production system. It is extremely important with precision and minimal deviations. Therefore the greatest potential for robots in the construction industry is within the prefabrication of elements unless a mobile factory is developed. For industrialization of the reinforcement process through prefabrication, optimal would be if the prefabrication production was in-house, i.e. within the same company, so that the sub-contractors could be excluded. In that way a possibility to address and industrialize the whole organization occurs. One of the benefits when all actors in a construction project are part of the same organization instead of several organizations is that the material waste situation can be turned into inventories instead (Prof IP).

**Transport limitations**

The transport represents a limitation when it comes to prefabricated reinforcement cages due to the dimensions of the trucks (CM). The size of the prefabricated reinforcement cages is limited by the dimensions of the truck for transport from off-site to on-site. This means that the cages have to be divided into transportable parts that are joint on-site (PdM). The number of transports increases when prefabricated reinforcement cages are chosen compared to cut and bent reinforcing bars, since the cages take up more space in the trucks (PE). The maximum load of the trucks is not reached during these transports since a large percentage of the volume of the prefabricated reinforcement cages is air (CM) (DQM and EM). Since the trucks transport a lot of air the trucks that transport cages are poorly optimized. In Sweden, the trucks have a maximum load of 35 000 kg which is desirable to reach. This load is however not possible to reach when transporting cages (PdM). The increased number of transports for the same amount of reinforcement has both a negative economic and environmental impacts (CM).
In addition to the transport limitations, a question that follows with prefabrication is the cranes’ lift capability on-site (SI). Since the cages are heavy they have to be lifted by cranes. Due to this, the cages have to have specified lifting points and be stable and safe enough to be lifted (PdM). Another issue that has to be addressed is the prefabricated elements’ piling compatibility with respect to transportation (CM).

It is not allowed to weld reinforcement connections in constructions that are exposed to fatigue, e.g. bridge construction elements (DE1). Binding is not as stable as welding which means that bound reinforcement cages are unstable, and often too unstable to transport (PdM) (DE1). Due to this, extra reinforcing bars for welding with the single purpose to increase the stability are often added to ensure that the cages do not collapse during transport (DE1). New Eurocodes have however opened up for the possibility to weld in bridge reinforcement structures as long as there are calculations showing that the fatigue requirements are reached. This will probably decrease the amount of spacer bars for fixation and stability in the future (TA).

![Figure 11. To the left: Prefabricated bounded reinforcement cage with stabilizing spacer bars for transportation (Jönsson, 2015). To the right: Picture of four prefabricated reinforcement cages. The two in the foreground have collapsed during transport due to instability issues (Törmänen, 2015).](image)

**Health and safety**

Benefits with using prefabricated reinforcement elements are an improved work environment; less heavy lifts and exposure for non-ergonomic work positions as well as increased safety (SI) (TA) (PdM). The work environment for the reinforcement workers improves when using prefabricated reinforcement elements instead of traditional on-site construction (BC). The exposure for non-ergonomic work positions is reduced and the safety is increased (SI) (TA) (PdM).
Heavy lifts can be avoided by the usage of prefabricated reinforcement cages and the work environment is thereby improved (PdM). The heavy lifts will decrease since the heavy prefabricated elements have to be lifted by cranes (TA). SI adds that on-site construction wintertime or in bad weather conditions is hard and is minimized with the usage of prefabrication.

**Time and cost savings**

In addition to the improved work environment, time savings is a benefit with prefabrication (TA) (SI). BC has a positive attitude towards prefabrication of reinforcement. It saves time at the construction site and thereby also money. PdM agrees and says that using prefabricated reinforcement elements the production time shortens resulting in cost savings. When using prefabricated reinforcement elements, in addition to elimination of a lot of mounting work on-site, the need to put out, sort and mark the reinforcing bars eliminates (PdM). Due to the fact that tasks like binding, welding, 2D drawings interpretation and reinforcing bar mounting minimize, less skilled workers are needed in the production (TA) (SI).

Choosing prefabricated reinforcement saves time, money and the number of work sheds since the need for manpower decreases. The cost for ordering prefabricated reinforcement cages is more expensive but the resulting savings in time and its effects, such as less manpower, fewer work sheds and other project expenses, compensates (PE). If serial manufacturing of prefabricated reinforcement cages is possible, the savings in money are even better (PM). In addition to this, if the cages are delivered just-in-time, the inventory decreases in comparison to using only cut and bent reinforcement (PdM).

Further on, the traffic disturbances related to ongoing infrastructure construction projects can be decreased with prefabricated reinforcement cages due to the decrease in construction time. Prefabrication shortens the production time and therefore the employee turnover increases. This turnover should be something for the organization to consider.

### 5.3.5 BIM and visualization

**Definition and usage of BIM**

Opinions about whether BIM was used in the Slammertorp bridge project differ between the respondents. According to PdM, BIM was used for the reinforcement. This view is however not shared with BC, who says that BIM was not used, but that 3D models were made for some parts of the bridge. PE is of the same opinion and says that, due to lack of time, BIM was not used. BC defines BIM is a 2D or 3D model in which smart information is added to the building parts, such as time plan, AMA\(^{12}\) codes and quantities. PM says that BIM is more than a model thus it includes a wide range of information, e.g. documents regarding quality, preparation and control. CM says that BIM is a tool that captures the whole structure in a model where necessary information regarding e.g. mounting, loading for transport and construction order is included.

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\(^{12}\) Allmän material- och arbetsbeskrivning. AMA is a series of reference literature published by AB Svensk Byggtjänst.
According to DE1, BIM is a trendy concept without a clear definition, which raises the question “Is it BIM or 3D modelling we are doing?”. The difference between BIM and 3D is that BIM include all information and eliminate the need for additional documents and tools since everything exists in the BIM (DE1) (PdM). Due to this, DE1 also argues that it was 3D design and not BIM that was used in the Slammertorp bridge project. The creation and usage of 3D modelling was an experiment in the Slammertorp bridge project (DE1).

BIM is virtual construction, with the ability to construct virtually before physical construction. All necessary information is gathered in one place. In order to fully use BIM in the production phase, tools such as tablet computers are required. Some computer experience is also necessary (TA). SI defines BIM as visual tool that shows time, cost, and drawings in the same model. IPM says that BIM is appreciated and works well in the construction industry. There are many benefits with BIM, it is a pedagogic tool that allows for analyses and information storage (IPM). Additional benefits with BIM are that it is easy to see and follow the projects, it facilitates for those with no or less experience to engage and allows for time savings. BIM is a good visualization tool where the goal is made visible (SI).

Quality assurance

BC says that a big advantage with BIM is that you can identify and solve potential problems early on, before they physically occur at the construction site. Using BIM demands more effort in the design phase, but this pays off in the production phase. Benefits with 3D are that it enables for early detection of errors and collisions since it is possible to see how reinforcing bars relate to each other. Errors can be solved during the design phase (SI). 3D models therefore have a higher quality compared to 2D drawings. 3D modelling forces the design engineer to think about mounting and other questions that may not occur when 2D drawings are made. It is easier to suggest changes to the structural engineer if a 3D model is available (CM). With 3D models the design engineer is forced to solve reinforcement problems already in the design phase. In 2D drawings a lot of information, e.g. bar radius, is not visualized but only presented as text. Sometimes, the numbers of reinforcing bars are presented in the 2D drawing do not even correspond to the factual numbers used. In the Unites States the reinforcement 2D drawings are more detailed than in Sweden. There are also documents that describe the mounting process which facilitates for less experienced to participate (PE).

BC says that working with BIM gives a greater quality control. 3D models visually enables for identification of reinforcement collisions (DE1) (BC) and it is therefore easier to communicate the problems and solve them (PdM). BIM is a great aid for both design and production (PdM). Furthermore, the usage of BIM reduces the risk of receiving incorrectly bent reinforcing bars from the supplier (PdM). Spacer bars are generally not included in 2D drawings but can be visualized in 3D models, which was the case for some of the parts in the Slammertorp bridge project. This additional information is a huge advantage for the production (PE). A quality weakness with 2D drawings is that if revisions are made, a time consuming process of insuring that everyone involved works with the latest version begins. If a 3D model is revised everyone instantly get access to the latest and correct version (PE).
**Visualization and engagement**

A difference between 2D and 3D is that 3D allows and enables workers with little or no experience to understand and engage in the reinforcement work process. 3D models facilitate discussions concerning reinforcement between experienced and less experienced. When problems occur a 3D model is an excellent tool for communication of problem, ideas and solving (PE). Reading and interpretation of 2D drawings demands great experience but 3D models are easier for inexperienced, and experienced, reinforcement workers to read which leads to increased efficiency and greater involvement of the reinforcement workers (PdM). The 3D models create a feeling of team spirit and togetherness since less experienced workers are able to participate in a greater extent. Thereby less experienced contribute to the project earlier on (PE). PM is of the opinion that BIM enhances the technical knowledge of the workers.

Those who fabricate the prefabricated reinforcement cages also need to understand how to read the drawings (EM). The above mentioned visualization advantages with 3D therefore also apply for the supplier in the prefabrication process.

**Communication with reinforcement supplier**

When it comes to prefabrication, a 3D model can be sent directly to the reinforcement supplier, given that they have the necessary software (PM). Today, BIM is often used in the projects with a high percentage of prefabrication (TA). BIM eliminates the risks of error, such as incorrectly bent reinforcing bars, in delivery. This kind of error more often appear if the reinforcement specification has been done manually. BIM is an efficient and productive tool, maintaining all necessary information assemble in one place and model (PE). Another advantage with BIM when it comes to the supplier is that 2D drawings often entail linguistic misunderstandings with foreign suppliers. This problem is minimized when 3D models are used instead (TA). Procurement can be done directly from the BIM since all necessary information is available. A benefit with this is that no human errors occur during reinforcement re-specification (PE).

**Requests**

One concern for the technical development and implementation of BIM is the request from the client, e.g. STA, since they still demand 2D drawings for review. Working with BIM despite the 2D standard request has resulted in additional work. However, STA has recently started to accept 3D models for review (DE1). According to DE1, STA demanded 2D drawings for review in the Slammertorp bridge project. The client’s lack in competence is a hurdle when it comes to 3D reviewing and therefore demands 2D drawings. According to TA, it is however easier to generate 2D drawings from a 3D model than to create 2D drawings from scratch. If all 3D generated 2D drawings have the same origin a quality assurance is also obtained (TA).

The main benefits of BIM lie not in the design phase but in the production phase. Therefore, if BIM is not requested from the production it will not be used by the design engineers (DE1). IPM, who works at a technical consultancy firm, says that BIM only is used upon the client’s request.
Since the decision to use 3D modelling was made late in the design phase, both 3D models and 2D drawings of the reinforcement were created separately in the Slammertorp bridge project which lead to extra work (DE1). The reinforcement specifications were sent as 2D drawings to the reinforcement supplier, since the 3D models were not completed, who converted these 2D drawings into 3D models. It would have been more efficient if 3D models had been sent directly to the supplier (SI). Errors almost always occur when the reinforcement specifications are made manually instead of being extracted from the 3D model (SI). Problems can occur when 2D and 3D drawings are made separately and do not correlate, which can be the case if they have not been generated from the same 3D model. Then, is it the 2D or 3D drawing that holds the latest updates (DE1)?

**Software**

If the reinforcement workers have no or little practice of 3D models it takes some extra time to understand how the model works and how it should be handled (PdM). BC agrees with this and says that this is one of the limitations with BIM. If you are new, it takes time to learn and in addition to this there are limitations in the software for handling complex structures. It is also important that you set up limitations for what should and should not be included in BIM. You have to find out what the project need so that you do not include unnecessary information (BC).

The main limitations for technological development lie not within the software but in the competence of using it and expensive licenses. BIM requires some computer knowledge or willingness to learn, but this will probably not be a problem with the facing generation shift (CM).

**Interface and compatibility**

It is essential to solve the compatibility problem between the different software in order to enhance technological development (DE2). The software is expensive (TA). For improved communication, the software AutoCAD has to be compatible with Tekla Structures (SI).

DQM says that they (reinforcement supplier) have no standardized order interface towards the client but all information received from the client is processed and adapted to their internal Excel format and then put on the server, made accessible to all employees at the reinforcement supplier. The format from the client could be pdf, Excel, email and Tekla. Of all clients only one (Skanska Sverige AB) is using Tekla Structures. The design department extracts information from Tekla Viewer but AutoCAD is used in most cases (DQM). There are great potentials for increased efficiency of the information exchange between the project and the reinforcement supplier. The optimum is if the project and supplier have software that are compatible with each other and enable for BIM sharing. Superior would be if the supplier had robots that directly receive and processes the project’s BIM (TA).
Development

Too little emphasis lies today in communication of real facts and figures (PM). According to PM, BIM contributes to time savings and less errors which leads to monetary benefits. PM says that BIM as standard would be appreciated. There are always a lot of discussions whether to invest in using BIM or not. Initially there is a cost but overall, there is a gain to invest in BIM (PM). It is important that the benefits with BIM are showing in the supplier chain in order for the suppliers to invest in BIM (TA).

Prof IP compares the construction industry to the manufacturing industry and says that Scania started their 3D modelling in 1996. If 2D drawings were requested, these were extracted from the 3D model. Shared product data information resulted in gains in quality. In the manufacturing industry it is important that the subcontractors are involved early in the process according to the Product Data Management. Already in the initial phase the design, the procurement and the production are engaged according to the PDM process. The biggest problems with the implementation of Product Data Management were the connections and interfaces between the different software. The technical development within the manufacturing industry has been huge recently. It has been systematized which has resulted in compatibility between software interfaces. This enables for different systems to be combined (Prof IP).

Setting up tests in virtual 3D environments before going into production reduces the number of physical prototypes and errors. This virtual prototype testing is a part of the production preparation process in the manufacturing industry. Virtual construction is the future in construction (Prof IP). In the construction industry, every project starts from a blank paper, including creating a new BIM from scratch. There is no standard for reusing the same BIM from one project to another (IPM). IPM further says that the outlook for BIM is great. A great success would be if the implementation of BIM and platforms were combined (IPM). IPM believes that this is the future. BC says that there is never enough time to test new ideas and solutions parallel to the project. The only way to try out new ideas is to find suitable projects where the new ideas can be implemented, which means that you never try out the ideas in test environments.

5.3.6 Differences between the construction and manufacturing industry

The biggest difference between the construction and manufacturing industry is the productivity, which is much lower in the construction industry. This is due to the differences in production topology, organizational structures and IT structures. A problem in the construction industry is that each subcontractor has their own organizational structure with their own roles. In the manufacturing industry, the roles and organization structures are more similar from one company to another compared to the construction industry. It would be beneficiary for the construction industry to level the organizational structure in order to increase the productivity. In addition to this, the manufacturing industry has a more established and advanced IT structures and the production strategies differ between the industries. Today it is all about mass customization in the manufacturing industry. Another difference is that the subcontractors in the manufacturing industry are more transparent with their profit margins which create more trusting relationships and open up for negotiations. The transparency is also a driving force for the evolution (Prof IP).
The differences in processes were illustrated by the R&D manager at Scania as a throw ball game. In the manufacturing industry, the player always knows whom he/she receives the ball from and to whom it should be thrown. It is an organized flow and enables for many circulating balls in contrast to the construction industry, where the players often are unaware of from whom to receive the ball and to whom it should be thrown onwards. This means that all players have to be focused and prepared all the time and therefore that only one ball can be thrown at a time (Prof IP).

Professional pride characterizes the construction industry and is a contributing factor to low productivity. In the manufacturing industry focus is on production and teamwork and not on specific roles. In order to increase productivity and move towards an industrial construction focus must be shifted from professional roles to operators (Prof IP).

The prefabricated reinforcement suppliers DQM and EM consider themselves to belong to both the manufacturing industry and the construction industry, since they offer a full cycle solution, e.g. drawings, prefabrication and on-site construction works.

**5.3.7 Organization and corporate culture**

A prerequisite for industrial construction is consistent teams. An example is the railroading teams where the team followed each other throughout new and different railroad projects and kept the collective competence within the team. This resulted in high performance due to development of good team work. Permanent teams like the railroading team are not found in the construction industry since a new team is formed in every new project and dissolved in the closure of a project. In the manufacturing industry the teams are permanent in every new project, just like the railroading teams were (Prof IP). This is agreed upon by SI who believes that it would be favorable if the same production and design team is consistent for collaboration in future projects and do not split after projects are executed (SI).

Industrialization entails a specialization of all disciplines. Compare the construction industry with the manufacturing industry. For example, an engineer in the construction industry should be able to design the whole “truck” whilst an engineer in the manufacturing industry is specialized in designing one specific part, e.g. the “wheel” or the “engine” (IPM). DE2 says that in the construction industry, every project stands for itself and that it is hard to communicate between projects. Moreover, DE2 says that even though it is a new constellation in each construction project it is impressive to see that everyone knows what to do. DE2 adds however, that it would be more favorable if every project ran through the same “project factory”, like in the manufacturing industry. This would demand a new organizational structure according to DE2.

One of the constraints for implementation of industrial construction is the conservative construction culture, where every project is considered to be unique. Rules and regulations are however all the same for every project and today it is too much focus on the unique end product and the required technology for industrial construction to be implemented. The processes and the implementation should be in focus when applying industrial construction (IPM). Prof IP considers the biggest barrier for implementation of industrial construction to be the corporate culture. The corporate culture has to change and it is important that the employees are engaged and understand WHY new tasks should be performed in a certain way. If change is to be made through implementation of new technology or processes, it is important to enlighten, communicate and create understanding among those affected by the
change. There are difficulties spreading innovative solutions and ideas in a large company (PE). Without the support from the management, implementation of industrial construction is impossible. The management has to be active in the change process, communicate to the right level and root engagement among the employees (IPM). It is important that the change management is supported by the management. Prof IP believes that it is the big construction companies that have the greatest potential and benefits the most of industrial construction.

In the manufacturing industry the work preparation documents are made by work preparators, who are the link between the design engineer and the operator. A similar structure could be implemented in the construction industry, with some modifications due to the relatively small volumes in an individual company in the construction industry compared to a manufacturing company. The competence that lays within the operator’s work preparation documents is much higher than the individual construction worker’s competence. Thus, the individual construction worker has higher competence than the operator (IPM).

The future of industrial construction is bright and can be driven by success projects where companies who have implemented industrial construction win more tenders since it is possible to offer a lower price. If industrial construction is fully implemented the whole organization would have to change, since all processes must change. The technology required for industrial construction is available and focus should therefore shift to management (IPM).
6 Adjusting a conventional reinforcement model for prefabrication

This chapter aims at answering the question of how existing reinforcement model should be adjusted in order to be compatible with automated robot reinforcement prefabrication. To exemplify this, adjustments of the existing 3D model, made in Tekla Structures, of the reinforcement in the foundation slab in the fourth intermediate support in the Slammertorp bridge will be made. Due to the shape and design of the existing reinforcement, focus is on prefabrication of a reinforcement cages.

6.1 Industrialized reinforcement process

In this suggested industrialized reinforcement process, calculations for the reinforcement are made and the required design is decided in the design phase, after which the reinforcement is modeled in a BIM software. At this stage, prerequisites for prefabrication are considered and required information is included in the BIM. The BIM will then be sent to a reinforcement supplier where all the reinforcement in the model will be prefabricated by robots in a highly automated process. No human revision of the BIM will be made at the supplier since all necessary information required for robot constructability have been added to the BIM in the design phase. After the reinforcement elements have been fabricated, the elements are lifted on trucks after which they are transported to the construction site where the elements are lifted into position before concrete casting. A flow chart of the proposed industrialized reinforcement process is presented in Figure 12.
6.2 Intermediate support no 4

The intermediate support number 4, showed during construction in Figure 14, consists of a reinforced concrete slab and a sliver pier. The slab has a width of 3.6 m, a height of 1.3 m and a length of 11.0 m. The sliver pier has a width of 1.0 m, a height that varies between 8.7 m and 8.6 m and a length of 10.5 m at the base. The length decreases toward the top of the sliver pier with an angle of 5°. Drawings made from a 3D model of the support are presented in Figure 13. According to reinforcement specification and the Tekla Structures model, there is a total of 670 reinforcing bars in the support, which corresponds to a weight of 8 300 kg, of which 4 000 kg constitute the reinforcement in the foundation slab and 4 300 kg is reinforcement in the sliver pier. Extra spacer bars were however added in the production phase to ensure stability and enable for constructability, corresponding to an increase of the total weight by approximately 5-10%.

Figure 13. A Tekla Structures model of the reinforcement in intermediate support no 4 in the Slammer-torp bridge. To the right, only the reinforcement in the foundation slab is visible. (Skånberg, 2013).
As shown in Table 5, 37% of the reinforcement in the intermediate support number 4 was prefabricated. Three different kinds of reinforcement elements were prefabricated for the support, constituting the reinforcement in the short sides of the foundation slab, the transverse reinforcement in the slab bottom edge and the reinforcement stirrups and upsticks that connect the slab to the sliver pier. The new industrialized reinforcement process is customized for a prefabrication share of 100% for the reinforcement in the support. Due to the design of the support, two reinforcement cages would be prefabricated separately; one for the foundation slab and one for the sliver pier.

Table 5. Weight and percentage of prefabricated reinforcement elements and cut and bent reinforcement in intermediate support number 4.

<table>
<thead>
<tr>
<th>Reinforcement category</th>
<th>Weight [kg]</th>
<th>Percentage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prefabricated elements</td>
<td>3050</td>
<td>37</td>
</tr>
<tr>
<td>Cut and bend reinforcement</td>
<td>5250</td>
<td>63</td>
</tr>
<tr>
<td>Total</td>
<td>8300</td>
<td>100</td>
</tr>
</tbody>
</table>
6.3 Requirements for prefabrication

For reinforcement cages to be automatically prefabricated by robots, based on information in a BIM, there are new requirements on what information has to be included in the BIM and on the design of the reinforcement cages. In addition to this, prefabrication entails requirements with respect to stability during transportation and lifting of the cages, as well as appropriate sectioning of the reinforcement cages into transportable elements. These requirements are further described in the following sections.

6.3.1 Constructability

When designing the reinforcement, stability of the cage during production has to be considered. This involves e.g. order of reinforcement layers and distance between layers. Moreover, the type of reinforcing bar bending shapes has to be chosen with robot constructability in mind. For example, for automated bending of the reinforcing bars, deviations from stated steel yield strength results in deviations in final bending angle. Due to this, the number of bends of each reinforcing bar ought to be minimized in order to minimize the final deviation from target design. As a result, reinforcement bending shapes A and B are preferable to bending shape C and F, see Figure 15.

![Figure 15. Reinforcement bending shapes A, B, C and F. Lowercase letters a, b and c represent lengths. The angle $\theta$ applies to angles $>90^\circ$ (BE Group, 2015).](image)

6.3.2 Mounting order

The exact mounting order of the reinforcing bars must be included in the BIM if the robot should be able to construct the cage accurately and automatically. This information can be assigned to the individual reinforcing bars as a serial number.

6.3.3 Transportation

In order to ensure stability of the reinforcement cage during lifting and transport from off-site fabrication to on-site, extra spacer bars have to be added and included in the BIM. There are two ways to connect reinforcing bars; either by welding or by binding. Generally in bridge construction, the reinforcing bars have to be binded due to fatigue requirements (Trafikverket, 2011). Fatigue is caused by repeated load cycles where each load cycle is considerably lower than the bridge's maximum load capacity, but this may ultimately result in failure (Norlin, 2014). However, welding can be allowed if the structural engineer can ensure that the stress range in the specific fatigue case is below requirements according to standards. For the
reinforcement in support no 4, an assumption is made that no welding of structural reinforcement is allowed. According to the design engineer in the Slammertorp bridge project, spacer bars added with the purpose to increase stability and enable for robot constructability can however be welded, as long as they are not welded to the structural reinforcement. Welded connections have a considerably greater stability than binded connections, which is utilized when possible in order to increase the stability of the cage. For visualization of a binded connection, see Figure 16.

![Figure 16 Detail of steel binding in a reinforcement cage (Jönsson, 2015).](image)

Sectioning of the reinforcement cages with respect to limitations due to transport dimensions has to be included in the BIM as well. The sectioned elements can be divided into groups in the BIM.

### 6.3.4 Additional information

Additional information such as center of mass for the reinforcing bars, coordinates for where the robots should grip the bars and coordinates for welding and binding points have to be included in the BIM.

### 6.4 Adjusted Tekla Structures reinforcement model

Within the scope of this master thesis, adjustments of the existing Tekla Structures reinforcement model for the foundation slab in intermediate support no 4 have been made with respect to robot constructability, to enable for industrialized prefabrication of a reinforcement cage. Spacer bars required to ensure the stability of the reinforcement cage during transportation and lifting have been added to the model as well. In addition to this, a feasible mounting order for the reinforcing bar groups constituting the cage has been developed. Sectioning of the reinforcement cage with respect to transport dimension limitations is however not included in the revision of the model, nor is additional information such as center of mass and coordinates for gripping, welding and binding. Mounting order and detailed description of required constructability adjustments are presented in Appendix A.2.
7 Analysis

This chapter combines empirical findings, research within the field of industrial construction and the theoretical framework in order to present an analysis of how to industrialize the reinforcement process. First a more general analysis of obstacles and potentials for implementation of industrialized bridge construction is presented, followed by more specific prerequisites for industrialization of the reinforcement process.

7.1 Implementation of industrial bridge construction

Discussions on the subject industrialization in construction are quite limited since there is no agreed definition on industrial construction (Kamar, et al., 2011) (Zhang & Skitmore, 2012). There is an identified lack of knowledge among both practitioners and academics about the concept of industrialization in the context of infrastructure projects (Larsson, 2012). The respondents differ in opinion whether there is an awareness of the potential benefits with industrial construction in the construction industry. However, it is agreed that the knowledge in how to address the current productivity problems does not exist (IPM, SI & Prof IP).

In this section, obstacles and potentials for implementation of industrialized bridge construction are presented within the areas organizational structure, information structure and production strategy. This section is partly based on theory presented in section 4.2.2.

7.1.1 Organizational structure

Project based

According to both empirical findings and theory, industrialization of the construction industry demands new organizational structures. First of all, there has to be repetitiveness and standardization of processes. This means that every project has to run through the same “project factory” (IPM, Prof IP & DE2) (Bertelsen, 2004) (Lindelöw, et al., 2015) (Larsson, et al., 2013). A step towards industrialization is to identify the similarities among projects rather than focusing on the uniqueness (Larsson, et al., 2013).

It is common that there are new organizations in each project consist of new people, making it difficult to systematically learn from the production (Blücher, et al., 2007). Due to the strongly project based organizational structure found in the construction industry with temporary organizations, there is a risk that a project’s team never reaches the final step of fully performing and efficiently allocate resources, according to Tuckman’s Team Develop-
ment Model (Tuckman & Jensen, 1977). The problem with inconsistent teams has also been identified by some of the respondents.

**Innovations and development**

In the construction industry, R&D investments are low. Studies show that the low investment in R&D has resulted in higher than necessary construction costs (Son, et al., 2009). An explanation is that a project’s budget constraints don’t allow for dedication of time for general activities, like product development and innovations. Implementation of new technique is countered by e.g. the bigger construction companies’ decentralized organizational structure. Since a project’s economical outcome rests on the site manager, a company’s R&D strategy depends on the site manager’s willingness and time (Claeson-Jonsson, et al., 2006). The responsiveness for ideas and innovations is much higher today than it was several years ago (PM). However, there is never enough time to test new ideas and solutions parallel to the project. The only way to try out new ideas is to find suitable projects where the new ideas can be implemented, which means that you never try out the ideas in test environments (BC). Within the realms of Lean, “Two steps forward and one step backward is OK; no steps forward is not OK” (Womack & Jones, 2003).

Due to low productivity in the construction industry, implementation of industrial construction is necessary in order to be competitive (Prof IP). The competitiveness of a company is increased by implementation of industrial construction since it increases the productivity (Blücher, et al., 2007). With industrial construction it is possible to offer a lower price and thereby win more tenders (IPM). Implementation of automation and robotics in construction is a way to standardize processes and thereby improve the quality, but it also increases the productivity since robots work faster than humans and are more reliable. The use of construction robots will also, through a reduction in manual labor through savings in skilled manual labor on-site, improve the contractor’s ability to compete (Kumar, et al., 2008).

**Change and implementation**

Theory states that industrialization is a wide concept including both implementation of new products and processes, innovations and changes in attitude and culture (Liker, 2004). In the empirical findings, of the big barriers for implementation of industrial construction has been identified as the conservative corporate culture and the fact that every project is regarded as unique which entails construction of prototypes. For the corporate culture to change it is important that the employees are engaged and understand the underlying reasons for performing tasks in certain new ways (IPM & Prof IP).

No organization has ever undergone dramatic and comprehensive change without someone somewhere taking the lead (Womack & Jones, 2003). Without the support from the management, implementation of industrial construction is impossible. The management has to be active in the change process, communicate to the right level and root engagement among the employees. It is important that the change management is supported by the management (IPM & Prof IP).

Lean implementation has to be supported by the management and further, the management must engage the whole organization in the improvement work (Prof IP). One essential component in the action plan for implementation of Lean is to find a change agent (Womack & Jones, 2003). At the company where IPM manages the implementation of platforms, the
management supported change agents have had a crucial role with successful results. When implementing a change, it is important to begin as soon as possible with an important and visible activity (Womack & Jones, 2003).

### 7.1.2 Information structure

#### Design for production

In order to reach constructability, integration between design and production is accomplished by integrating production competences in the early design phase of the project. BIM can be used as a tool to facilitate communication and thereby increase constructability (Jensen, et al., 2012). Early production involvement in the design phase decreased change feedback in the production phase regarding constructability since problems have already been solved in the design phase (DE1). BIM makes it easier for design and production to communicate problems and solve them and is therefore a great aid for both design and production (PdM). BIM also enhances the technical knowledge of the workers (PM). BIM, or virtual construction, reduces the number of physical prototypes and errors, which eliminate waste source number 7 *products of defects* (Womack & Jones, 2003), because it is possible to virtually test before going into production. Virtual prototype testing is a part of the production preparation process in the manufacturing industry and is the future in the construction industry (Prof IP).

An identified problem in the current situation regarding reinforcement mounting is that responsibility for validity of drawings and other information is expected to be taken by each individual person, which instead means that no one takes responsibility (Simonsson & Emborg, 2007). BIM is a way to tackle this problem since the following success factors with BIM have been identified in the empirical findings and the theoretical framework:

- Quality assurance, e.g. human errors decreases, latest version available to everyone.
- Higher level of detail.
- Engagement from less experienced, e.g. better understanding with visualization.
- Better communication and collaboration between design, production and suppliers, e.g. problem solving made possible before problem occur.

Working with BIM automatically gives a standardized process (BC & CM). When using standardized approaches the starting point is made visible, which is a basis for Lean and continuous improvements. Studies have showed that the combination of BIM and Lean has synergy effects and that through a combination, the outcomes of both Lean and BIM is enhanced. The implementation and usage of BIM technology can be seen as a catalyst or enabler for transformation into Lean (Dave, et al., 2010). However, the full potential of BIM is currently not reached since it requires additional computer knowledge and computer training, investment in expensive software and that decisions to use BIM is taken early in the design phase (CM, IPM & PdM). The interface compatibility is also an issue that has to be addressed (DE2) (Lindelöw, et al., 2015). Last but not least, the contractors, consultants and suppliers are reluctant to use BIM if it is not requested by the client (IPM & DE1). STA has however recently started to accept 3D models for review (DE1) and, starting 2015, BIM is demanded in all new procurements (Trafikverket, 2015b). This means that the work of producing both 3D and 2D in parallel probably will disappear and thereby waste source number 4 *over processing or defective processing* can be eliminated (Womack & Jones, 2003).
Knowledge transfer and communication

Today knowledge is not shared to new projects, but every project start on a blank paper (IPM). According to the respondents, no functioning system for knowledge transfer exists at Skanska Sverige AB today. Knowledge follows those who have been involved in the project and is not documented. Asking is the only way to access the knowledge (PE, BC, TA, CM, PdM & SI). This is a drawback when experienced employees retire or quit and the knowledge thereby leaves the company (PM).

According to National Institute of Building Science buildingSMART alliance (2015), BIM is a shared knowledge resource and enables for collaboration by different stakeholders at different phases of the life cycle of a facility. BIM carries some knowledge which it accessible for subsequent projects (PdM). Further, 3D models/BIM are excellent tools for communication of problem, ideas and solving (PE). Workers with little or no experience are able to participate and contribute earlier on and to a greater extent (PE & PdM). This eliminates waste source number 8 untapped creativity of the employees (Womack & Jones, 2003).

Regular meetings and close collaboration with the production facilitate the design process and are highly appreciated (BC). The frequency of meetings depends on the size of projects; big projects prioritize meetings in a greater extent than smaller projects (DE1). If there are many actors involved in a project, it is important with transparency (SI).

7.1.3 Production strategy

Craftsmanship and professional pride characterizes the construction industry and is a contributing factor to low productivity (Prof IP) (Al-Sudairi, et al., 1999; Norlin, 2014) (Koskela, 2000). In the manufacturing industry focus is on production and teamwork and not on specific roles and handicraft. In order to increase productivity and move towards an industrial construction a transition from professional roles to operators must be made in the production phase (Prof IP) (Koskela, 2000). In the manufacturing industry, the competence and knowledge that lays within the operator’s work preparation documents is much higher than the individual construction worker’s competence. Thus, the individual construction worker has higher competence than the operator (IPM). Industrialization entails a specialization of all disciplines with clearly defined tasks in production and development of work preparation documents in the design phase (Prof IP) (Liker & Franz, 2011). A majority of the respondents have also expressed that by investing more time and effort in the design phase of projects, considering for instance constructability, time and money can be saved in the production phase.

Revolutionary changes concerning industrialization of the construction industry are difficult, which is why more industrialized production processes on-site are more interesting than aiming for large and quick changes in what is produced off-site (Lind, 2011a).

Value stream mapping

A central concept within Lean is value stream, which is all the activities that follows when an order is placed; from concept into the hands of the customer. Value stream mapping is identification of all the specific activities occurring along the value stream (Womack & Jones, 2003). To map the process is to see the whole picture and not to sub-optimize, which is one of the core elements of industrial construction (Prof IP) (Lindelöw, et al., 2015). Greater effect
can only be obtained if wasteful activities are identified within the complete value stream (Blücher, et al., 2007). It is also extremely important that each firm along the stream don’t define value differently to favor the own firm (Womack & Jones, 2003). Lean focuses on how value is generated rather than how an activity is managed. In order to avoid defective assignments, i.e. waste, to be released downstream the action “stop the line” has to be executed in the design phase (Ballard & Howard, 1998a). It is essential to develop a process that quickly handles errors (PE).

A higher focus should be on information flow in the construction industry, rather than the current priority on material flow (Larsson, et al., 2013). The continuous improvement of standardized processes is assisted by standardized products which imply that it is important to be able to switch focus from products to processes (Prof IP) (Larsson, et al., 2013) (Höök & Stehn, 2008). By establishing systematics and structure, advantages can be obtained with respect to reoccurring problems. Standardization is a prerequisite for structure and documentation as well as for continuous improvements and development, since the starting point is made visible (Lindelöw, et al., 2015). Standardization is a prerequisite for Lean (IPM).

**Mass-customization**

In Lean, pull is a desirable production strategy, meaning that nothing is produced by the upstream supplier until the downstream customer signals a need (Womack & Jones, 2003). Mass customization, or make-to-order, means that the customer has the opportunity to make personal choices among some alternatives to mass production prices since costs for design and engineering work that have been made in advance can be excluded (Lindelöw, et al., 2015) (Liker & Franz, 2011). The construction industry is considered to belong to the production strategy engineer-to-order where the customer is involved in the design phase and all design and engineering work is done after an order has been made. Both make-to-order and engineer-to-order are pull production strategies. Based on empirical findings, make-to-order has been proven to be successful in the design phase of construction projects where calculation platforms have been used (IPM).

Waste source number 1 *overproduction* is not an issue since mass production is not a current production strategy in the construction industry (Womack & Jones, 2003).

**Mimic manufacturing industry principles**

Many studies presented in this master thesis have shown remarkable differences between the construction and manufacturing industry. The industrial production methods and processes from the manufacturing industry cannot be mimicked entirely, since the corporate culture in the construction industry is different. However, some processes concerning production engineering can be transferred to the construction industry whereas other areas have to be developed by the construction industry itself (Prof IP).

Lean is a fancy concept and desirable to implement for many industries. It is described as revolutionary and radical, but in reality it’s all about sound production strategy (Prof IP & IPM).
7.2 Industrialized reinforcement process: prefabrication

Benefits with prefabrication, identified both in theory and findings, are improved health and safety on-site, quality assurance and minimization of errors, less traffic disruptions, shortened construction time and less workers on-site. However, prefabrication requires more collaboration between design and production and early decision on usage of prefabrication. Usage of prefabricated elements leads to less flexibility and late change difficulties on-site. The prevailing economic situation determines whether prefabrication is economically justifiable (PdM & CM) (Caster & Deuschl, 2007) (Larsson & Simonsson, 2012).

At the construction site, normally, one reinforcing bar at the time is manually mounted and binded or welded. The ergonomics for this kind of labor is poor since the accessibility to binding and welding points is sometimes so bad that crawling is necessary (SI, TA, PdM & BC). Due to this, prefabricated elements are preferable in the production phase, but in order for prefabrication to be profitable the prefabricated share has to be relatively large (SI & DQM). The awareness of the benefits of prefabrication is however relatively low in the construction industry, but prefabrication is necessary in order to address the massive issues regarding productivity and efficiency in the construction industry (Pasquire & Gibb, 2002) (Larsson, et al., 2013).

Prefabricated reinforcement cages reduces the time for mounting and sorting reinforcing bars on-site but the transportations of reinforcing bars from off-site to on-site increases. Waste source number 2 waiting, number 3 excessive transportation and number 6 unnecessary motion are in somewhat reduced with prefabricated reinforcement. The amount of extra reinforcement, spacer bars, ordered for mounting can be reduced or eliminated if prefabricated reinforcement is used and thereby waste source number 5 unnecessary inventory is handled.

Previous research has shown that 22% of the total work in the production phase of office and house construction projects is dedicated to the reinforcement (Löfgren & Gylltoft, 2001). In the case study, it was found that approximately half of the total work in production was dedicated to work with the reinforcement (PE). It is likely to believe that this slightly higher figure is accurate since the reinforcement design is more complex in bridge projects. This implies that there are greater potentials for industrialization of the reinforcement process in bridge projects. A core element for industrialization is prefabrication (Larsson, et al., 2013). Many studies have shown that time savings in the production phase have been achieved by usage of prefabricated reinforcement.

7.2.1 Prerequisites for automated prefabrication by robots

Prefabricated reinforcement cages are often manually mounted off-site, but in an environment that is not affected by the weather conditions and with appropriate tools. Potentials for industrialization of this off-site reinforcement process exist. Usage of robots for automatically mounting the reinforcing bars into cages is a way to industrialize the process. This process is described in chapter 6. In short, it is a standardized process where all the reinforcement in bridge projects is prefabricated by robots. A reinforcement BIM is created in the design phase and then, without any manual revision by the reinforcement supplier, sent directly to a robot
for automated prefabrication. Implementation of an industrialized reinforcement process will mainly result in new and additional tasks in the design phase.

In the following sections, obstacles and prerequisites for the described industrialized reinforcement process are presented, based on empirical findings and theory.

**Design for constructability**

More time and effort has to be invested in the design phase where the constructability of the reinforcement elements has to be thoroughly thought of due to robot production requirements and limitations. This includes the choice of reinforcing bar types and the exact mounting order of the reinforcing bars (PdM). When fabrication is automatically performed by robots, it will no longer be possible to correct mistakes and solve problems in retrospect, which is why accuracy is of high importance. Since the knowledge of construction and mounting today lies within the production phase, collaboration between design team and production team will be required in the design phase and early involvement of the production team will thereby be required. Integration between design and production is listed as one of the five core elements of industrialized infrastructure construction (Larsson, et al., 2013). The respondents have all expressed a positive attitude towards early involvement of production in the design phase to enable for close collaboration between design and production.

Since mounting of individual reinforcing bars is heavily reduced at the construction site when reinforcement is prefabricated, tasks for reinforcement workers will change. Instead of reading reinforcement drawings it is essential to know how a prefabricated cage should be handled.

**Software compatibility**

The reinforcement has to be modelled in a BIM where the precision has to be high and required, additional information for the robots has to be included. To enable for information such as center of mass, coordinates for gripping points and binding points to be included in the BIM, a development of current BIM software might be required (Prof IP, DE1 & BC).

Interface compatibility between different software has been pointed out as an issue (SI)(TA)(DE2). It is desirable that software for calculations, 2D drawing and 3D modelling are compatible to avoid repetition of work and enable for increased efficiency regarding BIM in the design phase (DE2). To enable for automated prefabrication of reinforcement cages by robots, directly from a BIM made in the design phase, without any human revision of the information by the reinforcement supplier, a compatible interface between the BIM and the robots is essential. In addition to time savings when human revision of the reinforcement information can be avoided, this also entails a quality assurance.

**Transportation limitations**

A request for prefabrication of reinforcement cages demand adjustments regarding the design of the reinforcement to enable for transportation, e.g. where is it possible to weld stabilizing spacer bars and how should the reinforcement be sectioned into elements?
There will be increased demands on the stability of the reinforcement cages due to transport from off-site to on-site. Today, spacer bars are generally not included in the drawings/models but it is up to the production to decide where spacer bars are required. In order to avoid collapse of cages during transport and lifting on and off trucks by cranes, stabilizing spacer bars have to be added (SI) and included in the BIM. Furthermore, lifting points have to be specified in the BIM (PdM). When elements are prefabricated today, it is the supplier’s task to ensure that the stability of the elements is sufficient (DQM). However, for automated prefabrication by robots, directly from a BIM created in the design phase, this task will be moved from supplier to the design phase.

The dimensions of the trucks, is a limitation when it comes to transportation of prefabricated reinforcement cages (CM). The reinforcement has to be sectioned into elements of appropriate dimensions to fit the trucks’ dimensions. The maximum allowed load for the trucks is not reached when transporting prefabricated reinforcement cages since a large percentage of the volume is air (CM). However, the transports can be optimized through well thought out sectioning. Today, sectioning is usually performed by the reinforcement suppliers, but if reinforcement cages are automatically prefabricated by robots, this task will be moved to the design phase instead.
8 Conclusions

This chapter concludes the general findings and connects them to the research questions. The chapter first answers the question of how systematic technological development can be achieved in bridge construction, followed by the more specific research question of what changes have to be made at Skanska Sverige AB in order to implement an industrialized reinforcement process where all reinforcement in a bridge project is automatically prefabricated by robots, directly from a BIM without manual revision.

8.1 Systematic technological development

How is systematic technological development achieved in bridge construction?

The construction industry is characterized by low productivity, especially in comparison to the manufacturing industry. The large differences in productivity between the manufacturing and construction industry are related to fact that the industries are characterized by different production strategies, organizational structures and information structures. In order to benefit from the productivity stimulating approaches applied in the manufacturing industry, the construction industry has to change in the above presented three areas.

Knowledge in how to use Lean and industrial construction in order to address the current productivity problems do not exist. If an awareness of the potential gains and benefits with Lean and industrial construction had existed in the construction industry, changes would have been visible a long time ago.

Based on interviews and literature review, it can be concluded that a systematic technological development is made possible by organizational structures and processes that allow for and are susceptible to implementation of continuous technical improvements. It is therefore important that the project based construction industry shifts focus from project’s processes to processes for projects. Project based industries have issues dedicating time for general activities, like product development and innovations, because of the project’s budget constraints. Today, a company’s R&D strategy rests on the site managers willingness and time to apply and implement new processes and techniques. A consequence of low investment in R&D is higher than necessary construction costs.

In the construction industry, every project is considered to be unique, from which it follows that in every project, a prototype is constructed. There are however similarities and repetitiveness between projects. Because of the construction industry’s inertia and conservative culture, there is a reluctance to identify and admit similarities. Industrialization requires similarities between projects. A way to identify similarities is to map the processes and further to
standardize products and processes. By mapping, the starting point is made visible, which is a prerequisite for systematic improvements. When the whole picture is made visible, issues with sub-optimization can be addressed.

Crucial factors for change and implementation are support and financing from management. No organization will ever undergo dramatic and comprehensive change without someone somewhere taking the lead. The management has to be persistent and active in the change process, communicate to the right level and root engagement among the employees. For the corporate culture to change, it is important that the employees are engaged and understand the underlying reasons for performing tasks in certain new ways.

For systematic technological development within bridge construction, the following five core elements have been identified:

- Shift focus from project’s processes to processes for projects.
- Investment in R&D, independent of project budget.
- Map processes.
- Identify similarities and standardize.
- Support, persistency and financing from management.

### 8.1.1 Obstacles and potentials for industrial construction

*What are the benefits and disadvantages with industrial construction in bridge projects and what are the obstacles and potentials for implementation?*

The five core elements of industrialized infrastructure construction are; planning for efficient production, integrated design and production, continuous improvement, standardization, prefabrication and automation. When these core elements are implemented, benefits are achieved, such as; quality assurance and minimization of errors in production, increased constructability and knowledge exchange, strengthened ability for a company to compete, continuous improvements through standardized processes that enable for everyone to always work with the best available process, higher turnover of projects since standardized products mean less time for design which enables for lower prices, improved health and safety on-site, shortened construction time and thereby lowered construction costs. However, a drawback with industrial construction is less flexibility and late change difficulties at the construction site. One of the main prerequisites to benefit from the advantages is cooperation and communication.

Industrial construction is based on the manufacturing industry’s industrialized processes and methods. Since the conditions for the manufacturing and the construction industry are very different, it is essential to point out that all parts cannot be mimicked. However, referring to the productivity figures, the construction industry has much to gain by being inspired by the manufacturing industry. To implement more industrialized construction and thus increased productivity, changes have to be made regarding production strategies, organizational structures and information structures.
Organizational structure

The current project-based organizational structure has to change into a more process-driven structure. With this come new work methods and tasks that require a change in the corporate culture.

- Commitment and financing for change from the management.
- Transition from temporary organizations to consistent teams.
- Move R&D from projects to general company strategy.
- Address conservative culture and craftsmanship pride by engaging and explain reasons for change.

Information structure

The most important factor for industrialized information structure is to shift knowledge repository from humans to platforms and processes. By this, the company and not the company’s working force will possess the knowledge and skills.

- Use tools such as BIM that integrates design and production and ease for communication and problem solving in an early phase. BIM enables for higher level of detail and quality assurance since it reduces the number of physical prototypes. With visualization, engagement and understanding from less experienced are achieved and the current state is always made visible.
- Investments in software licenses and development of software interphases.
- BIM training and education is required.
- BIM, as a way of working, should be required from both consultants and suppliers.
- It’s important with transparency between actors to visualize processes and profit margins and create long term trust between actors. This is also a driving force for development.
- Internal and external communication between actors, roles and phases are success factors.
- Development and usage of platforms for calculations and design in the design phase is a step towards industrialization.

Production strategies

Changes in current production strategies to more predictable and unambiguous processes and flows that are susceptible for development are required for industrialization.

- Clearly define tasks for different roles for transition from generalists to specialists.
- Maneuver from craft based production to automation, robotics and a higher share of prefabrication. New work methods entail new professional roles and thus require different skills than the skills currently associated with the construction industry. In order to avoid dependence on high skills in the production, the competence should be put in work preparation document.
- Map processes to see the whole picture and not to sub-optimize. Consequently, flows can be organized: From whom will I receive to whom will I send it onwards? When, where and how?
• Shift production strategy from engineer-to-order to make-to-order (mass customization) through e.g. usage of standardized platforms for calculations and design.
• Early integration of design and production in order to plan for efficient production, e.g. minimization of errors and increased constructability.

8.1.2 Increased productivity with Lean

How can Lean be used as a tool for increased productivity through elimination of waste in bridge construction?

Several wasteful activities have been identified in bridge construction. In the production, reinforcement collisions and poor constructability have been identified. These wasteful activities could have been eliminated with the Lean principle “stop the line” in the design phase.

BIM is a tool that reduces and eliminates wasteful activities, however, BIM is not used unless requested from production or demanded in the design phase. In order to benefit from the advantages of BIM in all projects, someone has to be responsible for an expansion. A change agent is important for all changes and is one of the first steps towards implementation of any actions, e.g. new techniques and processes, that eliminate waste.

8.2 Industrialized reinforcement process: prefabrication

In this section, more concrete suggestions are presented on how a contractor, that carries out both design and production, can proceed from the current situation to implement an industrial process where all reinforcement in bridge projects is prefabricated. Prefabrication is here assumed to automatically be done by robots, directly from a BIM without any manual revision. The BIM used is sent directly from the contractor to the supplier.

8.2.1 Current reinforcement process

How does the reinforcement process in bridge projects, from design to production, look today?

In summary, the reinforcement process in bridge projects is time consuming, both in design and production. Since the share of prefabricated reinforcement usually is low, the working conditions on-site are characterized by heavy lifting and ergonomically unsound working positions for reinforcement mounting. BIM is rarely used to its full potential and the request of BIM depends on each projects urge to use it. 2D drawings are the standard procedure, but sometimes 3D models are made. However, 3D models are then often made in parallel to 2D drawings. Early involvement of production in the design phase is a success factor. For this kind of early involvement, benefits like increased constructability, problem solving before problems occur and usage of prefabrication can be achieved. However, decisions on usage of prefabricated reinforcement elements are often taken in a late stage when the design already has been established. Due to this, time consuming design rework for prefabrication require-
ments and the share of prefabrication is low which means that the full potentials with prefabrication are not reached. When prefabrication is used, the contractor’s reinforcement drawings and models are revised by the reinforcement supplier, which entails extra work, i.e., over processing.

8.2.2 Adjusted reinforcement model

How should the existing reinforcement model, in the BIM software Tekla Structures, of an intermediate support in a studied bridge, be adjusted in order to be compatible with automated prefabrication of reinforcement cages done by robots?

If the reinforcement is to be automatically prefabricated, directly from a BIM, by robots, a high level of accuracy and detail in the BIM is essential. Mounting order of the reinforcing bars, constructability issues and stability of the reinforcement cage have to be considered in the design phase. Since the knowledge about reinforcement constructability exists in production, collaboration between the design and production is required in the design phase. For further explanations about required adjustments of the existing Tekla Structures reinforcement model, see section 6.4.

8.2.3 Action plan for implementation

What changes have to be made at a contractor in order to implement an industrialized reinforcement process where all reinforcement in a bridge project is automatically prefabricated by robots, directly from a BIM without human revision?

Implementation of a standardized method for prefabrication of all reinforcement in concrete bridges is a way to industrialize the reinforcement process and an example of a technological development. An industrialized reinforcement process requires that more time is invested in the design phase of the project. The construction industry is generally fragmented; however, early involvement of the production in the design phase is facilitated if both design and production belong to the same company. Here, a proposed action plan for implementation follows.

Change management

- Engagement from management and implementation of prefabrication of reinforcement as a part of the company’s philosophy.
- The management has to decide that prefabrication of reinforcement should be used a standardized working method. Decision whether prefabrication should be used or not should no longer be taken within each project. Remove decision making about prefabrication of reinforcement from individual projects.
- Begin as soon as possible with an important and visible activity with focus on prefabricated reinforcement.
- Financially invest in e.g. software licenses, training and education, and reorganization.
In-house prefabrication support unit

- Appoint a unit responsible for horizontal change management with mandate to implement an industrial reinforcement process. This unit need overview of the project portfolio and will function as a prefabrication informer and support for the projects design teams.
- Long term relationships are important for industrial construction. The long term relationships with reinforcement suppliers should be the responsibility of the in-house prefabrication support unit.

Technical issues

- Interface compatibility between BIM and prefabrication robots has to be solved.
- Software development; the information required by the robots has to be included in the BIM. This might require a new role for relation with software developer.
- Reinforcement supplier must develop robots for automated reinforcement prefabrication.

New tasks in the design phase

- The exact mounting order of the reinforcing bars has to be decided. Reinforcement design and choice of reinforcing bar types have to be made with constructability consideration with the requirements for automated reinforcement prefabrication.
- The reinforcement BIM has to include information such as mounting order of the reinforcing bars, gripping points, binding points and center of mass.
- Stabilizing spacer bars have to be included in the BIM. Prefabricated cages have to be stable enough to endure transport and to be lifted by cranes without collapsing.
- Sectioning of the prefabricated reinforcement into elements with respect to transport limitations. Optimization of transports ought to be sought.
- BIM is an essential tool for the suggested reinforcement process. Therefore, BIM training and education will be necessary.
- Production has to be included in the design phase in order to design with consideration to limitations that exist on the construction site, e.g. crane lift capacity, area for reinforcement cages inventory and cage element assembly.

Standardized work procedure documents

- Documentation of the production’s reinforcement constructability knowledge and documentation of knowledge about the design of prefabricated reinforcement elements. Documents will ensure that knowledge is accessible independently of transmitter. This will enable for the design team to address questions that former were addressed by production and supplier.
- Establishment of a checklist document for BIM proceedings in order to ensure that all details for e.g. mounting order, sectioning the reinforcement elements to fit transport limitations, including of stabilizing spacer bars (transport and lifting), gripping points, binding points are considered.
- Update and publishing of these documents have to be done regularly in one forum and be the responsibility of one transmitter.
One of the fundamental principles of industrial construction is to wholeheartedly and completely implement industrial changes. To achieve increased productivity and increased competitiveness, the transformation has to be fully endured. As the architectural engineer and inventor R. Buckminster Fuller said “You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.”
9 Discussion

This chapter discusses the findings and the conclusion as well as the research quality. Additional insights that have arisen during the process are elaborated. Lastly, suggestions for further research are presented.

9.1 Discussion

All of the respondents in the case study are employed by the same company and consequently, the experiences shared and opinions expressed might to a certain degree suffer from bias. However, the other respondents within the same company are not connected to the case study and work for several different departments. The perspective is also broadened by the external interviews with academia and employees at other companies. It can be questioned whether the interview sampling is representative or not since the majority of the respondents have had a positive attitude towards prefabrication and industrial construction. The outcome of this master thesis might therefore be biased due to this.

In this master thesis, general conclusions are derived from one design-build case study, where the design and production were conducted by one contractor. Consequently, the conclusions are limited to this kind of conditions. However, since STA has adapted productivity strategy with increased share of design-bid-build contractual forms for infrastructure projects, this limitation is justified. Additional case studies could nevertheless have attested the conclusions and increased the validity and reliability of this master thesis.

This master thesis has ended up in findings and conclusions regarding change management and no literature on change management have been reviewed. However, change management is a great part of Lean and therefore the advice and analysis on change management is sprung from Lean. It would have been advantageously if the support for the industrialized reinforcement process suggested had been investigated, in order to examine the feasibility of the process. On the other hand, all of the respondents have expressed a positive attitude towards industrialization.

Tekla Structures has been used for adjustments in the existing reinforcement model, required to enable for an industrialized reinforcement process. It has not been investigated whether Tekla Structures is the most suitable software for reinforcement modelling with prefabrication prerequisites, but it was chosen since the existing reinforcement was modeled in Tekla Structures and because software licenses were available at Skanska Sverige AB.

Infrastructure is financed by taxes, which is why inefficient infrastructure projects affect the society negatively in many aspect. It is in the interest of both society and the individual company to build more cost efficient with maintained or improved quality. For the individual
company, especially the competitiveness can be enhanced. Productivity growth is desirable within the construction industry, but knowledge in how to address the question and knowledge about potential benefits with new approaches and techniques do not exist. The major differences between the manufacturing industry and the construction industry mean that productivity approaches from the manufacturing industry cannot be fully mimicked. In combination with ignorance, industry inertia and conservative culture, this can be an explanation for the low level of implementation of productivity strategies, such as Lean and industrial construction. The suggested industrialized reinforcement process is still an engineer-to-order production strategy and not mass-customization, which has been advocated as a desirable production strategy for increased productivity. The industrialized reinforcement process suggested does not involve a standardization of the reinforcement cage design and dimensions, but the reinforcement will be optimized for each individual project. The scope of this thesis has not included parametric platforms for calculations and design, but usage of this in a greater extent is probably the future and entails a transition to mass-customization.

The proposed industrialized reinforcement process is a first step towards industrialization and removal of wasteful activities and consequently a productivity growth. However, the proposed process will not solve all problems. There are still limitations and potentials for further improvements of the proposed process. For instance, it cannot be excluded that human errors regarding constructability occur in the design phase, resulting in prefabrication problems in production. In order to reduce the risk of human errors, the optimum would be if there were software that ensured constructability and determined required mounting order for a given reinforcement design. The suggested reinforcement process entails a technological development, however, for a systematic technological development the continuous improvement work cannot stagnate.

9.2 Recommendations for further research

Recommended further research can be divided into two fields; technical and organizational.

For further technical research we suggest research questions such as:

- Development of parametric platforms for calculation and design of reinforcement.
- Development of software interfaces between BIM software and prefabrication robot software
- How should Tekla Structures, or any other BIM software, be developed in order to meet the demands for prefabrication done by robots?

And for organizational research we suggest research questions such as:

- How should a more general implementation of industrial construction in infrastructure be carried out at a contractor or at a technical consultant?
- How does the contractual form inflict on the potentials for industrial construction?
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Appendix

A.1 Interview questionnaire

Interview questionnaire for construction phase

Name:

Role in the Slammertorp bridge project:

Years of experience in the construction industry

Company:

Date:

Mapping workflow

1. At what stage were you involved in the Slammertorp bridge project?
2. What were your tasks regarding reinforcement?
3. Describe the tasks required for mounting of the reinforcement.
   a. What are main tasks?
      i. What are the tasks’ elements?
      ii. What is required in order to perform the task (e.g. tools, inventory, resources and drawings)?
   b. Were these tasks specific for the project or general?
4. Arose waiting time before any tasks could be carried out (e.g. delayed material or other tasks were not performed yet)?

Communication

5. Describe the information that was needed to perform your tasks regarding reinforcement
6. What actors did you communicate reinforcement information to during the project?
   a. What communication tools were used?
   b. Was this specific for the project or general?
   c. Do you see any potential for improvement regarding the communication?

BIM

7. What do you consider BIM includes?
8. What is your general attitude towards BIM?
9. Was BIM used for the reinforcement in the project Slammertorp bridge?
a. If yes, how was this different to working in 2D?
b. Did you experience any advantages and/or limitations and obstacles working with BIM?
c. Did the level of details change with BIM?
   i. If yes, in what respects?
d. Do you wish to use BIM in future projects?

Design for production

10. Did the production raise any requests in the design phase regarding the reinforcement design and reinforcement drawings?
   a. If yes, at what stage?
11. Was the level of details in the drawings sufficient?
12. Were there any errors or production unfriendly design in the reinforcement documents?
   a. If yes, did they demand any changes?
   b. If yes, what kind of errors and how common are they?
   c. How were the changes managed and to who were they communicated?
   d. What consequences did the rework cause?
13. In which format was the reinforcement information given to you (e.g. electronic, paper, telephone call)?
14. Was rework of the reinforcement documents needed before they could be used?
15. What do you consider to be problematic regarding the exchange of reinforcement documents?
   a. Was this specific for the project or general?

Prefabrication

16. What is your general attitude towards prefabrication of reinforcement?
   a. What do you think of the future for prefabricated reinforcement versus traditional construction?
17. What criteria determine the choice to prefabricate or not (e.g. time, earlier experience, habit)?
18. At what level was the reinforcement in the Slammertorp bridge project prefabricated?
   a. Which reinforcement elements were prefabricated?
   b. How did prefabrication inflict in your work?
   c. Who decided to go for prefabrication?
   d. What influence did you have over the design of the prefabricated reinforcement elements?
19. What benefits and limitations and obstacles are connected to prefabricated reinforcement?
   a. Do any changes regarding safety and health occur when prefabrication is chosen over traditional reinforcement construction?
20. What resources can be saved when choosing prefabrication (e.g. time, money, labor, and inventory)?
21. When it is particularly appropriate to choose prefabrication?
22. What kind of inventory and transports does traditional construction of reinforcement require?
23. What kind of inventory and transports does prefabricated reinforcement require?

Overall
24. What are the potentials for a standardized reinforcement process?
25. Do you work with “normalläge”?
   a. Are there any advantages or disadvantages with ”normalläge”?
26. Do you experience that there are opportunities to influence and change the way you
   are working now?
   a. How do you proceed if you want to change?
   b. Do you experience that the paths for communication of changes are efficient?
   c. If no, how would you have liked the paths for communication should look?
27. Do you experience that your colleagues’ ideas about improvements are seized?
   a. If yes, how is this done?
28. Do you experience that the knowledge from previous projects is transferred to new
   projects?
   a. What tools are used for the knowledge transfer?
   b. Are there any advantages or disadvantages with the tools for knowledge transfer?

**Interview questionnaire for the design phase**

**Name:**

**Role in the Slammertorp bridge project:**

**Years of experience in the construction industry**

**Company:**

**Date:**

**Mapping workflow**

1. At what stage were you involved in the Slammertorp bridge project?
2. What were your tasks regarding reinforcement?
3. Describe the tasks required for design of the reinforcement.
   a. What are main tasks?
      i. What are the tasks’ elements?
      ii. What is required in order to perform the tasks (e.g. tools, inventory, re-
          sources and drawings)?
   b. Were these tasks specific for the project or general?
4. Did any waiting time occur before any tasks could be carried out (e.g. delayed materi-
   al or other tasks were not performed yet)?

**Communication**

5. Describe the information that was needed to perform your tasks regarding reinforce-
   ment
6. What actors did you communicate reinforcement information to during the project?
   a. What communication tools were used?
   b. Was this specific for the project or general?
   c. Do you see any potential for improvement regarding the communication?

**BIM**
7. What do you consider BIM includes?
8. What is your general attitude towards BIM?
9. Was BIM used for the reinforcement in the project Slammertorp bridge?
   a. If yes, how was this different to working in 2D?
   b. Did you experience any advantages and/or limitations and obstacles working with BIM?
   c. Did the level of details change with BIM?
      i. If yes, in what respects?
   d. Do you wish to use BIM in future projects?

Design for production

10. Did the production raise any requests in the design phase regarding the reinforcement design and reinforcement drawings?
    a. If yes, at what stage?
11. Was the level of details in the drawings sufficient?
12. Were there any errors or production unfriendly design in the reinforcement documents?
    a. If yes, did they demand any changes?
    b. If yes, what kind of errors and how common are they?
    c. How were the changes managed and to who were they communicated?
    d. What consequences did the rework cause?
13. In which format was the reinforcement information given to you (e.g. electronic, paper, telephone call)?
14. Was rework of the reinforcement documents needed before they could be used?
15. What do you consider to be problematic regarding the exchange of reinforcement documents?
    a. Was this specific for the project or general?

Prefabration

16. What is you general attitude towards prefabrication of reinforcement?
    a. What do you think of the future for prefabricated reinforcement versus traditional construction?
17. Do you believe it is possible to, in the design phase, modify the way of working and the reinforcement documents (e.g. mounting sequence, gripping points, binding points, coordinate system, level of detail) in a way so that it is possible to send the reinforcement documents directly to an robot for automated prefabrication of reinforcement elements?
    a. Can this be done with the current competence?
    b. If not, what kind of competence is missing?
18. What level was the reinforcement in the Slammertorp bridge project prefabricated?
    a. Which reinforcement elements were prefabricated?
    b. How did the prefabrication inflict in your work?
    c. Who decided to go for prefabrication?
    d. What influence did you have over the design of the prefabricated reinforcement elements?
19. Is there an awareness in the design phase whether the reinforcement is going to be prefabricated or not?
    a. Does prefabrication affect the design of the reinforcement?
20. Is the production’s needs included in the design of the reinforcement or is the design mainly affected by the design and structural requirements?

Overall

21. What are the potentials for a standardized reinforcement process?
22. Do you work with “normalläge”?
   a. Are there any advantages or disadvantages with ”normalläge”?
23. Do you experience that there are opportunities to influence and change the way you are working now?
   a. How do you proceed if you want to change?
   b. Do you experience that the paths for communication of changes are efficient?
   c. If no, how would you have liked the paths for communication should look?
24. Do you experience that your colleagues’ ideas about improvements are seized?
   a. If yes, how is this done?
25. Do you experience that the knowledge from previous projects is transferred to new projects?
   a. What tools are used for the knowledge transfer?
   b. Are there any advantages or disadvantages with the tools for knowledge transfer?

Procurement

Name:
Role:
Years of experience in the construction industry:
Company:
Date:

Mapping the workflow

1. At what stage are you involved in projects?
2. What were your tasks regarding reinforcement?
3. Describe your tasks for reinforcement.
   a. What are main tasks?
      i. What is done in each task?
      ii. What is required in order to perform the task (e.g. tools, inventory, resources and drawings)?
      iii. Does this workflow differ from project to project or is it general?
4. Do waiting time occur (due to e.g. lacks in software, competence, information or unfinished tasks) before your work with the reinforcement can be done?
5. Does the production or the design team have any requests regarding the reinforcement?
   a. If yes, at what stage?
   b. If yes, what kind of requests?

Communication
6. Describe what kind of information that is required for your tasks regarding reinforcement?

7. What actors do you communicate reinforcement information to during a project?
   a. What communication tools were used?
   b. Was this general or depends on each project?
   c. Do you see any potential for improvement regarding the communication?

8. What do you consider to be problematic regarding exchange of reinforcement information?
   a. Was this general or depend on each project?

BIM

9. What do you consider BIM includes?
10. What is your general attitude towards BIM?
11. In what extent is BIM used in projects?
   a. Did you experience any advantages and/or limitations and obstacles working with BIM?
   b. Do you wish to use BIM in future projects?

Prefabrication

12. What is your general attitude towards prefabrication of reinforcement?
   a. What do you think of the future for prefabricated reinforcement versus traditional construction?
13. What level of prefabricated reinforcement is often used in projects today?
   b. Which reinforcement elements are often prefabricated?
   c. Who decided to go for prefabrication?
   d. What influence did you have over the design of prefabricated reinforcement elements?
   e. How does decision of prefabrication affect your work?

14. Which limitations are there today with prefabrication (e.g. transportation, competence, costs)?

15. If prefabrication is chosen, do the communication and exchange of reinforcement information with the supplier differ compared to if it would have been traditional reinforcement?

16. Is it robots or humans that fabricate the prefabricated reinforcement elements?
   a. To whom and in which format (e.g. pdf, Excel, Tekla, paper) do you exchange reinforcement information?

Overall

17. What are the potentials for a standardized reinforcement process?
18. Do you work with “normalläge”?
   a. Are there any advantages or disadvantages with “normalläge”?
19. Do you experience that it is possible to influence and change the way you are working now?
   a. How do you proceed if you want to change?
   b. Do you experience that the paths for communication of changes are efficient?
   c. If not, how would you have like the paths for communication to look?
20. Do you experience that your colleagues’ ideas about improvements are seized?
   d. If yes, how is this done?
21. Do you experience that the knowledge from previous projects is transferred to new projects?
   a. What tools are used for the knowledge transfer?
   b. Are there any advantages or disadvantages with the tools for knowledge transfer?

**Technical department**

Name:

Role:

Years of experience in the construction industry:

Company:

Date:

**Mapping workflow**

1. At what stage do you involve in projects?
2. What were your tasks regarding reinforcement?
   a. What are main tasks?
      i. What are each task’s elements?
      ii. What is required in order to perform the task (e.g. tools, inventory, resources and drawings)?
   b. Is the workflow specific for each project or general?
3. Does any waiting time occur (due to e.g. lack in software, competence, information or other tasks not performed in time)?
4. Does the production or the design team have any requests regarding the reinforcement?
   a. If yes, at what stage?
   b. If yes, what kind of requests?

**Communication**

5. Describe what kind of information that is required for your tasks regarding reinforcement?
6. What actors do you communicate reinforcement information to during a project?
   a. What communication tools are used?
   b. Is this general or depends on each project?
   c. Do you see any potential for improvement regarding the communication?
7. What do you consider to be problematic regarding the exchange of reinforcement information?
   a. Is this general or depend on each project?

**BIM**

8. What do you consider BIM includes?
9. What is your general attitude towards BIM?
10. In what extent do you use BIM in projects?
a. Do you experience any advantages and/or limitations and obstacles working with BIM?
b. Do you wish to use BIM in future projects?

**Prefabration**

11. What is you general attitude towards prefabrication of reinforcement?
   a. What do you think of the future for prefabricated reinforcement versus traditional construction?
12. What level of prefabrication is usually used in projects?
   a. Which reinforcement elements are often prefabricated?
   b. Who decided to go for prefabrication?
   c. What influence did you have over the design of the prefabricated reinforcement elements?
   d. How does the decision of prefabrication affect your work?
13. What limitations are there today with prefabricated reinforcement (e.g. transportation, competence, costs)?
14. If decision of prefabrication is taken, do the contact and exchange of reinforcement information with the reinforcement supplier differ compared to traditional reinforcement?
15. Is it robots or humans that fabricate the prefabricated reinforcement elements?
   a. To whom and in which format (e.g. pdf, Excel, Tekla, paper) do you exchange reinforcement information?

**Overall**

16. What are the potentials for a standardized reinforcement process?
17. Do you work with “normalläge”?
   a. Are there any advantages or disadvantages with “normalläge”?
18. Do you experience that it is possible to influence and change the way you are working now?
   a. How do you proceed if you want to change?
   b. Do you experience that the paths for communication of changes are efficient?
   c. If not, how would you have like the paths for communication look?
19. Do you experience that your colleagues’ ideas about improvements are seized?
   a. If yes, how is this done?
20. Do you experience that the knowledge from previous projects is transferred to new projects?
   a. What tools are used for the knowledge transfer?
   b. Are there any advantages or disadvantages with the tools for knowledge transfer?

**Industrial construction**

Name:

Role:

Tasks:

Years of experience in the construction industry:
Industrial construction

1. What do you consider is included in Industrial construction?
2. Do you experience any advantages and limitations and obstacles regarding industrial construction?
3. Do you think that the construction industry is aware of the potential benefits of industrial construction?
4. What do you think of the future for industrial construction?
   a. At what stages and at which actors are the greatest potentials?
5. What are the biggest obstacles for implementation of industrial construction (e.g. software, actors, culture, requirements, communication)?
6. What are your possibilities to impact the implementation of industrial construction?

Standardization

7. What are the potentials for standardizations in the different stages in the construction industry?
   a. In what extent is standardized processes applied in the design phase?
8. Do you experience that it is possible to influence and change the way you are working now?
   a. How do you proceed if you want to change?
   b. Do you experience that the paths for communication of changes are efficient?
   c. If not, how would you have like the paths for communication look?
9. Do you experience that the knowledge from previous projects is transferred to new projects?
   a. What tools are used for the knowledge transfer?
   b. Are there any advantages or disadvantages with the tools for knowledge transfer?

Lean

10. What do you consider is included in Lean?
11. Do you experience any advantages and limitations and disadvantages with Lean?
12. Do you think that the construction industry is aware of the potential benefits of Lean?
13. What do you think of the future of Lean?
   a. At what stages and at which actors are the greatest potentials?
14. What are the greatest obstacles for implementation of Lean (software, actors, culture, requirements, communication)?
15. Do you experience that your colleagues’ ideas about improvements are seized?
   a. If yes, how is this done?

BIM

16. What do you think BIM includes?
17. What is your general attitude towards BIM?
18. In what extent do you use BIM today?
   a. How has the development to today’s level of BIM usage been?
19. What do you think of the future of BIM?
a. At what stages and at which actors are the greatest potentials for BIM implementation?
20. Do you experience any advantages and limitations and obstacles with BIM?
21. What are the greatest hindrances (e.g. software, actors, culture, requirements, communication) for implementation of BIM?

Prefabrication

22. What is your general attitude towards prefabrication?
23. In what extent is prefabrication used in building projects versus infrastructure projects?
   a. How has the development to today’s level of prefabrication usage been?
24. How do you look on the future for prefabrication?
   a. In what stages and at which actors are the greatest potentials?
25. Do you experience any advantages respective hindrances, limitations and obstacles with prefabrication (e.g. client requirements, transportation, competence, economy, software, culture, communication)?
26. What is your general attitude towards prefabrication of reinforcement?

Industrial production academia

Name:
Role:
Area of research:
Years of experience in the area of research:
Company:
Date:

Industrial production

1. What does Industrial production means?
2. What are the biggest differences between the manufacturing industry and construction industry?
3. What do you think Industrial production include?
   a. Do you think that industrial production is applied in the construction industry?
4. What can the construction industry learn from the manufacturing industry?
   a. How do you think an industrialization of the construction industry could be carried out?
   b. In what stages and at which actors are the greatest potentials?
5. Do you experience any advantages and limitations and obstacles with industrial construction?
6. What do you think are the prerequisites for industrial construction?
   a. What are the greatest hindrances (e.g. actors, culture, requirements, communication, software) for implementation of industrial construction?
7. Do you think that the construction industry is aware of the potential benefits with industrial construction?
8. What do you think of the future for industrial construction?
9. What are your possibilities to influence the implementation of industrial construction?

**Standardization**

10. What are the potentials for standardization in the different stages in the construction industry?
11. Do you think that knowledge exchange is applied within the manufacturing industry?
   a. Which tools are used for knowledge exchange?
   b. Are there any advantages and obstacles with the system for knowledge exchange?

**Lean**

12. What do you think is included in Lean?
13. Do you experience any advantages and limitations and obstacles with Lean?
14. Do you think that the construction industry is aware of the potential benefits with Lean?
15. What do you think of the future of Lean?
   a. In what stages and for which actors are the greatest potentials found?
16. What are the greatest hindrances for implementation of Lean in the construction industry (e.g. software, actors, culture, requirements, communication)?

**BIM**

17. What do you think BIM includes?
18. What is your general attitude towards BIM?
19. In what extent are visualization tools and information platforms used in the manufacturing industry?
   a. How has the development to today’s level of usage been?
20. What do you think of the future for BIM?
   a. In what stages and for which actors are the greatest potentials found?
21. What are the greatest hindrances (e.g. software, actors, culture, requirements, communication) for implementation of BIM?

**Prefabraction**

23. What is your general attitude towards prefabrication?
24. What do you think of the future for prefabrication?
   a. In what stages and at which actors are the greatest potential for prefabrication?
25. Do you experience any advantages and hindrances, limitations and obstacles for prefabrication (client requirements, transportation, competence, economy, software, actors, culture, communication)?

**Reinforcement supplier**

Name:

Role:

Years of experience in the field of reinforcement:
Mapping workflow

1. At what stage are you usually involved in projects?
   a. What kind of projects?
   b. Are there any differences if the order concerns cut and bent reinforcement versus prefabricated reinforcement cages?

2. Describe your tasks regarding reinforcement
   a. What are the main tasks and what is required to perform them?
   b. What kind of information do you need?
   c. Are there any differences if the order concerns cut and bent reinforcement versus prefabricated reinforcement cages?

3. Does it occur any waiting and problems due to lack of software, skills, information or that previous tasks are not finished in time?

4. Approximately, how much time is needed for prefabrication orders?

5. Is the workflow efficient or is there room for improvements?

6. Are there any standardized workflows?

Communication

7. Which actors do you communicate with during the project?
   a. Are there any differences if the order concerns cut and bent reinforcement versus prefabricated reinforcement cages?

8. Are there any lacks or problems with the current communication?
   a. What potentials are there for improvements?

9. How is the reinforcement documents handled? E.g. which format, from whom, to whom, at what stage in the order chain, any revisions?
   a. What potentials are there for improvements?
   b. Are there any differences if the order concerns cut and bent reinforcement versus prefabricated reinforcement cages?

10. Are there any similarities and differences between the clients?
    a. What kind of claims do the different clients have? E.g. regular meetings, software, transparency?

BIM

11. What do you think BIM includes?

12. Do you use BIM for the reinforcement?
    a. What software is used?
    b. What are the benefits and problems regarding BIM for the reinforcement?
    c. What is your attitude towards BIM?

13. Which factors could contribute to a more comprehensive implementation of BIM?
    a. Which factors hinders the implementation of BIM?

Prefabrication

14. Which reinforcement elements are prefabricated and how common is it?
    a. What parts of a construction are often prefabricated?
b. Does the reinforcement quantity change if a tied reinforcement cage has to be transported compared to on-site construction?

c. What kind of influence do you have regarding design and choice of prefabricated elements?

15. What limitations exist regarding prefabrication? E.g. transport, skills and competence, economy?

16. Is transport planning a big part of you tasks?
   a. How is it done and what limitations exist?

17. To what extent is the prefabrication done by robots?
   a. Which parts are often prefabricated by robots?
   b. What kind of information and documents do the robots require?
   c. Is manual processing of the required reinforcement documents necessary or is possible to extract needed information from already existing documents? E.g. extract from Tekla.

18. What kind of experience and skills do those who perform the manual prefabrication have?
   a. What experience is required in order to read reinforcement documents for prefabrication?

19. What is your general attitude towards prefabrication cages?

**Industrial production**

20. Do you consider yourself to belong to the manufacturing industry or the construction industry?
   a. Why do you classify yourself as that?
   b. Is mass-customization or mass production applicable to your company?

21. What is your general opinion regarding industrial processes?
   a. What kind of benefits and problems do you think exist with industrialization?
   b. How can your business be more industrialized?