BIM in Infrastructure

Using BIM to increase efficiency through the elimination of wasteful activities

MARTIN MATTSSON
MATHIAS RODNY

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Martin Mattsson
Mathias Rodny

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Royal Institute of Technology (KTH)
Department of Civil and Architectural Engineering
Division of Structural Design and Bridges

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Royal Institute of Technology (KTH)
Department of Real Estate and Construction Management
Division of Project Communication

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Preface

This master thesis of 30 credits addresses the use of BIM in infrastructure projects and denotes the end of our education within the Civil Engineering and Urban Management programme at The Royal Institute of Technology, KTH. We have in this study combined our knowledge from two different master tracks, namely Architectural Design and Construction Project Management, and Civil Engineering and the work has been supervised by professor Väino Tarandi at the department of Real Estate and Construction Management and adj. professor Lars Pettersson at the department of Civil and Architectural Engineering. The thesis has been conducted in cooperation with Skanska Sverige AB at the division of Major Projects.

The idea for this thesis was brought forward by Skanska and the delimitation of the research topic that followed has been conducted by the authors in cooperation with Lars Pettersson, who also has been our supervisor at Skanska. Many different ideas and potential topics to investigate have emerged during the research process and consequently the process of delimitation has been rather extensive.

We would like to thank all the respondents for devoting time to participate in the interviews and for sharing their knowledge and experience which has given us valuable input to this research. Furthermore, we would like to thank the people involved in the case study for allowing us to participate in meetings which has provided us with valuable observations as well as knowledge that we will have use for also outside of the context of this thesis. We would like to express our gratitude towards Erkki Törmänen and Claes Jansson at Skanska Infrastructure for involving us in their work. We would also like to thank Väino Tarandi, our supervisor at KTH, for guidance and valuable feedback.

Last but not least, we would like express our gratitude towards Lars Pettersson for his commitment and dedication, feedback and support and valuable ideas and reflections throughout the entire duration of this research.

Stockholm, June 2013

Martin Mattsson & Mathias Rodny
Abstract

The construction industry has for decades been suffering from low productivity growth and production processes that could be made more efficient if the occurrence of non-value adding activities could be reduced. Building Information Modeling, BIM, provides a new set of tools and new ways of working within the industry that has been attributed to numerous advantages of different kinds at different stages of construction projects.

The main purpose of this thesis have been to describe how BIM applications can be used to achieve a more efficient construction process through the reduction of wasteful activities in infrastructure projects. Through this we aim to find ways to increase the level of efficiency in production and to create incentives for construction companies to increase the use of BIM applications in infrastructure projects.

The findings presented in this thesis are based on a literature review, observations from a case study and interviews. The literature review has been conducted to gain a deeper understanding for the studied area as well as for creating a theoretical foundation on which the analysis is based. The case study bridge project has provided observations from the planning and design process as well as from the construction process. In addition to this, interviews have been carried out with people involved in the project as well as with other experienced people at the company, and all together this has provided the opportunity to investigate how BIM can be used throughout the project chain, from design to production.

In this study we have found several types of non-value adding activities in construction as well as identified numerous obstacles for successful implementation of BIM in infrastructure projects. In addition to this, the results from this study show that there are many benefits related to the implementation of BIM that can improve efficiency in infrastructure projects. The conclusion derived from this study is that BIM applications can be used to support a detailed collaborative planning and design process, which in turn creates the prerequisites for a more efficient production process through the elimination of non-value adding activities.

Keywords: BIM, Lean, Waste, Efficiency, Design
Sammanfattning

Byggbranschen har i årtionden präglats av låg produktivitetsökning och produktionsprocesser som skulle kunna effektiviseras om förekomsten av icke värdeskapande aktiviteter reducerades. Byggnadsinformationsmodellering, BIM, erbjuder en ny uppsättning verktyg och nya arbetsmetoder inom branschen som har tillskrivits många olika fördelar i olika skeden av byggprojekt.

Det huvudsakliga syftet med denna rapport har varit att beskriva hur en effektivare byggprocess kan uppnås i infrastrukturprojekt genom att minska förekomsten av slöseri med hjälp av BIM-verktyg. Genom detta strävar vi efter att finna sätt som bidrar till att öka effektiviteten i produktionen samt att skapa incitament för byggföretag att ytterligare öka användningen av BIM i infrastrukturprojekt.

De resultat som presenteras i denna rapport baseras på en litteraturstudie, en fallstudie samt intervjuer. Litteraturstudien har genomförts för att skapa en djupare förståelse för det studerade området samt för att etablera en teoretisk grund vilken analysen baseras på. Fallstudien utgörs av ett broprojekt vilket har tillhandahållit möjligheten att göra iakttagelser från både projekterings- och byggeprocessen. Utöver detta har intervjuer genomförts med personer involverade i projektet samt med andra erfarna personer på företaget, och sammantaget har detta har skapat möjligheten att undersöka hur BIM kan använts under projektets gång, från design till produktion.

I denna undersökning har vi kunnat identifiera flera typer av icke värdeskapande aktiviteter inom byggbranschen samt ett antal hinder för en framgångsrik implementering av BIM i infrastrukturprojekt. Utöver detta visar resultaten från denna studie att det finns många fördelar relaterade till implementeringen av BIM som har potentialen att förbättra effektiviteten i infrastrukturprojekt. Den slutsats som kan dras från denna undersökning är att BIM-verktyg kan användas för att stödja en detaljerad samverkande projektering, vilket i sin tur skapar förutsättningar för en effektivare produktionsprocess genom elimineringen av icke värdeskapande aktiviteter.

Nyckelord: BIM, Lean, Slöseri, Effektivitet, Design
# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>2D</td>
<td>Two dimensions</td>
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<tr>
<td>3D</td>
<td>Three dimensions</td>
</tr>
<tr>
<td>AEC</td>
<td>Architectural, Engineering and Construction</td>
</tr>
<tr>
<td>B-rep</td>
<td>Boundary representation</td>
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<tr>
<td>BIM</td>
<td>Building Information Modeling</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CSG</td>
<td>Constructive Solid Geometry</td>
</tr>
<tr>
<td>DC</td>
<td>Design coordinator</td>
</tr>
<tr>
<td>DE</td>
<td>Design engineer</td>
</tr>
<tr>
<td>ES</td>
<td>Estimator</td>
</tr>
<tr>
<td>GE</td>
<td>Geotechnical engineer</td>
</tr>
<tr>
<td>GL</td>
<td>Group leader</td>
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<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>PE</td>
<td>Project engineer</td>
</tr>
<tr>
<td>RFI</td>
<td>Request for Information</td>
</tr>
<tr>
<td>SC</td>
<td>Sub-contractor</td>
</tr>
<tr>
<td>SP</td>
<td>Surveying personnel</td>
</tr>
<tr>
<td>SV</td>
<td>Supervisor</td>
</tr>
<tr>
<td>TPS</td>
<td>Toyota Production System</td>
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## Glossary

<table>
<thead>
<tr>
<th>English</th>
<th>Swedish</th>
</tr>
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<tbody>
<tr>
<td>Abutment</td>
<td>Landfäste</td>
</tr>
<tr>
<td>Bridge seat</td>
<td>Lagerpall</td>
</tr>
<tr>
<td>Bridge bearing</td>
<td>Lager (bro)</td>
</tr>
<tr>
<td>Pile cut-off level</td>
<td>Pålkapningsplan</td>
</tr>
<tr>
<td>Design-bid-build</td>
<td>Generalentreprenad</td>
</tr>
<tr>
<td>Design-build</td>
<td>Totalentreprenad</td>
</tr>
<tr>
<td>Driven pile</td>
<td>Slagen påle</td>
</tr>
<tr>
<td>Expansion joint</td>
<td>Övergångskonstruktion</td>
</tr>
<tr>
<td>Girder</td>
<td>Balk</td>
</tr>
<tr>
<td>Pier</td>
<td>Mellanstöd</td>
</tr>
<tr>
<td>Pile</td>
<td>Påle</td>
</tr>
<tr>
<td>Rebar scheduler</td>
<td>Armeringsspecare</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>Armering</td>
</tr>
<tr>
<td>Scaffolding</td>
<td>Ställning</td>
</tr>
<tr>
<td>Structural member</td>
<td>Konstruktionsdel</td>
</tr>
<tr>
<td>Stud</td>
<td>Svetsbult</td>
</tr>
<tr>
<td>Surveying</td>
<td>Utsättning</td>
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Chapter 1

Introduction

This introductory chapter will present the background to the research as well as present the research question, purpose, limitations and definitions.

1.1 Background to the research

The Swedish construction industry is facing increased competition, not least from the growing international market. At the same time, the industry is suffering from low productivity growth and high resource consumption (Statens Offentliga Utredningar, 2012). Furthermore, a study concludes that wasteful activities, i.e. activities that neither adds value nor is needed to complete a task, can be estimated to constitute up to 35% of the total production cost in construction projects (Josephson & Saukkoriipi, 2005). This puts an economic strain on the actors on the market and in order to be competitive, construction companies have to increase their profitability during the entire life cycle of construction projects.

Building Information Modeling (BIM) has emerged as a new field within construction that has been attributed to many potential benefits. However, to this day, BIM has foremost been applied for house design in the building sector and has not yet been utilized to the same extent in the sector of civil engineering.

On-site solutions and problem solving during production rather than during planning is common in the construction industry and the costs for alterations and changes during the production stage greatly exceed the costs for changes during planning (Strafaci, 2008). The implementation of BIM applications in infrastructure projects offers the possibility to foresee potential problems during construction, thus enabling for increased levels of efficiency through the reduction of non-value adding activities.
Skanska Sverige is currently implementing BIM applications in the planning and design phase of a bridge project that started construction during the spring of 2013. This has provided the opportunity to investigate how BIM applications can be used in infrastructure projects to increase efficiency through the reduction of wasteful activities.

1.2 Problem statement

The construction industry is characterized by production processes that could be made more efficient if the occurrence of non-value adding activities were reduced. The reduction of wasteful activities is a valuable step for supporting sustainable production processes in construction. Building Information Modeling is a new way of working within the construction industry that has been attributed to numerous advantages of different kinds at different stages of construction projects. This thesis aims to investigate how BIM applications can be used in infrastructure projects to increase efficiency through the reduction of wasteful activities. Therefore, the research question that this thesis aims to answer is:

In what way can BIM applications be used to increase efficiency in infrastructure projects through the elimination of waste?

In order to answer the research question the following sub questions are posed:

- What types of wasteful activities can be found in the production process of infrastructure projects?
- What are the obstacles that hinder successful implementation of BIM in infrastructure projects?
- How can BIM applications be used to enable for structural members to fit the first time?

For definitions of the terms efficiency, first time fit and waste, see section 1.5.

1.3 Purpose

The main purpose of this thesis is to describe how BIM applications can be used to achieve a more efficient construction process through the reduction of wasteful activities in infrastructure projects. Through this we aim to find ways to increase the level of efficiency in production and to create incentives for construction companies to increase the use of BIM applications in infrastructure projects.

As a second step towards increased use of BIM applications in infrastructure projects we aim to identify the current obstacles and hurdles for successful implementation in
the referred to area. Furthermore we aim to illuminate the wasteful activities that reside within construction projects and thereby show the potential for improvements in efficiency levels.

1.4 Limitations

This research has been limited to investigate the BIM-related benefits applicable for the production phase of infrastructure projects. Moreover, this includes benefits obtainable for bridges, roads and tunnels.

Due to the limited timeframe for this thesis, observations related to production have only been made for surveying, piling and reinforcement works for the foundation of the bridge project described in the case study chapter.

In this study, the term waste does not refer to unwanted materials.

1.5 Definitions

Efficiency

In the field of economics, the term efficiency refers to performance and denotes the relationship between inputs and outputs of a business (Nationalencyklopedin, 2013). For further elaboration on resource efficiency and efficiency of flow, see section 3.1.4.

First time fit

First time fit refers to a concept designed by the authors and does not refer to a generally adopted concept or definition. The authors define the concept as the objective of generating a design that strives to ensure that structural members are compatible with each other and fit together the first time they are assembled, thus resulting in an effective production process.

Waste

Based on definitions established by Womack & Jones (2003) and Liker & Morgan (2006), we have in this research defined the term waste as activities that do not add any value for the customer. A more detailed description of the concept can be found in chapter 3 under section 3.1.5.
Chapter 2

Method

This chapter, including its subchapters, is intended to clarify how the research has been conducted and to describe the research methods that have been used. Moreover, the chapter provides a deeper insight into the details regarding data collection through the literature review, interviews and observations, and accounts for the reliability and validity of the outcome.

2.1 Approach

The factual information in this thesis is based on two main sources; a literature review and a case study. The literature review has been conducted to gain a deeper understanding for the studied area as well as for creating a theoretical foundation on which the analysis is based. The case study regards a bridge project that has provided observations from planning and design as well as from construction. In addition to this, interviews have been carried with employees at Skanska as well as representatives working for a sub-contractor, and all together this has offered a great opportunity to investigate how BIM can been used throughout the entire project chain, from design to production.

2.2 Research design

The research design constitutes the framework for how to collect and analyze data. This provides a plan for relating the research problem to relevant empirical and theoretical research. The research design; exploratory, descriptive or causal, is chosen depending on the structure of the research problem (Ghauri & Grønhaug, 2010).

Exploratory research is a justified research design for when the research problem is not fully understood and a level of flexibility need to be maintained. A descriptive research
design is suitable for research in which the research problem is structured and fully understood and the procedures for data and information gathering are structured as well. In accordance to descriptive research, causal research is an adequate research design for problems that are structured and well understood. But in addition to this, a causal research design addresses cause-and-effect problems and the main aim is to distinguish what causes that result in a specific effect. (Ghauri & Grønhaug, 2010).

This research is based on a structured and well understood research problem that is aimed at describing in what way the use of BIM can affect project outcomes. Therefore, the research as such is of descriptive nature and consequently a descriptive research design has been used.

2.3 Reasoning

In logic, deductive and inductive reasoning are two different approaches for reaching conclusions. Deductive reasoning can be described as a top-down approach that uses hypotheses and observations to process a broader spectrum of general information into a more specific conclusion. The process of inductive reasoning works in the opposite direction and is consequently referred to as a bottom-up approach in which specific information is processed into broader theories or generalizations (Ghauri & Grønhaug, 2010).

This research is aimed at developing general conclusions based on specific observations, interviews and theory. Therefore, the reasoning applied in this thesis has an inductive approach. One remark regarding inductive reasoning is that the reliability of the general conclusion is very much depending on the representativeness of the empirical findings and the literature that the reasoning is based on (Brink, et al., 2006). Therefore, the question of reliability will be addressed further on in this chapter.

2.4 Research method

There are two different fundamental methods for data collection in research; qualitative and quantitative. The methods represent different techniques for capturing information relevant for a specific research question. When determining which method that best suits the research, consideration should be taken to the research problem and the purpose (Ghauri and Gronhaug, 2005).

One major difference between quantitative and qualitative methods is that the latter do not use measurements to arrive at a conclusion. In quantitative research, data is often quantified, tested, verified and analyzed while maintaining an objective approach in order to arrive at a result. In qualitative research, data is foremost interpreted in
order to understand the researched phenomenon while using a more subjective approach in order to arrive at an explanatory conclusion (Ghauri & Grønhaug, 2010).

This research is aimed at capturing data through observations and interviews and in order to arrive at a conclusion the data will be interpreted as opposed to measured. Combining this with the fact that the research is aimed at describing how the reduction of wasteful activities can be related to the use of BIM, the research method used in this research is of qualitative nature.

2.5 Data collection

The data required to support the conclusion arrived upon in this thesis can be divided into two categories; primary and secondary. Primary data are collected with the purpose to solve the problem at hand whereas secondary data is gathered for some purpose other than solving the problem in question (Ghauri and Grønhaug, 2005).

The approach to conducting this research started by collecting secondary data via a literature review that has been based on scientific reports, articles, books and documentation on Lean Construction and BIM. The literature study aims at creating the theoretical foundation on which the analysis is based and through the review of existing literature we wish to obtain the tools that enables for BIM to be analyzed by the use of Lean thinking.

The empirical studies have provided primary data for this research and it consists of observations through active presence during planning and design meetings at Skanska and through interviews with the people at the company as well as with people working for a sub-contractor. In addition to this, primary data in the form of observations have been gathered at the construction site which has provided the opportunity to evaluate if any effects could be measured during production.

2.6 Sampling

With regards to the research problem, this study has required the involvement of people engaged in the case study as well as other people within the company that provide more general experiences. In order to capture as much information as possible from the case study, as many project participants as possible have been interviewed. This has resulted in a total of 14 interviews where the majority of the respondents have been people related to the case study. In addition to these, interviews have been conducted with engineers and production personnel from other projects.
2.7 Interviews

In the field of research, interviews can either be classified as structured, unstructured or semi-structured. Structured interviews rely on a categorization of questions and a predefined format for the interview procedure while focusing on systematic sampling together with quantification and statistical approaches. In contrast, unstructured interviews allow the respondent to discuss more freely while involving opinions, feelings and behavior in the answering process. For this type of interview, the role of the interviewer is to provide guiding questions for which the answers will be interpreted afterwards. For semi-structured interviews, the group of respondents has been deliberately chosen and the questions and topics to be discussed have been decided beforehand. In likeliness to unstructured interviews, semi-structured interviews are aimed at capturing information related to opinions, feelings and behaviors and this interview design is well suited for inductive research (Ghauri & Grønhaug, 2010).

The interviews conducted in this research have been semi-structured and the aim has been to allow for the respondents to elaborate on the topics in order to gain as much information and new insights as possible. A list of questions has been compiled beforehand but the interviews have been conducted in the sense of a conversation in which the respondent has been allowed to elaborate freely on the topic. Specific questions have been posed to obtain information regarding roles, work procedures and other similar facts, whereas more general questions have been posed to capture the experience-based knowledge on the research topic. Considering the fact that the respondents have different knowledge and come from different professions, the semi-structured interviews have allowed us to choose what questions to ask each respondent in order to maintain a level of relevance. The interviews have foremost been conducted at the Skanska headquarter and at the site office for the case study. In addition to this, interviews via video conferencing and telephone have been used in a number of cases where the geographical distance has been too big.

All interviews but one have been recorded in order to ensure that no essential information was lost. These recordings have then been transcribed in full in order to be able to properly quote the respondents. The transcripts have served as a basis for the empirical findings, the analysis and the conclusion. The recordings have made notes redundant which has allowed for us to focus on follow-up questions. The reader should be made aware of the fact that all interviews have been conducted in Swedish and that the answers have been translated to English, which means that the choice of words and phrasing are affected by the authors’ ability to translate.

In order to encourage truthful answers, the respondents have been informed beforehand that the interviews are kept anonymous and that instead of names, abbreviations for their titles have been used for referencing. We are of the opinion that this does not affect the credibility of the answers.
2.8 Case study

Case research provides the opportunity to study contemporary phenomenon in real life contexts. Moreover, case studies are particularly well-suited for research for which existing theory is limited or where the case can provide new valuable insights. A distinction is made between single and multiple case studies, but for inductive research approaches the single case study design is preferable (Ghauri & Grønhaug, 2010).

This research includes a case study that according to Ghauri & Grønhaug (2010) can be described as a “single case design, holistic”, which can be explained as one case research involving one unit of analysis, namely the studied bridge project. Skanska has currently attempted to implement BIM tools in the planning and design phase of the mentioned bridge project which has provided the opportunity to examine if BIM applications can be used in infrastructure projects to increase efficiency through the reduction of wasteful activities.

2.9 Validity and reliability

The reliability and validity of empirical findings is important for all research. Validity refers to the truthfulness of findings, thus providing a measurement for how well conclusions represent reality (Ghauri & Gronhaug, 2010). Reliability is a measurement of consistency and refers to the repeatability of the study. In this sense, reliability is aimed at ensuring that the same results would be obtained by any researcher given that the same or comparable methods were used during the same or comparable conditions (Brink, et al., 2006). Put simply, this refers to securing that research procedures can be repeated with the same results. Therefore, good reliability requires that the process of gathering, presenting and analyzing data is well documented and that sources are recognized (Ghauri & Grønhaug, 2010).

This research is to a large extent based on the empirical findings from interviews. In order to cover the case study we have attempted to interview as many of the project participants as possible. Moreover, interviews have been recorded and transcribed without censoring in order to eliminate the risk of information loss.

The focus of the research has been to reach conclusions that are applicable for construction companies in general. The reader should however be aware of the fact that all but two of the interviewees represent Skanska and therefore the empirical findings through interviews, as well as from the case study, can be derived from the company.
Chapter 3

Theory

This chapter will present theoretical findings in the field of Lean and BIM. A comprehensive introduction to the principles of lean thinking is presented together with theory on processes and wasteful activities. Theory on the concept of BIM is introduced by presenting the definition of BIM, its development, applications, benefits and obstacles for implementation.

3.1 Lean

Lean theory contains a number of different concepts that can be applied to explain how the use of BIM in planning and design can generate benefits during production. Therefore, this chapter will introduce what “Lean” is and present the underlying principles that constitute the foundation for the concept.

3.1.1 Introducing Lean

The term ”Lean” was first introduced in 1988 by John Krafcik to describe the manufacturing system used by the Toyota Motor Corporation (Holweg, 2006). Since then, the principles derived from the Japanese car industry have been formed into a concept with numerous definitions on different levels of abstraction. On a general level, lean is described in terms of philosophy, culture and values relating to guiding principles and goals. On a systematic level, lean is described as a system for production, operations and management. More commonly however, lean is described from a more practical perspective as a set of management tools, instruments and methods (Modig & Åhlström, 2011). Regardless of the level of abstraction used to define “what lean is”, the different definitions of the concept have a common denominator - lean thinking offers the possibility to eliminate activities that absorb resources but create no value, i.e. “waste”, and through this accomplish more and more
while using less and less resources (Womack & Jones, 2003). Despite the fact that lean principles originate from the automobile industry, the concept has been spread, adapted and applied to other businesses and industries. For example, “Lean Construction” is one of many examples of how lean theory has been applied to other industries in order to achieve more effective business processes through the elimination of wasteful activities.

### 3.1.2 Lean Production & TPS

Lean production or lean manufacturing primarily refers to the production practice originating from the Toyota Production System (TPS). Lean production can from a general point of view be defined as “an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability” (Shah & Ward, 2007, p. 7). More specifically in the case of Toyota, “TPS is based on lean principles including a focus on the customer, continual improvement and quality through waste reduction, and tightly integrated upstream and downstream processes as part of a lean value chain” (Liker & Morgan, 2006, p. 5). The production practice at Toyota evolved through a continuous learning process within the company that went on for decades (Holweg, 2006) and originally, the guiding principles of lean philosophy have been greatly influenced by the environment that prevailed in Japan after the Second World War. The Toyota Motor Corporation was founded during a time characterized by shortages in virtually all forms of resources due to geographical conditions and the expenses of war. From this sprung the need to utilize resources as efficiently as possible (Modig & Åhlström, 2011). After the end of the war, at the time when the Japanese industry had to be rebuilt, delegates from Toyota went to America to study American manufacturing methods. The Japanese delegates concluded that the mass production methods observed throughout the American car industry was not suited for the Japanese industry. To begin with, mass production generated big inventories that were very unsuitable for Toyota given the strained financial situation in Japan. Secondly, the delegates observed how mass production generated a lot of defects, something that fundamentally differed from their business philosophy (Holweg, 2006). Instead, Toyota began the development of a competitive production system that was aimed at lowering costs by eliminating waste, and as a result, Toyota would manage to overcome the difficult conditions that existed in Japan and become one of the leading car manufacturers in the world.
3.1 Lean

3.1.3 Lean principles

According to Womack & Jones (2003), there are five fundamental Lean principles:

- the specification of customer Value
- the identification of the Value stream
- making value Flow continuously
- letting the customer Pull value from the enterprise
- striving for Perfection in all parts of the production chain

Value

Value can only be defined by the customer and needs to be specified in terms of a specific product that meets customer needs at a specific time at a specific price. The producer creates the value but the customer defines it. Therefore, the specification of value is essential to any enterprise (Womack & Jones, 2003). Based on the definition that “waste is what cost time and money and resources but does not add value from the customer’s perspective” (Liker & Morgan, 2006, p. 10), the specification of value is fundamental to the process of eliminating waste.

The term “customer” is an important part of lean theory. American statistician William Edwards Deming broadened the definition of “customer” by introducing the idea that “the next process is the customer”, suggesting that consideration should be taken to both external end-customers as well as internal customers when defining value (Dibia & Onuh, 2010). Consequently, each step in a business process should be considered as an internal customer that needs to be supplied with the right resources at the right time by the preceding step in the production line.

The Value stream

The Value stream can be 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” (Womack & Jones, 2003, p. 353). More specifically, this includes problem-solving tasks related to the process of turning a concept into a finished product through detailed design and engineering; information management tasks related to the process of going from order taking to product delivery through scheduling; and physical transformation tasks related to the process of turning raw materials into a finished product. Moreover, the activities within the Value stream can be divided into three different categories:

- value-adding activities
- non-value-adding activities that are necessary (type one muda)
- non-value-adding activities that are unnecessary (type two muda)
Muda is a Japanese word for “waste” and type one muda represents activities that do not add any value but are still essential for the business process given the current conditions, while type two muda represent activities that can be excluded immediately without any adverse effects (Womack & Jones, 2003). According to Harmon (2003), value-adding activities need to meet three criteria:

- the customer must be willing to pay for the activity
- the activity should physically transform the product in some way
- the activity should be performed correctly the first time

Activities that do not meet these three criteria are consequently classified as waste or muda. Some examples of muda are mistakes and errors that require rework, downstream processes waiting on upstream processes or simply products that do not meet the needs of the customer, be it internally or externally (Womack & Jones, 2003).

Flow

The lean principle of flow can be defined as “the progressive achievement of tasks along the value stream so that a product proceeds from design to launch, order to delivery and raw materials into the hands of the customer with no stoppages, scrap or backflows” (Womack & Jones, 2003, p. 348). With regards to this, waste can be eliminated if people, materials, products, services and information are allowed to flow without disruption through the value stream.

Pull

The pull principle refers to a system in which nothing is produced by upstream suppliers until downstream customers have expressed a need. This way, products are “pulled” by the downstream customer from the upstream producer only when there is a need instead of products being “pushed” downstream by the producer, which do not respond to customer need and result in unnecessary inventory that is considered to be muda (Womack & Jones, 2003).

Perfection

Womack & Jones (2003) have defined the principle of perfection as “the complete elimination of muda so that all activities along a value stream create value”. It is however not possible to completely eliminate waste in practice but the principle is intended to encourage the pursuit of continuous improvements.

3.1.4 Efficiency of flow

In addition to the lean principles that have been presented in the previous section, there are a number of concepts that can be applied to explain how lean thinking relates to efficiency. Traditionally, efficiency has been considered to be achieved by utilizing
resources, such as machines, as efficiently as possible. For example, when focusing on resource efficiency, machines should ideally be put to use and produce output constantly. In contrast, efficiency in lean thinking focuses on the units being produced rather than the machines, in order to make the units flow efficiently through the entire production process at the right time and only when needed (Modig & Åhlström, 2011). Prior to presenting a definition of what efficiency of flow is, a number of concepts need to be described.

Processes

Lean thinking is a strategy designed to achieve efficiency by focusing on flows rather than resources (Modig & Åhlström, 2011). The efficiency achieved by optimizing flow resides within processes and the term should therefore be examined further. A general definition used in operation management literature states that “a process specifies the transformation of inputs to outputs” (Laguna & Marklund, 2011, p. 2). Furthermore, transformations can be divided into four different categories:

- **physical**, such as raw material being transformed into a finished product
- **locational**, such as products or people being transported or moved
- **transactional**, such as cash being exchanged for stocks
- **informational**, such as data being interpreted into valuable information

In order to take on a lean process perspective, processes should not only transform inputs to outputs but also refine them (Modig & Åhlström, 2011). Accordingly, the transformational activity needs to fulfill the criteria of a value-adding activity. The input being refined can be referred to as a “flow unit”, which is defined as “a transient entity that proceeds through various activities and finally exits the process as finished output” (Laguna & Marklund, 2011, p. 5). With regards to lean thinking, the flow unit represents the product that should flow through the value stream without interruptions, gaining value as it passes through each activity within the process.

Flow units can be divided into three different categories; materials; information; and people. All businesses, regardless of type, consist of processes that handle a combination of all three kinds. Considering the fact that processes are defined by its flow units, it is essential to take on the perspective of the flow unit when striving to improve a process through lean thinking (Modig & Åhlström, 2011).

In addition to the flow unit, processes are defined with regards to system boundaries, i.e. where a process starts and ends, and to the level of abstraction for which the process is described. For instance, a business process on a high level of abstraction can be exemplified as the chain that goes from procuring raw material, to refining it, and finally selling it to the end-costumer, whereas a process on a lower level of abstraction can be exemplified in the form of the processing of raw material by a machine. Any process can be subdivided into one or more activities that consist of a number of tasks. It is therefore essential to adopt a holistic approach and define processes with respect
to its components in order to achieve lean thinking in every step of the business process (Modig & Åhlström, 2011).

**Lead time, cycle time and Little’s law**

*Lead time* or throughput is defined as the time required for a flow unit to pass through a process, from input to output. The *cycle time* is defined as the average time between two successive flow units as they exit a process as output. This way, cycle times determine the average time for a process to repeat itself. Little’s law states that lead time equals the number of flow units being processed multiplied by cycle time (Modig & Åhlström, 2011).

\[
\text{Lead time} = \text{number of flow units being processed} \times \text{cycle time}
\]

Little’s law explains that lead time depends on the number of flow units being processed and cycle time. Consequently, increases in either cycle time or the number of flow units result in increased lead time. Long cycle times occur when tasks cannot be carried any faster or when capacity is too low (Modig & Åhlström, 2011).

**Bottlenecks**

A *bottleneck* is an important factor that affects the efficiency of processes. It can be defined as the step within a process that has the longest cycle time, and processes with bottlenecks have two characteristics (Modig & Åhlström, 2011):

- before a bottleneck there will always be a queue of materials, information or people
- bottlenecks reduce the flow of units and therefore, subsequent steps in a process will not be utilized to its full capacity

Consequently, bottlenecks result in non-value-adding waiting time that reduces efficiency by increasing the overall lead time of the process. Hence, it is important to identify bottlenecks when striving to make processes more efficient. Bottlenecks arise due to variation in the processing time for flow units, and only when steps within a process need to be carried out in a predetermined order. The problem of variation can be addressed by standardization but it is hard to eliminate completely, especially when the flow units are represented by unpredictable actions of people instead of materials (Modig & Åhlström, 2011).

**The efficiency of flow**

Combining the concepts presented earlier, the efficiency of flow can be defined as the sum of value-adding time in relation to the overall lead time. Consequently, efficiency can be increased through reduced lead times or an increased amount of value-adding activities. In conclusion, businesses are comprised of different forms of resources that process flow units from input to output. There is a transfer of value between resources
and flow units, in which the resource (the sender) adds value to the flow unit (the receiver). Traditionally when focusing on the efficiency of resources, the target is to ensure that the resource adds as much value as possible during a given period of time. In contrast to this, efficiency of flow focuses on ensuring that the flow unit receives as much value as possible during a given lead time (Modig & Åhlström, 2011). This fundamental idea within lean thinking allows businesses to map their processes and adjust their focus to the elimination of all activities that do not add value.

### 3.1.5 Waste

Lean thinking relies on the identification and elimination of waste. As defined by Womack & Jones (2003), waste or “muda” refers to “any human activity which absorbs resources but creates no value”. In accordance to this, it is stated that “waste is what costs time and money and resources but does not add value from the customer’s perspective” (Liker & Morgan, 2006, p. 10). Originally, seven types of wastes have been identified within the context of manufacturing by Taiichi Ohno at Toyota and an eighth was later introduced together with the original seven by Womack & Jones (2003). The eight wastes include:

1. overproduction
2. defects
3. waiting
4. excessive transportation
5. inappropriate processing
6. unnecessary inventory
7. unnecessary motion
8. design of goods or services not meeting customer needs

The eighth waste, although being non-value-adding, does not necessarily need to be further elaborated on considering that “it is arguable that the consequence of this eighth category is inherent in the seven wastes previously defined” (Hicks, 2007, p. 237). Subsequent authors have introduced additional wastes, such as underutilization of people’s competence (Koskela, 2004), however only one additional waste will be addressed in this thesis, namely the waste of “making-do” introduced by Koskela (2004). Initially the original seven wastes will be presented below.

**Overproduction**

Overproduction refers to the event in which resources produce too much output or too soon, which result in excessive inventories that have consumed resources without adding any value (Hicks, 2007).
Defects
Defects relate to finished products or services not fulfilling the requirements of the costumer, resulting in poor delivery performance and quality problems (Hines & Taylor, 2000).

Waiting
Waiting or queuing occurs when downstream processes experience inactivity due to upstream processes not delivering new input on time (Hicks, 2007).

Excessive transportation
Excessive transportation relates to movement of materials that do not fulfill any value-adding purpose (Womack & Jones, 2003).

Inappropriate processing
Inappropriate processing is defined as “extra operations such as rework, reprocessing, handling or storage that occur because of defects, overproduction or excess inventory” (Hicks, 2007, p. 237), i.e. processing steps that are not originally required to fulfill customer requirements.

Unnecessary inventory
Unnecessary inventory refers to raw materials, work-in-progress and finished products that are not directly required to fulfill customer needs, which result in extra processing, excessive transportation and use of space that is non-value-adding (Hicks, 2007).

Unnecessary motion
Unnecessary motion refers to movement of resources such as people, machines and equipment that do not fulfill any value-adding purposes. Unnecessary movement arises from inefficient layouts of the production site, defects, rework and excessive inventory that need to be moved (Hicks, 2007).

Making-do
A definition of this waste category is that “making-do as a waste refers to a situation where a task is started without all its standard inputs, or when the execution of a task is continued although the availability of at least one standard input has ceased” (Koskela, 2004, p. 1). The definition also presupposes that the term input refers not only to materials but also to machinery, tools, personnel, external conditions and information. Three different causes of making-do have been identified; the efficiency syndrome; the pressure for immediate responses; and the improper division into levels of assembly. The efficiency syndrome relates to the urge of focusing on the efficiency of resources, i.e. to have resources utilized as much as possible, instead of the efficiency of
flow. The pressure for immediate responses refers to the belief that by starting a process early, even without all the essential inputs, the process will be completed earlier. Lastly, the improper division into levels of assembly refers to situations in which the number of inputs grows to uncontrollable levels. It is concluded that “making-do is fundamentally caused by the phenomenon of variability in production” (Koskela, 2004, p. 4) and the consequences of making-do are longer lead times, thus resulting in declining efficiency of flow and increases in production costs. Moreover, making-do can result in poor quality and defects that require rework (Koskela, 2004).

3.1.6 Waste in construction

There have been several studies made to analyze the actual time and cost for the waste in construction projects. A productivity study conducted by Simonsson & Emborg (2007) concluded that 43% of the time spent on reinforcement fixing for the superstructure of a bridge could be categorized as wasteful activities that did not add any value. Moreover, Josephson & Saukkoriipi (2007) note in their report that when observing construction projects, as little as 17.3% of the time was used for directly value-adding activities. In the report, it is also stated that the cost of defects in construction projects is estimated to be in the order of 6-11% of the total project cost. In addition to this, a report by Josephson & Hammarlund (1998) states that defects occurring during production can be estimated to reach levels of up to 6% of the production cost. Furthermore, Kalsaas (2010) states that up to 17% of the working time in construction projects can be identified as waste. In accordance to this, Mossman (2009) describes that approximately half of the construction time can be classified as waste and that it makes up about 55-65% of the total cost for production.

In a report, it is concluded that the lean waste categories of overproduction, waiting, transportation, processing, inventories, movement and production of defective products can be found in construction projects (T. Formoso, et al., 1999). In addition to this, the authors of the report introduce an additional category of waste related to for example burglary, vandalism, accidents and damages due to weather conditions. In line with this, another study concludes that the most common waste categories found in construction projects are rework, defects, waiting, delays, material waste, poor material allocation and unnecessary material handling (Alwi, et al., 2002).

3.2 Building information modeling

Building Information Modeling – a widespread concept known to many, but with a purport yet only grasped by few (Deutsch, 2011).

There are numerous books and papers written on the BIM topic. Some of these publications are pure introductory descriptions about the origin of BIM and its
theories, while others are handbooks about how to use specific tools. When reading a fraction of these it is made clear that there are a lot of different definitions of the concept BIM. It is occasionally described vaguely as something that is used to streamline the building process, while in some cases as a tool for creating and sharing building information, all the way from planning and design to the maintenance phase. This chapter will give a comprehensive introduction to the concept and its development as well as give a description of its applications, purposes, possible benefits and obstacles.

3.2.1 Introducing BIM

BIM is the extensive process of developing and using a computer-generated model to simulate the phases of a construction project digitally. Consequently, this includes simulation of planning, design, construction and operation of buildings and structures (Azhar, et al., 2008). BIM can also be looked upon as a modeling technology that can produce, communicate and analyze building models. In the area of BIM, building models are characterized by components represented by digital objects that contain data regarding graphics, attributes and parametric rules that allow them to interact in an intelligent way. The components carry data that describes object-related behavior, which can be used for analysis such as quantity take-off, clash control and digital energy and performance testing (Eastman, et al., 2011). Thus, the building information model is an intelligent parametric representation of the building or structure from which data can be extracted and processed in order to generate information that can be used as a basis for facilitating decision-making (Azhar, et al., 2008).

A building information model has a lot of applications and purposes. Visualizations through 3D rendering can be generated, drawings and shop drawings can be extracted and building codes can be reviewed through analysis of object parameters. Facility management can be facilitated with regards to renovations, maintenance and operation, cost estimation can be done through analysis of the quantity of materials, and construction sequencing can be used to make scheduling more effective. Apart from this, a large number of different analysis and simulations can be carried out on the model to improve performance and to avoid collisions of building parts (Azhar, et al., 2008).

3.2.2 Development of BIM and 3D modeling

Long before BIM was introduced to the construction industry, the development of the essential modeling part of the concept, or more precisely 3D modeling, was initiated. According to Eastman, et al. (2011) 3D modeling was increasingly becoming an important area within research during the 1960s, which resulted in software capable of creating simple three dimensional structures. Figure 3.1 illustrates one of the first
mechanical structures with moderate geometrical complexity created by Ian Braid at Cambridge University in 1973.

Figure 3.1 - Illustration of the model of one of the first complicated mechanical parts containing moderate geometrical complexity (Eastman, et al., 2011, p. 34).

The model was created with a new modeling method called boundary representation, also denoted B-rep, which was one of the first tools able to model solid items. Parallel to Braid’s development in 1973, another way of modeling called Constructive Solid Geometry, or CSG, was developed. Both worked well as modeling methods, but with differences in the way the model was represented and built up with regards to the program code. Initially, these two methods were rivals competing to become the commonly accepted method of modeling. However, since the different methods had contradictory advantages, a combination of these was increasingly being used and subsequently came to be today’s standard method for modeling programs (Eastman, et al., 2011).

Following the initial development progress, the expansion of computer aided design (CAD) has proceeded in a great pace. According to Eastman, et al. (2011) an essential step towards today’s way of using CAD was the introduction of object-based parametric modeling. The unique information stored in each object together with the introduction of object rules and the classification of objects into different categories or families created the foundation for “smart” models that for instance could detect clashes or deviations from defined standards.

As well as CSG and B-rep was the basis for CAD modeling, the development of object-based parametric modeling laid the foundation for all the present BIM software. In year 2000 the company Charles River Software created the design tool Revit. This software was to some extent similar to previous programs i.e. the intent was to enable
for architects and designers to design buildings in three dimensions. However, the biggest difference to contemporary software was that Revit had fully adopted the concept of object-based parametric modeling in 3D modeling. The software was capable of creating a model which did not only include geometrical information, but also information regarding non-geometrical information such as quantities and measurements. This important addition to CAD is now a fundamental basis for all BIM software (Eastman, et al., 2011).

Alongside with the development of Revit, the developer of the software Tekla was doing both research and progress in the similar area. Dr. Chuck Eastman of College of Architecture at Georgia Tech, US argued that: “There is enough cultural and social awareness about BIM that it will eventually become part of our daily work process. Tekla has been BIM even before the name was created [...]” (Orndorff & Tanase, 2010, p. 5). He points out that even though the acronym BIM was becoming more and more popular in this context, this did not imply a paradigm shift in the way of designing models. The term BIM was actually first used and mentioned by van Nederveen & Tolman in the journal Automation in Construction back in 1992 (Eastman, et al., 2008). However, when researching the origins of parametric modeling and non-geometrical information, Engelbart (1962) published the report Augmenting Human Intellect: A Conceptual Framework already in the 1960s. In this report he describes how an architect is able to create an unconventional model of a building with the help of a computer.

“So far the structure that you have built with your symbols looks just like what you might build with pencil-and-paper techniques -- only here the building is so much easier when you can trim, extend, insert, and rearrange so freely and rapidly [...]” – (Engelbart, 1962, p. 67)

As the quote states, Engelbart’s notional model made it possible for the user to easily modify measurements and lines. Further on, he also mentions the possibility of executing a functional analysis of the structure, such as testing leeway for doors. Moreover, according to Engelbart, the opportunity arose to share the model with the stakeholders for which the information was relevant. The stakeholders, for example constructors and clients, could then modify and add information on the basis of their needs. He recognized the striking potential of a model that could be shared among, and carried information from different actors within the construction process. Even though many BIM tools are relatively new, the methodology behind the concept BIM has been present, if not completely visible, for the last 50 years. In the report The information content of BIM, Mario Guttman states that Engelbart actually was the one who “outlined the basic principles of BIM” (Guttman, 2011, p. 29) in 1962 and that it is the technological capabilities and not the actual vision of BIM that has changed since then.
3.2.3 **BIM applications**

BIM has a lot of different uses, for different actors and for different stages of construction projects. Moreover, BIM provides the “improved ability to link design information with business processes” (Eastman, et al., 2011, p. 152). There are a lot of general application areas for BIM and considering the fact that different stakeholders have different business processes, the way BIM is used can differ between different actors and different delivery methods. This chapter will briefly introduce the general uses for BIM.

**Conceptual design**

BIM can be used early on by designers for conceptual design, sketching, space planning, orientation on site, and ensuring program compliance with regards to site-related factors. In addition, the design information generated through the conceptual design allows for preliminary analysis and simulations of what is being built. By using design exploration tools, designers can create mass objects in free forms and shapes that can act as a basis for more detailed design in later stages. Compared to 2D sketching, this quick and easy form of 3D sketching can more easily communicate visual and spatial information between concerned project parties (Eastman, et al., 2011).

**Analysis & Simulation**

The object-related information inherent in a BIM model enables for analysis and simulations of what is being constructed. Moreover, it enables for designers to determine beforehand if the design will satisfy the expected functions for the structure. In house design for example, analysis can be performed to ensure that the mechanical systems are properly sized with regards to codes and standards, and that the structural systems meet functional requirements. Apart from predicting how the different systems within a building will function, simulations can also aid in determining how well the design will satisfy the indented operations within the building (Eastman, et al., 2011). Even though most literature on BIM focuses on house design, there are numerous analysis and simulations that apply to infrastructure projects. For example, BIM simulation can predict the impact of seismic events on bridges, roads and tunnels, which helps designers to generate durable design solutions (Bennet, 2012). Moreover, road safety simulation can ensure that the road design meets the requirements for sight distances, taking into account both road geometry as well as external obstructions (Strafaci, 2008).

**Design coordination**

Traditionally, design coordination and clash control have been carried out manually by using 2D paper drawings on a light table or digitally by using the layers of 2D CAD drawings. In contrast to this, automated reviews of 3D models have become
increasingly more common for clash detection which is an effective and automated way of detecting design errors. However, simple automated clash detection of 3D models often detects irrelevant clashes as well as it lacks the ability to categorize them. Furthermore, if the level of 3D geometry is too low it is difficult to detect objects within objects. Clash detection through the use of BIM on the other hand, provides the ability to combine clash detection with analysis based on pre-defined rules. This way, clashes can be identified, categorized and interpreted as to be of relevance or not. This way, BIM-based clash detection provides an automated and highly time effective way of reducing design errors that would otherwise have emerged as cost consuming problems during production (Eastman, et al., 2011).

**Detailed design drawings**

Based on the BIM model, designers can generate construction level design information in the form of drawings and documents. As the model is represented in all three dimensions, drawings of sections and plans can easily be generated in infinite ways in very short time, compared to time consuming 2D CAD drawing production for which each section or plan has to be created from scratch (Eastman, et al., 2011).

**Design communication**

BIM can also be applied for effective design review. A number of different disciplines have to collaborate during planning and design in order to successfully carry out construction projects. BIM provides a more effective environment for collaboration compared to traditional working methods. Through the use of digital documents and models, data and information transfer is made more efficient and reliable (Eastman, et al., 2011).

**Quantity take off and cost estimation**

With the help of BIM software, precise quantities for materials can be obtained as reports. For instance, documentation of reinforcement including information about the quantities and properties of the material can be obtained (Tekla, 2013). Cost estimates can be extracted from BIM software through quantity take off. This way, the object-related information stored within the model can more easily be converted into bills of quantities that provide accurate cost estimates, while minimizing the risk for human errors and miscalculations (Eastman, et al., 2011).

**Schedule simulation (4D)**

BIM offer the possibility to link scheduling and planning to the 3D model. This allows for work tasks to be linked to physical objects and visualized sequentially, which effectively communicates scheduling in a completely new way (Eastman, et al., 2011).
Prefabrication

Using BIM models creates an informational basis that makes it economically viable to increase the level of prefabrication in construction projects. 3D modeling combined with analysis based on object-related rules increases the reliability for parts fitting together, which in its turn leads to shorter cycle times and consequently increased efficiency during production (Eastman, et al., 2011). Moreover, it is stated that “there is a great potential for efficiency gains by standardization, repetition and modular approaches” (Statens Offentliga Utredningar, 2012, p. 69). Findings from a case study suggest that construction time can be decreased and that the number of activities required to complete the structure is reduced, making the process easier to manage and plan (Larsson & Simonsson, 2012). Moreover, it is concluded by Aram, et al. (2012) that using BIM for designing, fabricating and erecting concrete reinforcement can potentially improve the productivity of the entire process.

Machine control

The BIM model can, when combined with a GPS system, create the prerequisites for machine control in the field, which makes the construction process both faster and more accurate (Eastman, et al., 2011).

3.2.4 BIM benefits

Building information modeling has become a central subject in the AEC industry. There is an ongoing transition that proceeds from basic 2D drawings towards the use of 3D and object based BIM models. These models, filled with project information, can be utilized in many ways, by various stakeholders and in many areas throughout a project, all the way from feasibility study to the maintenance of the structure (Eastman, et al., 2011). There are innumerable benefits originating from the use of BIM and it is of outmost importance to make them visible in order to promote further implementation of BIM in infrastructure. This section will address a number of important benefits that stems from the implementation of BIM.

Visualization

Looking back at what Engelbart (1962) wrote, he stated that working with computer aided systems is working in an augmented way which is supposed to enhance the human intellect. And, as mentioned in the introduction, the way of working with BIM is a model-centric methodology. Compared to working with 2D CAD drawings, this enables for enhanced visualization of the structure (Azhar, et al., 2008). From improved visualization originates benefits such as:

- better overview and understanding
- compatibility and clash detection
- risk reduction
Visualization of 3D models is of great advantage for every stage of construction, and for all stakeholders who use it. As stated in literature, “use of building models as a visualization tool is one of its most obvious uses with the clearest advantages. The 3D model of the project helps different parties to better understand the concept and especially the details of the design, forming a common mental picture and understanding far more quickly and effectively than with traditional drawings” (Eastman, et al., 2011, p. 503). This is supported by Jongeling (2008) who states that the implementation of a 3D model helps to create a more perceivable and comprehensive structure, which when used during a detailed design process results in a construction process with fewer errors. Considering the design phase, Eastman, et al. (2011, p. 253) states that using the BIM model for visualization leads to “more accurate design drawings, faster and more productive drawing production, and improved design quality”. In line with this, Azhar (2008, p. 1) concludes that BIM “helps architects, engineers and constructors to visualize what is to be built in a simulated environment and to identify potential design, construction or operational problems”. Consequently, visualization during planning and design can be used to reduce the risk of problems and defects during production.

As introduced earlier, clash control is the ability to review the design of a structure to check for drawing errors that result in structural members colliding with each other. Without a 3D model, this review process is conducted by analyzing existing 2D drawings manually, alternatively combining 2D CAD drawings digitally. However, clash detection by 2D drawings is a really error-prone process due to the deficiency of the third dimension available in 3D models. The additional dimension in 3D modeling enables for an easier and more reliable control. Moreover, the opportunity to perform automatic clash control through the use of software applications simplifies and accelerates the control process (Eastman, et al., 2011). According to Azhar, et al. (2008), most companies that have implemented BIM use it for exactly those reasons i.e. as a visualization tool and for clash control. Accordingly, Joseph H. Jarboe, president for the Associated General Contractors of America, states that clash control is actually one of the most essential benefits originated from BIM usage (McGraw-Hill Construction, 2012). Furthermore, in 2007, the Center for Integrated Facilities Engineering at Stanford University gathered information from 32 construction projects where BIM had been used. The results showed that, by using BIM for clash detection, savings of up to ten percent of the contract value could be achieved (Azhar, 2011).

Preventive planning and design

The use of BIM can make existing processes more effective by providing new working methods that support detailed and preventive planning and design. Benefits related to this can be exemplified by:

- fewer requests for information (RFIs)
- decreased need for redesign
- evaluation of what-if scenarios
Traditional 2D drawings are restricted with regards to how much information that can be shown in one drawing, as well as the number of drawings, or sections that can be produced. Hence, using 3D models allows for enhanced accessibility to information since the model can be used by others than the designers for accessing information. According to Azhar (2011, p. 243), the previously mentioned investigation conducted at Stanford University concluded that “seventy-nine percent of BIM users indicated that the use of BIM improved project outcomes, such as fewer requests for information (RFIs) and decreased field coordination problems”. It is the occurrence of problems and errors during production that increase the number of RFIs, unnecessarily involving people in time consuming decision making that could have been avoided (Eastman, et al., 2011). However, as stated in the previous quote, BIM has been shown to decrease the number of errors in the field while at the same time providing easy access to information when needed.

MacDonald (2012) states that: “integrating multidisciplinary design inputs using a single 3D model allows interface issues to be identified and resolved in advance of construction, eliminating the cost and time impacts of redesign”. BIM can in this respect be used for detailed preventive planning that reduces the number of errors in the field. In addition to the reduction of redesign and rework, there is another benefit, namely the possibility to efficiently evaluate what-if-scenarios. Objects in a 3D BIM model are, as stated in the chapter on BIM development, coupled to each other. Due to this, Strafaci (2008) means that what-if scenarios can be evaluated more efficiently in the design phase. And if more information, like for example economics, is connected automatically to the model, the efficiency gets even higher. Furthermore, this is supported by the quote below.

“Early access to the rich information in the models helps everyone on the project team gain more insight into their projects. As a result, the team can make more-informed decisions much earlier in the planning, design, construction, or renovation process—when decisions can have the greatest impact on project cost, schedule, and sustainability” – (Autodesk, 2011, p. 2)

MacDonald (2012), Strafaci (2008) and Autodesk (2011) are only a fraction of those who share the same opinion about BIM: that early decision making and more detailed planning and design is a great BIM-related benefit that results in a construction process containing fewer errors originating from design glitches. In line with this, Strafaci (2008) describes the differences in the ability of impacting the design of a construction between a project using BIM and one in which 2D drawings are used. This comparison is illustrated in Figure 3.2 below.
In the figure, line number one illustrates the ability for the designer to impact the design, both economically and performance wise. This ability of impact is high during the preliminary design but decreases steady as the project proceeds towards the operation phase. Line number two illustrates the cost for design changes, showing a small cost in preliminary design and with a steady increase throughout the project time. Moreover, Strafaci differentiates between what he refers to as a “BIM” workflow and a “drafting-centric” workflow. In the latter, where 2D drawings are used, most of the design work, as line number three shows, is conducted in the construction documentation phase where costs are increasing and the ability to impact the design has decreased since the preliminary design. In line four on the other hand, which represents the work process when using BIM, a lot of the effort is put down early in the design phase (Strafaci, 2008). Consequently, by working with BIM the project efficiency can be increased due to shorter construction time, less design related errors and fewer changes in design during construction (Eastman, et al., 2011; Strafaci, 2008).

**Improved collaboration**

Two other benefits related to BIM usage are:

- better collaboration
- better project prediction

In the literature on BIM, it is stated that BIM supports and facilitates collaboration within the project group throughout the entire duration of construction projects (Eastman, et al., 2011). Via a case study, Dahlqvist & Winberg (2010) points out that
3.2 Building information modeling

the usage of BIM increases the collaboration among the stakeholders of a project. Furthermore, according to Engelbart (1962), people work with a higher level of efficiency and produce better results in groups with good collaboration and good communication. Along these lines Adam Strafaci states that “building information modeling — BIM — is not a product or proprietary software program. It is an integrated process built on coordinated, reliable information about a project from design through construction and into operations” (Strafaci, 2008, p. 1). Many similar statements can be found about the fact that BIM has nowadays developed into a way of working which, when utilized correctly, enables for a high level of communication and information exchange (Eastman, et al., 2011). This is supported by the following statement from a case study concluding that “the collaborative 3D viewing sessions also improved communications and trust between stakeholders and enabled rapid decision making early in the process” (Azhar, et al., 2008, p. 7). In addition to this, Eastman, et al. (2011) indicates that compared to working with 2D drawings, BIM makes it easier to conduct simultaneous work in the design phase. This is due to the fact that it is easier to apply changes to the model which automatically carries out the modifications in all dimensions and to all digital drawings connected to the model, compared to 2D drawings which have to be changed individually. Also, Strafaci (2008) means that by using a 3D BIM model, design changes can be addressed quicker and this gives the engineers and project team a better prediction of the project.

3.2.5 Obstacles for BIM implementation

Even though BIM has been proven to generate benefits when implemented, there are still many barriers that have to be overcome in order for BIM to be widely adopted by the construction industry. One of the largest barriers is that construction companies believe that BIM training would cost their company too much money and human resources (Yan & Damian, 2008). In line with this, Kaner, et al. (2008) state the investment costs needed for training and software purchase is relatively high when implementing BIM.

The success factors for BIM implementation is to a large degree people-oriented and apart from the fact that too little research concludes case study evidence of the economic benefits with BIM, there is a social and habitual resistance to changing the way that work within the construction industry is carried out (Yan & Damian, 2008). This is supported by Eastman, et al. (2011) who state that resistance to changes of the current work process is an obstacle for successful BIM implementation.

There are also technical barriers that hinder the adoption of BIM in the construction industry. The issue of interoperability between software has been identified as an obstacle that hinders efficient collaborative design. Moreover, the fact that the software developers need to assume the financial risk for developing specialized
software is an obstacle that limits the available range of products on the market (Eastman, et al., 2011).

Legal issues have also been identified as an obstacle, considering the fact that the improved collaboration that BIM provides also means that responsibilities and rewards need to be legally regulated in new ways (Eastman, et al., 2011). The issue of ownership over the model is a legal risk that needs to be managed in order to facilitate BIM adoption (Azhar, et al., 2008). The industry is to a large extent regulated by contracts that were developed even long before CAD was introduced and consequently there is a need for new contracts that cover the new exchange of design information (Hartmann & Fisher, 2008).

Additionally it has been identified that there is a lack of people with expertise in both BIM and structural engineering (Kaner, et al., 2008). This is illustrated in another study by the statement that “the most often mentioned barrier was the lack of skilled personnel and the learning curve of new tools” (Ku & Taibat, 2011, p. 185).
Chapter 4

Findings

This chapter presents the empirical findings obtained through observations from a case study and through interviews. To begin with, the specific findings from the case study will be presented by briefly introducing the construction company Skanska followed by an introduction to the case study. Subsequent to this, data gathered from interviews and observations are presented. The respondents are kept anonymous and categorized accordingly to their professions by the abbreviations presented in the abbreviations section in the beginning of this thesis.

4.1 Case study

4.1.1 Presentation of Skanska AB

Skanska AB is one of the largest construction companies in the world, employing about 56 600 people worldwide and 11 000 people in Sweden. Founded in the southern part of Sweden in 1887, the company has evolved from a producer of concrete products into a construction company providing construction works for housing and infrastructure as well as engaging in the development of housing and commercial real estate. In 2012 the company had revenues on the Swedish market of approximately 27 billion SEK, and the Skanska Group has domestic markets in Europe, North America and South America (Skanska AB, 2012).

The financial goal for the company is “to be the leading project developer in local markets and within selected product areas such as residential units, offices and commercial, and within selected types of infrastructure projects” (Skanska AB, 2012).
4.1.2 Introduction to the case study

For the reason of finding empirical evidence of how BIM is used in infrastructure, this thesis includes observations from a roadway bridge project that to a certain extent have used BIM tools during planning and design.

The bridge is called the Slammertorp Bridge and is part of the Mälarbanan project in which about 20 km of the railway between Tomteboda and Kallhäll in the Stockholm area is being expanded from two to four tracks. This broadening is done in order to separate the commuter trains from the rest of the rail bound traffic with the objective of achieving both better punctuality and faster and more frequent passages. Even though the project as a whole is a design-bid-build project with Trafikverket\(^1\) as a client, Skanska has the responsibility for both design and construction through a design-build contract for the bridge in question.

The construction process of the bridge started in late 2012 and is scheduled to be completed in late 2014. Due to the expansion of the railway, the current Slammertorp roadway bridge, which is crossing the railway tracks, will not be compatible with the increased track width and consequently a new roadway bridge has to be built. The new Slammertorp bridge is illustrated in figure 4.1 below.

![Figure 4.1 – Illustration of the Slammertorp Bridge (Skanska, 2013).](image)

Spanning 135 meters with a slight curvature, the bridge rests on top of four mid piers that carry two cross beams which in turn carries the deck. The bearing parts of the bridge are constructed out of concrete and due to difficult ground conditions a number of the bridge piers, the foundation for a temporary portal, and one of the abutments have to be founded on piles.

\(^1\) The Swedish Transport Administration
4.1 Case study

Even though the bridge is located outside of central Stockholm, many factors contribute to difficult conditions that need to be considered. Firstly, the bridge is both located in a water protection area and in the absolute connection to the Görväln nature reserve which introduces additional consideration to environmental thinking during construction. Also, due to surrounding industrial activities, the project area is exposed to approximately 400 daily heavy traffic movements that require precautionary planning. In addition to this, there are a number of ancient remains and protected trees that are situated adjacent to the construction site.

4.1.3 BIM in the Slammertorp project

BIM is an ambiguous concept with many dimensions and it is therefore important to present to which extent BIM has been implemented in the case study. Skanska have established a sequential order for how to implement BIM, in which the number of applications is increased as new work processes are implemented. The order for implementation is illustrated in Figure 4.2 in which the first implementation step is located to the left and the subsequent steps are represented by the following steps. The general BIM applications have been compiled and categorized into a total of four different steps, corresponding to the order for which they should be implemented (Skanska AB, 2012).

![Figure 4.2 – Illustration of the implementation sequence for BIM applications at Skanska.](image)

With regards to Skanska’s implementation plan and the Slammertorp project, BIM has only been implemented in the form of 3D planning and design. Moreover, only some parts of the structure have been designed in detail in 3D. To this day, those structural members include pile groups and reinforcement for a number of the piers. Consequently the BIM maturity level in this project is relatively low and should be taken into consideration when drawing conclusions about the effects of BIM usage in this project.
The use of 3D modeling has been initiated by the project manager with the ambition to, as far as possible given economy and scheduling; try out new ways of working with 3D planning and design with the intention to gain experience in the field of BIM. The project is not a pilot project for BIM and the use of 3D modeling has been carried out while taking into account budgeted costs and scheduling for traditional 2D planning and design. Consequently, the case study does not cover the entire BIM concept but it does give insight to an important part of it, namely 3D modeling. For the duration of the work on this thesis, three primary work processes during production have been observed and those are; surveying, piling, and reinforcement works. As an example, Figure 4.3 below illustrates how the model of the bridge was applied for planning and design of the pile groups.

Multiple models have been put to use in the project, partly due to the sheer size of them. Therefore, models for each of the four piers including the two abutments as well as one model for the superstructure have been created in Civil 3D. Apart from these seven models, an additional model depicting the entire bridge as a single 3D object without any intelligent information will be created for the purpose of using it during production. In addition to this, a model for the reinforcement for a number of the piers has been created in Tekla. Regarding information and data sharing, the 3D models have not been shared in between project members. Instead, 2D drawings have been extracted from the model to be used by others.
4.1.4 Planning meetings

Detailed collaborative planning and design

Observations have been made that 3D modeling is not the only thing that sets this infrastructure project apart, but the way that planning meetings have been conducted can also be an important factor for the project outcome.

Planning meetings have been held on a regular basis two times a week. The meetings have foremost involved the design engineers, supervisors, the design coordinator and the project manager but craftsmen and experts have also been participating on a regular basis. The design engineers have been geographically separated from the rest of the project as they are stationed in Malmö whereas the rest of the project members are based in Stockholm. This gap has been bridged by using video conferences during all meetings. This has also allowed for the design engineers to easily share their desktop and display the 3D models and drawings on a big screen.

According to the project participants, the way that the meetings have been held is not a common procedure. For example, DE3\(^2\) states that “I have been working here for several years and have never experienced this kind of work procedure for planning and design”. This is confirmed by DE2 who says that “I believe that, normally, very few projects have meetings in the way that we have had and as often as we have had them, but off course that very much depends on the individuals who are involved in the project”. What sets the project apart is the fact that a lot of devotion has been put into solving potential problems digitally during planning and design, partly by the help of 3D modeling, before they arise during production. This is supported by DE1 who says that “one good example of the planning work we did in the project regarded the piling works. Specifically the fact that the craftsmen were involved in the planning process, which gave us the possibility to address and solve a lot of potential problems beforehand”. Moreover, DE2 states that “you can never eliminate all problems through planning because there is always a risk of unforeseen events during production, but a lot of problems can actually be discovered. Especially problems related to the design of the reinforcement. In that particular area you can solve a lot of potential errors and structural conflicts by having ha dialogue”. In addition to this, DE1 says that “the more issues you can address early, the better it is. If planning and design cost a little bit more, you will have saved that money in the end due to the fact that disturbances during production cost more than extending the planning process for a week”. The positive attitude towards detailed collaborative planning and design is also shared by the supervisors. For example SV2 states that “the planning meetings have been beneficial. The production staff is allowed to give their opinions and introduce changes

\(^2\) A description of the abbreviations used for different respondents is presented in the very beginning of the report in the Abbreviations section. The interview information for each respondent is presented in the Bibliography.
CHAPTER 4. Findings

to the design that better suits the production process”. Moreover, DE2 states that “when visiting construction sites I often hear that the reinforcement workers feel that their opinion regarding the design is seldom considered. I believe that by involving these people in the design process you increase the sense of commitment because of the fact that their opinions count”.

DE3 is of the opinion that “these planning meetings have been beneficial for us” and as a concluding remark, DE2 states that “the planning meetings are not dependent on BIM. We could still have had them even if we would have worked with traditional 2D planning, and in the same way we could work with BIM without having these forms of meetings. However I believe that it is important to already in the early stages of the project involve production and have a dialog in order to achieve a better design”. At the same time, DC1 is of the opinion that “the most important task is to get designers and producers to communicate. Once you get past a certain point, the dialogue seems to continue by itself”.

During the meetings it has been observed that the presence of a design coordinator has been a critical factor regarding what issues have been addressed as well as for how thoroughly they have been discussed. The task for the design coordinator has been to monitor the meetings and ensure that all participants communicate and develop a design in understanding with each other. During those meetings for which the design coordinator has not been able to participate in, the following observations have been made:

- issues have not been discussed at the same level of detail
- meetings have ended earlier due to lack of topics to discuss
- the number of discussed issues have been lower
- existing methods and solutions have not been challenged to the same degree

Having a design coordinator present at the meetings have resulted in more issues being illuminated and discussed by design engineers and production personnel, while combining their expertise to jointly come up with solutions.

**BIM in meetings**

During the planning and design meetings in the case study, observations have made that when the meeting revolved around the model it was noticeable that people regardless of their professions were interested and engaged in discussions regarding what was visualized. Moreover, it was obvious that the communication between the participants was facilitated due to the fact that the model made it easier for the participants to explain their reasoning as they could illustrate their thoughts with the help of the model.
4.1.5 **Identified benefits of BIM implementation**

**Surveying**

*Fewer requests for information*

Considering the communication between the surveying personnel and the designers, SP1 states that it is easier for the surveying personnel to use a 3D model compared to requesting information from any of the designers. In a 3D model it is easy to just pick a relevant line from the model and use it in the stakeout work. This is also the opinion of PE1 who says that “what is good is that the surveying personnel can in the field chose to put the whole model in the measuring device. In that way, all points in the model gets available and one does not need to add any specific points into the device beforehand”. PE1 says that experience from another project where a BIM model is used shows that this facilitates the work for the surveying personnel.

Furthermore, DE1 states that the communication between the designer and the surveying personnel is experienced to be less frequent but more informative when using a BIM model which has been experienced in another project. As the surveying personnel often demands different coordinates of the site from the designer, it is not seldom that when designing in 2D, these coordinates might be wrong in the sense of for example height or location. By using a 3D model on the other hand, DE1 says that through this follows the great advantage that the surveying personnel can simply chose the coordinates they want directly from the model instead of requesting additional information from the designers. And, if the correct software is used, the model can be directly downloaded into the measuring device sparing the surveying personnel from the job of picking out single coordinates.

*Improved visualization*

It has been noticed that a 3D model is advantageous when it comes to visualization for the surveying personnel. SP1 states that since for example the abutments do often have quite a complex shape, a 3D model is greatly beneficial when it comes to understanding the structure. Due to the lack of a 3D model in previous projects, SP1 states that “it can be hard to understand the geometric shapes of the abutments, not least because they can be positioned perpendicular to neither the track nor the road extension”. It is also mentioned that the possibility to be able to “twist and turn” the model would greatly facilitate the understanding of the structure.

*Reduction of rework*

It is stated by SP1 that during production in the case study, there is a big occurrence of rework related to surveying. This type of rework is said to be avoidable or at least reducible by the help BIM. For example for piling, it is usually the surveying personnel, alternatively the surveying manager that produces the information needed to be able to do the surveying work at site. SP1 says that this information is gathered from the designers and usually consists of pile coordinates, inclinations and directions.
It is not uncommon that this information is received as a pdf-file, or even as a paper document from which the necessary information is copied and put into a list of codes used by the surveying personnel. The perception of this way of working is that there is a large potential for improvements if a 3D model could be used instead of copying information by hand.

**Piling**

*Visualization and quality assurance*

In the field of geotechnical engineering, working with a 3D model in the design phase enhances the opportunities for a more reliable design. GE1 states that BIM and 3D models can be a very helpful visualization tool for the designer in the design phase. Even though it is possible to deduce and understand tricky parts of the construction by using 2D drawings, 3D models make it possible to, in an easier and more comprehensive way, understand these parts of the structure. This has in the case study been observed as a major advantage originating from the use of 3D modeling. With the help of the model it has during design meetings been possible for different professionals within the project to analyze how the piling works affect both existing and planned nearby structural members. This is supported by SV1 who states that it is possible to discover problems in the design phase and thereby solve these problems before they occur in the production. In the case study, the model was used in the design phase for the following examples:

- to check the compatibility between the piles and the rock surface
- to check for pile collisions in the ground
- to check that the piling machine would not collide with existing power lines
- to check for pile collision above cut-off level
- to check for overall production compatibility

During the design of ordinary piling works, GE1 says that it is not unlikely to encounter various difficulties. As written, one example of when the 3D model in the case study was used was when the piles were designed with respect to the rock surface. Problems with some vigorously sloping rock surfaces could be detected through the usage of the 3D model, and thus this area of the pile group could be designed more thoroughly. This resulted in additional measurements of the rock surface level at site in the affected pile-positions which led to the creation of what the designers thought was a safer design. So, by using 3D modeling the opinion is that the 3D model greatly improved the understanding of where the piling works could become critical. Also, some of the occurring problems are said to be easier foreseen in the design phase consequently making it possible to find solutions to these problems before they emerge in the production (GE1).

Visual compatibility controls under the cut-off level were in the case study conducted since many piles were designed with different inclinations and in different angles and
directions. SV2 says that it is really beneficial to use the model for visualization since “it is hard to see in a 2D drawing how the piles are inclined under the ground surface”. This compatibility control resulted in an observation of two piles from different pile groups that, in the model, were put unnecessarily close to each other. Another result of the compatibility control is the fact that during the piling works, two piles were driven so that from the surface it looked like they were colliding below the ground surface. This example, which is shown in Figure 4.4 below, caused the piling works to stop for investigation. But, as the coordinates of the driven piles were measured and inserted into the model, it was quickly shown that no collision had occurred and it was not long before it was possible to continue driving the remaining piles.

As the amounts of piles were relatively low, these compatibility controls could be performed without any automatic collision control tools. At the same time DE1 states that they improved the assurance of the design as well as potentially leading to a production containing less interference.

Furthermore, the quality assurance of the design in general increases by using a BIM model. GE1 states that when designing in a more traditional 2D manner, there is always a risk that, when searching for information, the sources can be considerably scattered in a number of different drawings. This enhances the risk for a range of potential errors such as usage of outdated paper drawings or the fact that there could be a large time span between when a document is modified until it is uploaded into the system. When using a BIM model on the other hand, the information always originates from the same source; the model. Then, if something gets changed or redesigned in the model, these changes are supposed to directly apply to the affected drawings which
consequently reduce the risks for handling errors. GE1 says that “if some information is changed, it is changed in the model and not manually in some drawings”. Though, SV1 states that in the case study, the goal has not been to fully use a 3D BIM model and its associated tools. Instead, since this is the first time many of the persons involved in the project are working with a 3D model, the purpose has mainly been to get everyone to learn about available 3D modeling techniques.

**Optimization of piles**
During design of the piles in the case study, the 3D model has proven to be very beneficial when it comes to the optimization of the actual piles. In the project, both the ground surface and the rock surface were modeled into a 3D model. During design and planning of the piling works, this implied the possibility to optimize the position and inclinations of the piles to obtain a pile group both as computationally secure and materially efficient as possible. For example, during the design and planning phase, some piles were moved from their original positions. This was due to the fact that their inclination followed the possible inclination of the rock surface, which would make it hard to get them fixed. This issue was easy to foresee quickly in the model and here, neither any calculations nor any comparisons between any 2D drawings needed to be conducted. It is stated by GE1 that the surface models truly helped to easily optimize the pile positions in order to avoid disturbances related to for example the rock surface inclinations.

It has also been observed in the design and planning meetings that in a design-build contract the entrepreneur can optimize the production by being able to choose the preferred methods and materials. As the design meetings have proceeded, discussions have been carried out concerning the position, types and number of piles which have resulted in as optimized solutions as possible. This is supported by SV1 says that this is especially evident in a design-build contract where it is easier for the entrepreneur to affect the design than in for example a design-bid-build contract. In the latter case, the scenario is rather to be assigned project documentation by the client which can be difficult for the entrepreneur to influence.

**Time savings in design phase**
When talking about time consumption, the opinions seem to differ among different professions in the project whether it takes longer time or not to design in 3D compared to traditional 2D. GE1 states that in the case study, the 3D modeling of the piles was carried out faster than it would have been in traditional 2D design. This is also the opinion of GE2 who says that using BIM within geotechnical engineering in general is a time saving procedure compared to traditional 2D design. Though, both indicate that there is somewhat of a redistribution of the time spent in the design phase. Initially it takes a bit longer time to build up the whole model based on the project data, but when it comes to producing drawings it is easier and leaner to do this from the model rather than doing it in 2D (GE1). But as in many other cases this depends on the size and complexity of the projects. For example a simple drawing is produced faster with
the help of traditional 2D software, but when it comes to designing bigger projects the opinion is that one saves time by doing a 3D model. GE2 also says that it “obviously takes a bit longer to initially produce the actual model, but as a project continues much more information, such as coordinates, heights etc., is demanded from the designer than in the startup of the project”. If this kind of information is added into the model in the beginning of the project it goes much faster to deliver required information to the project later on.

Work procedure planning

In the case study the intention with the model has been to create an as detailed model for the piling works as possible. As a result of this, it has in the planning and design meetings been observed that it has been possible for the designers together with Skanska Foundation to actually plan the procedure of the piling works in great detail. A model of the piling machine itself was downloaded into the model which enabled for various controls of widths, lengths and heights. As a result of this, some obstacles for the machine were directly detected. For example, a post for an old high voltage power line including its brace which had been put into the model did cause some trouble. It did not collide with any of the piles, but as the piling machine was imported into the model it was evident that the distance between one pile and the power line post was too small with regards to operating the piling machine. Consequently, the pile group was changed a bit already in the design phase making it possible to drive the piles correctly and without disturbances from the power line post. Also, together with the production personnel, the model was used to analyze what the optimal machine path was before the machine had even arrived at site. By doing this, a well based decision of where to drive the machine could be taken where factors such as piles above cut-off level, power lines and track propagation had been analyzed. What otherwise could have become production errors was now foreseen already in the planning phase, resulting in concrete solutions and avoidance of potentially unwanted production stops.

Reinforcing

Compatibility and collision control

Many participants both in the Slammertorp project and other projects believe that BIM and 3D modeling has one of its greatest strengths when it comes to the design of the reinforcement. By using BIM in the design for the reinforcement it has been observed that it is possible to perform compatibility and collision controls which reduces the amount of errors in the design. This is confirmed by SC2 who has been involved in many different projects and observed that 3D modeling generally results in a design containing fewer errors. By modeling in 3D, SC2 says that it has been experienced many times that major faults and errors are more easily foreseen, resulting in changes in the design before reinforcing. The faults and errors are said to be anything from collisions of single bars to parts where the reinforcement is simply not buildable. In the case study, compatibility for the design has been checked for example for the following cases:
• compatibility between the studs of the bridge bearings and the surrounding reinforcement
• collision between reinforcement bars
• compatibility between the anchoring details of the expansion joints and the surrounding reinforcement

SV2 says that it is for these kinds of problems that one can see the major benefits of BIM as it is easier to foresee production related disturbances already in the design phase. In the case study, the bridge seats have been modeled in full detail together with the bearings which have made it possible to see that they will be compatible with each other.

Extended collaboration
As for the relation between companies, the usage of BIM is in the case study experienced to increase the collaboration between the contractor and the subcontractors, at least among those who are using BIM. DE1 states that it is possible for some sub-contractors to use the contractors model for their tasks which saves time and reduces effort that otherwise would have had to be done during the assemblage of the information in the model.

SC1 is of the opinion that what must be a prerequisite for being able to use BIM in a proper way is that “the client and the supplier have to trust each other. The communication and information exchange between these two has to be of that type where information is shared from both parts”. In the case study the supplier of reinforcement feels that the cooperation with the client has worked really well and that optimized solutions could be developed. SC1 says that “the main reason for using BIM is simply to reduce the costs and streamline present work tasks”. This has also been observed in planning and design meetings as where persistent discussions have been held and where optimized reinforcement solutions have been worked out with the help of the 3D model.

Prefabrication
When it comes to optimizing the structure, SC1 says that BIM creates a better basis for construction of prefabricated reinforcement. Because of the advantage of generating a better visualization, one gets a better overview for how the prefabricated members are supposed to be designed and it also increases the possibility to improve these designs. These 3D models are then also easy for the supplier to convert into machine control files for the available machines that cuts and bends the reinforcement bars which have been the case in the case study. SC2 states that the advantage of using prefabricated reinforcement cages and nets is that it saves time for the craftsmen to have them delivered rather than producing them at site. But it is not only the craftsmen’s time that is reduced through this way of working. SC2 further emphasizes the additional advantages that have to do with for example reduction of time
consumption for cranes and other lifting machinery at delivery and handling of the material.

In addition, DC1 is of the opinion that “in order to prefabricate you need to maintain a very high level of detail when you generate your design”. Also, DC1 means that the level of details in the produced design is often too low to be able to prefabricate and in this regard you need to have a detailed design process involving experience from production, regardless if you design in two or three dimensions.

As discussions have been held with the production crew, the main opinion is that prefabrication of reinforcement is a really time saving operation. SV2 says that the installation of a number of reinforcement cages in the case study took the production crew a short time to install compared to the rather long time it could have taken to build the entire cage by hand on site.

**Time savings**

Considering the time effort in design, SC1 is of the opinion that it is both faster and smoother to model up the reinforcement in a 3D model rather than in traditional 2D. SC2 says that when it was tested to produce drawings in 2D, it was noticed that this took a bit longer. On the other hand, comments from colleagues suggest that it goes a bit faster to produce simple 2D drawings. One reason for this individual difference is said to depend on the fact that people are used to work in different ways. SC2 says that “the general opinion is that it takes longer to produce a 3D model compared to 2D drawings. This could certainly depend on the fact that 3D modeling is quite a new way of working which requires somewhat of a learning period. There are also a lot of features in the software which are hard to grasp at the moment, but that in the future probably will be more frequently used”. SC2 also states that when you are able to use mentioned features in a proper way, the modeling will go much faster than it presently does.

SV1 says that using a 3D BIM model could simplify the daily work and reduce the time consumption due to the fact that it is possible to go directly into the model to look for details and measurements. It is said that “in the model, all data is assembled in one file which means that one does not have to take the time to start gathering information from different drawings which sometimes can be a relatively time consuming task”. PE1 is of the same opinion, and says that “everything can be gathered from the same place and you can avoid the hassle with paper drawings”.

When working with BIM it is possible to get the program to understand which bars that are coupled to what phase of the construction. In this way, for example the delivery of the reinforcement can be made more efficient in different ways. SC1 says that “the reinforcement can be delivered section by section and also with colored tags which reduces the handling time of the bars at site” which according to SC1 normally is quite a time consuming work procedure. SV2 also refers to the handling of the reinforcement at site as a time consuming activity and says that this can be optimized.
by using a 3D model. It is then possible to in an easier way group the bars that later on should be mounted in connection to each other and for example put these in the bundles for the crane to lift.

Furthermore, SC1 states that using 3D and BIM models contribute to facilitating the time estimation of construction processes. It is experienced that if an estimation of the time consumption should be made by using 2D drawings, one have to be very skilled to get it right. It is said that “you've got more opportunities to see and accurately schedule how to reinforce in a 3D-model. This results in time savings in the production”.

Visualization

The advantage of BIM which is talked about by all professions in the case study is the fact that BIM and 3D modeling helps to visualize the project components in a very good way. Especially when it comes to reinforcement, 2D drawings are experienced to be quite tricky to understand correctly. According to DE2, sometimes the large quantities and the high complexity of the reinforcement make it difficult to present the details in a comprehensive manner when using traditional 2D drawings. This is exemplified by DE2 who says that “the superstructure of a bridge comprises of intersecting structural members containing reinforcement in complex geometries and it is very difficult to illustrate this in a comprehensible way through 2D drawings”. PE1 says that considering this, the usage of BIM truly helps understanding these components. Figure 4.5 below illustrates how a drawing made from a 3D model could look like, which in this case is an illustration of the reinforcement for a bridge pier in the case study bridge project. It is also stated that especially inexperienced people might have some difficulties with reading 2D reinforcement drawings, and that BIM in that sense is a very good tool for understanding how the structural members are composed (PE1). Also, SP1 states that “it is more than common during reinforcement works to overhear the production staff asking themselves how certain bars are supposed to be mounted as it is difficult to interpret and understand reinforcement drawings”. This is also supported by SV2 who says that even experienced craftsmen and supervisors might have difficulties in directly understanding the 2D drawings. Furthermore, SV2 says that “not everyone have the ability to look at a 2D drawing and then at the same time think in three dimensions. In a 3D model you can understand the design much easier compared to traditional reinforcement drawings in 2D”.
Considering the reinforcement, DE1 states that the 3D model has been experienced as a great advantage compared to traditional 2D drawings. The usage of the 3D model in the design phase helps the designer to see that the reinforcement bars actually fit as they are modeled with their true dimensions and not just as single lines which can be the case when designing in 2D. For example, in an earlier project where 2D drawings were used, it happened to be that the last bars that were supposed to be mounted did not fit due to a simple design mistake. This error slipped through the design phase unnoticed which in this case resulted in a time consuming rework procedure in the construction phase. It is stated that this could then have been avoided if the designer had a better possibility to visualize the structural members before construction. Moreover, DE1 states that “in a previous bridge construction project where 2D design was used, the bridge was designed with an uncommon type of edge beam and as it happens, the reinforcement did not fit at the time of mounting. Due to the fact that the reinforcement bars were drawn as simple lines, the dimensions of the reinforcement bars had not been taken into consideration and consequently there were collisions”. 3D modeling offers the possibility to avoid these kinds of errors. This is supported by DE1 who says that “when using 3D modeling I am assured that the structural members are compatible and do not collide with each other. This is very reassuring for my part and it feels good to know beforehand that my solutions are buildable”.

DE2 states that a BIM model could surely be of good use in bridge projects when considering the reinforcement. In the case study, it is seen to be certainly beneficial to use the model for visualization for example when it comes to the expansion joints, at girder connections or places where the complexity or amount of reinforcement is high. Furthermore, DE1 states that for example when designing complex construction parts in simple 2D, the experience is that it sometimes is too hard to understand the
structure which can lead to that the designer skips that part in hope that the
craftsmen will figure it out during construction. 3D design on the other hand does not
let the designer leave anything to chance. DE1 says that “everything has to be drawn
in detail in order to obtain a true model”. DE2 states that the benefit of having a
model for visualization does not only consider the design crew but also the craftsmen
and the people working at site. This is supported by SV1 who says that “looking at
advanced structures, BIM enables for us to visualize exactly in what order to mount
the bars”.

In the case study, DE3 says that the model is going to be used for visualization in the
construction phase. As a result of creating a “true model”, DE1 says that it is easier to
see how the designer have thought that the structure should be constructed, which in
turn makes it easier for example for the craftsmen to foresee construction related
problems in the work preparations. Also, DE1 states that a great advantage originating
from the usage of a 3D model is the opportunity to carry out the work preparations
with the help of the model. This significantly enhances the ability for the craftsmen,
supervisors and everybody else involved to prepare for the subsequent work in the
project. Also, SV2 states that the visualization increases the craftsmen’s ability to
understand the complex structures and makes it easier to understand how to perform
production tasks. One other example of this advantage was in an ongoing bridge
renovation project where some specific tasks were supposed to be performed by a
subcontractor. DE1 says that this subcontractor had an opinion regarding how the
work tasks were to be conducted before arriving at the site, but as a work preparation
was performed with the help of the model it was realized that many of the tasks could
not be carried out as planned. By doing this, numerous of production disturbances
could be avoided in the planning phase which consequently resulted in large cost
savings. By sticking to this way of working for several of other work operations, the
opinion is that numerous of disturbances have been avoided resulting in both cost
savings and the development of a leaner construction process.

4.1.6 Identified obstacles for BIM implementation

This section will address the findings relating to obstacles for BIM implementation in
the Slammertorp bridge project. By identifying hurdles and obstacles, the aim is to
create a foundation for how to improve existing processes in order to promote increased
use of BIM in infrastructure projects. During planning meetings and through
interviews with actors within the project, a number of obstacles have been identified.
These are presented below as to be:
4.1 Case study

- time
- cost
- knowledge & training
- the client
- industry inertia
- sub-contractors
- organizational issues
- technical issues

**Time**

Time has proven to be a limiting factor for the successful implementation of BIM in the case study. During planning and design meetings it has become apparent that the lack of time has forced the designers to retreat to production of traditional 2D drawings, consequently abandoning the work processes related to BIM. They are in agreement that more time would allow them to use BIM to a larger extent. For instance, one of the designers argued that “the safe solution is to produce traditional 2D drawings. It is too uncertain to model in 3D considering the fact that we do not know how long time it takes” (DE2). The lack of BIM experience is made obvious and the fear of not meeting deadlines is a big obstacle that has limited the use of BIM.

There are a number of factors contributing to the experienced shortage of time. First of all, the produced drawings for the bridge need to be sent to the client, Trafikverket, for review and approval at specific dates. Considering the fact that the project schedule concerned traditional 2D drawings despite the objective to model as much as possible in 3D, the amount of time was limited. On top of this, observations have been made that there exist a widespread way of thinking within the construction industry that put great emphasis on fast production of construction drawings. This is confirmed by one of the design coordinators who said that “normally you rush out into production by the fear of not completing the whole project on time. The finishing date established early on by the client in the tender documents are normally set quite tight, putting time pressure on the entire project” (DC1). This way of thinking is reflected in the way that scheduling is carried out which creates tight timeframes for planning and design works, leaving too little time for adapting to a new way of working with BIM.

There are different opinions about the difference in time consumption for 3D modeling compared to traditional 2D design. One designer is of the opinion that modeling in 3D is more time consuming. One explanation given is that “it takes longer time to model in 3D because there are simply more things that have to be done” and in addition to this “working with 3D modeling is still quite new to us and that contributes to a higher time consumption” (DE2). The designer emphasizes that “considering that this is a new way of working for us, we need more time to be able to finish on time” (DE2). This statement is explained by another designer who claims that “there is always a learning period but as soon you have the proper knowledge and have adapted to a new way of working, modeling in 3D will be carried out much faster” (DE1). Furthermore,
one of the designers believes that “the actual design work for the bridge can be done just as fast in 3D as in 2D but the problem is that Trafikverket requires 2D drawings, which forces us to redesign everything in 2D in order for them to receive the traditional drawings that they want” (DE3). Consequently, the design work has to be carried out twice and logically there is no time for that given the project schedule.

Another observed obstacle related to time regards the fact that too little time is generally allocated for planning and design, which results in inferior prerequisites for implementing BIM. As described in section 4.1.4, planning meetings have been held as frequently as twice a week but as the foundation works have been initiated at site, it is observed that the planning meetings have seized despite the fact that the design for the superstructure is not completed. Another example is given by ES1 who says that “in some cases the production is started without approved drawings. This is due to the fact that there is simply not enough time for the designers to finalize all drawings before construction has to start”.

Cost

Cost is a crucial factor for further adoption of BIM within the industry. The general impression is that BIM cost more money than traditional 2D planning and design and this is a big obstacle due to the fact that the decision makers for implementing BIM in the infrastructure projects also are responsible for the economy. A supervisor explained that “we experienced a lot of resistance in the beginning from management who believed that the costs were too high” (SV2). This is supported by one of the designers who meant that “if you do not realize the benefits and do not understand the profit you can make by using BIM, then you only think that it will cost more money for planning and design and that this phase will take longer time than expected and moreover that it will prevent us from starting production on time, forcing us to extend the time schedule. This mindset is simply a consequence of not realizing the benefits of BIM” (DE1). For the case study, the budget was set for traditional 2D planning and design but the decision was still made to try to accomplish as much 3D modeling as possible. One designer meant that “it would have been good to get some form of economic backup. There are money for development and research within the company and the risk by not receiving any additional funding is that if the projects are supposed to bear the cost for BIM implementation the project management won’t be willing to bear that cost” (DE2). Moreover, the designer explained that “if you are the project manager you are interested in your project doing as well as possible, that is your goal. Then, it is unlikely that you would be interested in funding the development of BIM” (DE2). The designer meant that instead, Skanska should consider how to develop BIM and support the projects. For this case study, this is an obvious obstacle for successful implementation of BIM.

An additional obstacle related to costs is the fact that reporting of hours is much more structured for planning and design compared to production. One designer means that “if we work an additional two hours during planning and design, one can detect the
additional costs right away, but the gain you obtain through coming up with better design solutions is hard to come up with a number for” (DE2). Another designer explains that “our hours are so easy to distinguish and if the hours spent on different tasks during production were as visible, for example for how long the work crew were forced to a standstill due to errors or unforeseen problems, then we would get a direct connection between the hours spent on design compared to the hours that could be saved during production. But that is not the way you do things currently” (DE3). Put simply, it is simpler to foresee the additional costs for BIM implementation during planning and design, than it is to predict the possible cost reductions during production originating from it and this is an obstacle for successful implementation of BIM.

Knowledge & training
Too little knowledge or training has been identified to be an obstacle for successful BIM implementation. One of the designers support this by saying that “personally, I believe that I needed more training, more tutoring and access to more people that know this better than I do. Currently I’ve had one person to ask for guidance but he has been very busy and hard to get a hold of” (DE3). In addition, one of the supervisors says that “people need to learn more about BIM and how to use it. This goes for the entire chain of people involved from design to production” (SV1). Moreover, one of the geotechnical engineers concluded that “the level of knowledge is one of the biggest obstacles for BIM implementation” (GE1). The geotechnical engineer means that BIM is quite a new concept in the infrastructure industry and there are only few people that currently have the knowledge to be able to work with it. A prerequisite for an effective implementation could then be to have a BIM manager in the workgroup or in the projects considering the fact that “too few people know the software and it feels like a big procedure to get familiarized with it yourself” (GE1). Moreover, another geotechnical engineer state that “people are too busy and have too much work on their hands to be able to devote time to sit down and learn the software” (GE2). The engineer means that even though time can be saved in the long run it is difficult to find the time to learn new software.

When elaborating on the topic of essential success factors for BIM implementation, one of the designing engineers says that “I do believe that the time frame could have been longer, but it can always be longer so that is not the most essential factor. Instead when it comes to the matter of resources, it is more important to have someone who is an expert on BIM and 3D modeling that I can ask for advice. It is in that respect that I feel that I would have required more resources in this project” (DE3). This corresponds to what a number of the engineers within the project have said and through observations one can conclude that there is no or little knowledge about BIM among the people working in production. Consequently, the need for further training has been a clear obstacle for successful implementation of BIM in the case study.
The client

There are several factors related to the client that have created obstacles for successful implementation in the Slammertorp project. As mentioned earlier, the client demands traditional 2D drawings and one design engineer confirms the issue by stating that “there is a problem for us, which is that the client still demands traditional 2D drawings, which in its turn leads to double workloads. If we were allowed to work solely in 3D then the costs would definitely be reduced” (DE2). The opinion is that the client has to follow the current development and start approving 3D models as legal documents. This is confirmed by DE2 who states that “Trafikverket needs to keep up with the development within the industry, and hopefully it’s just a matter of time” (DE2). The review process can be time consuming and DC1 confirms this image by saying that “there is almost always a lot of quibbling with the reviewers” (DC1). This consumes time and resources that could otherwise have been put into the process of using 3D modeling to a larger extent in the project.

Moreover, in the contract and tender documentation it is specified that the submissions should be in dwg format, i.e. CAD drawings. However in reality, the client have requested drawings in pdf format, forcing the design engineer to model the bridge in three dimensions, extract two-dimensional drawings from said model and then export them into pdf format, leaving no evidence that the bridge was modeled in three dimensions in the first place. DE3 states that “we have basically been forced to redesign the entire bridge in traditional 2D in order to deliver specifications for the reinforcement that corresponds to the client demands. Based on this, it is not hard to realize why the cost for design has been so high in this project”. DE2 is of the opinion that the norms and standards need to change in order for the client to keep up with the development. This is exemplified by stating that “ten years ago when we started using three-dimensional calculation software, we immediately got review comments, saying that our calculations did not fulfill the current demands for calculations. They demanded that we use the traditional 2D calculation software that they were accustomed to. However, in the latest edition of the guidelines from Trafikverket, it is basically demanded that calculations be done in three-dimensional software. It has taken ten years to reach this point and I believe that if we look five to ten years ahead the client must have adapted in order to keep up with the development” (DE2).

Another obstacle related to the client can be found in the form of late changes during planning and design. For example, the client changed the location of the railway tracks late on, forcing parts of the bridge to be redesigned. In addition to this, other important data such as the placement of the bridge and the impact load have been changed late in the design phase. Apart from these changes, important information for the design has been hard to get a hold of from the client. For example one of the designers explained that “we still have not got the information about which pier that should be grounded, despite the fact that we have requested this information on several occasions. Furthermore, we just received a review comment that we have not presented the grounding for the piers” (DE2). All together, these are factors that affect the
scheduling and as stated earlier, shortage of time is a critical obstacle for successful BIM implementation.

**Industry inertia**

Observations have been made that inertia within the construction industry is an obstacle for further adoption of BIM. DE3 states that “the construction industry is conservative in general and there is a mindset of doing things in the way they’ve always been done”. This is supported by DC1 who also says that “the development within the industry has been very slow for several decades”. The resistance against new technology is partly depending on the lack of experience and knowledge. As stated by one of the design engineers, “this mindset is simply a consequence of not realizing the benefits of BIM” (DE1). However, DE2 and DE3 are in agreement that, as new generations that have better understanding for computer technology enters the industry, the resistance will decrease. DE2 points out that “there are a lot of people with great forward thinking within the industry but in general the adoption of new technology has been rather slow” (DE2).

**Sub-contractors**

There are several obstacles for BIM implementation related to sub-contractors. The lack of proper knowledge and experience of BIM is an obstacle that has been exemplified in the case study. One of the design engineers describes that “during the project we have experienced that the fact that the sub-contractors do not work with 3D modeling is a big problem for us. This has led to additional work for us due to the fact that we have to extract information from the model and send to them on several occasions. If instead they would have been able to work with 3D modeling, they could have used our model and added their information to it. That way I believe that we could have saved a lot of time and reduced the number of requests for information” (DE2). As an example DE2 describes how the engineers have had to extract information from the model numerous times by request of the sub-contractors and as an example, “we have had to extract data in the form of measurements and heights for both the bridge and the railway tracks as well as for coordinates. In addition to this, they request that we review their work by inserting it into our model manually to check for defects and errors” (DE2).

Moreover, DE1 means that “the sub-contractors are experts within their areas and we cannot compete with that, and that is not the intention either. Instead we should focus on creating a good cooperation in between ourselves and this cooperation is facilitated if we use 3D modeling. If the sub-contractors work in the same software as us, it is easy for them to use our model and that minimizes the possibility of errors” (DE1). This is supported by DE2 who says that “as soon as you involve people in the process there is always the possibility of human error, especially when you extract information manually from the 3D model to use for creating 2D drawings from scratch. If instead, we would have worked in the same model we had eliminated many errors or at least reduced the risk of errors occurring” (DE2).
Organizational issues

A number of organizational issues have been identified as obstacles for successful implementation of BIM in the Slammertorp bridge project. Foremost, there has been no plan for the implementation of BIM. Instead, decisions have continuously been taken during planning meetings to model certain structural members in three dimensions. The extent to which 3D modeling has been used has, as described in earlier sections, been limited by a number of factors such as time and costs. Consequently, 3D modeling has only been utilized sporadically. Moreover, there has been no plan for how to use the model in production and consequently a lot of the benefits related to modeling in three dimensions are lost.

Another factor contributing to the hurdle of implementing BIM in the case study is the fact that the responsibilities for the models are undefined. There has been a lack of coordination, internally as well as externally. The structure for information sharing has also limited the use of the model, due to the fact that there has not been a project portal.

Technical issues

In addition to the obstacles described previously, there are a number of technical issues that create obstacle for BIM implementation. One being that the software tools used in the project is not optimized for bridge design. GL1 says that “we have to use a lot of different software due to the fact that they are specialized for different purposes and consequently there’s a lot of going back and forth between them”. In addition to this, DE3 means that “we do not have the proper tools and what we use is actually software for road design which we have to adapt for bridge design. We lose a lot of the intelligent functions by doing this and we have to manage a lot of difficulties when adapting our way of working to the road design software”. This is confirmed by GL1 who says that “the target group within infrastructure is too limited for the software companies to be interested in developing software specifically adapted to our needs”.

One of the biggest challenges with 3D modeling for infrastructure projects is the geometries. DE3 explains that “you normally want fixed angles when designing houses but for bridges you work with radii, slopes in all directions and complex geotechnical geometry that requires a lot from the model and creates a lot of difficulties”. This is supported by GL1 who says that “bridges are dependent on complex geometries and when choosing specific software that addresses some of your needs, you lose some of the special functions provided by others”. The fact that you have to alternate between different software is by GL1 seen as an issue for the employees’ work environment. GL1 states that “it is less motivating to use BIM when there isn’t a specific software available that would have made our work more efficient”.

In addition to this, incentives for extended use of BIM applications could have been created if the model was used for machine control such as for the piling. However, DE1 states that “during the procurement for a piling entrepreneur in another project, we
looked for a sub-contractor who could use the model for machine control, but without finding any”. DE1 says that the reason as to why the piling companies do not use any technology that makes it possible to use the model for machine control is that the contractors simply do not demand it. Therefore the sub-contractors lack incentives to implement BIM compatible machine technology.

### 4.2 General findings

This section presents the empirical findings obtained through interviews that does not exclusively relate to the case study. These findings provide more general data in the form of valuable experiences and knowledge on the topics of waste in construction, BIM benefits, and obstacles for successful BIM implementation. By presenting findings of general character we aim to support more general results in the concluding chapter of this thesis.

#### 4.2.1 Waste in construction

**Reinforcement collisions**

When asking a supervisor if there usually are any clashes during reinforcing, the answer is simply “Yes, all the time. You have to do a lot of changes. The reinforcement collides, it does not fit in the forms and consequently you have to cut, modify and make alterations” (SV2).

Furthermore, it is stated that for example the work with the bridge bearings is a work procedure that normally causes disturbances in the production. Another common thing to cause disturbances is said to be the fact that the anchoring studs of the bridge bearings collide with the reinforcement in the seat on top of the pier or abutment, in which the bearing is installed. It is said that usually reinforcement bars are designed straight through the seat without consideration to the studs, often resulting in collisions that has to be managed at site (SV2).

When constructing bridges, SV2 states that “collisions always occur” when mounting the expansion joints. These collisions are examples of disturbances in the production phase that causes unnecessary additional work, which according to SV2 can be avoided through collision and compatibility controls. This is confirmed by DE1 who says that “sometimes the expansion joints do not fit as a result of late procurement. This is due to the fact that in the initial design, one type of joint is used, but later on when construction have already started the joint might be changed for economic reasons and consequently it does not fit”.
Figure 4.6 above shows the result of a collision between the fastening details of an expansion joint and an existing reinforcement bar. In order to be able to mount the expansion joint, SV2 states that the fastening detail has had to be cut and bent in place as shown in the figure.

While collisions between reinforcement bars have been identified as a normal occurring problem in infrastructure projects (SV2), many believe that it is specifically for these problems that BIM has the biggest potential to make existing processes more effective.

**Human errors**

SV2 states that BIM can probably help to eliminate some of the human errors that are prone to occur in the projects. Considering reinforcement, SV1 is of the opinion that there is often something wrong with for example either the quantifying for ordering or the measurements of the arriving material, such as lengths or bend radii, which result in rework. In a traditional design, these errors mostly occur due to the fact that the numbers are handled in a way where small mistakes are hard to spot. Furthermore, DE1 also states that it happens that the amounts of reinforcement bars are wrongly quantified. Usually, this is due to the fact that someone sits down with the 2D drawings and starts to count and keep record of how many of the different reinforcement types that has to be ordered. This procedure is greatly prone to human errors and the risk to for example order wrong amount or wrong dimensions of a bar is high (DE1). This is also the opinion of DE2 who says that “it is easy to specify the amount and dimensions of the reinforcement bars wrongly when doing it manually. But it is not as if there is an error every time”. Also, SV1 states that “if a connection could be made between what is inserted into the model when the reinforcement is designed and the amount of each reinforcement type could be made, it would be possible to avoid specification errors”. Also, SV1 says that the compatibility between
the different objects is hard to check, especially when it comes to 2D reinforcement drawings. For example in the case study, some reinforcement cages were ordered for the concrete slabs in the mid supports. On the one hand, these cages were modeled in 3D, but due to the fact that the measurements were manually copied some mistakes were made. This resulted in a delivery of slightly too small cages that had to be fixed at site. So, by using BIM and 3D modeling it firstly gets easier to spot the compatibility problems that might be present. Also, if the reinforcement is defined correctly in model it is possible to obtain the exact material quantities without any human intervention.

Gap between design and production

Through interviews with people in both design and production, it is made clear that there is a gap between the way that reinforcement is designed and how the production crews prefer to build. This is illustrated by SV1 who states that “a design engineer seldom knows how to install the reinforcement in reality”. SV1 means that this is due to the fact that the designers rarely have experience from production and this is seen as a problem as it is difficult to discuss solutions when the designers do not have the same understanding for how the work is carried out. This is supported by GL1 who says that “the designers have limited knowledge about actual reinforcing works”. This is explained by the fact that before, the role of the designer was just to calculate and dimension the reinforcement which was then sent to an experienced rebar scheduler who assured that the configuration of the reinforcement was feasible by defining the installation sequence, and exact material measurements. Today, the quality assuring role of the rebar scheduler has been transferred on to the designers, which most often do not have as much experience as the rebar schedulers did. DE1 confirms this by saying that “the production personnel are the ones who actually know how things are built and which way that is the most effective, especially when it comes to the design of reinforcement”. Moreover, ES1 states that “it plays a huge difference if the designers know how to reinforce or not. Those who possess that knowledge can more easily create a design that has a higher level of constructability”.

DE3 states that “there is a need for consensus between how construction work is carried out and how we define our design”. DE3 is of the opinion that there is a need for more feedback between production and planning by saying that “I believe that better cooperation between production and planning would enable for us to experience more benefits from our 3D models”. Figure 4.7 below is illustrating the complexity of reinforcement, highlighting that the configuration of the bars can be difficult to install in practice.
In addition to this, it is indicated that it is important to involve experience from production in the design for every project, considering that “the opinion of how to best install the reinforcement seems to differ between different craftsmen. Some prefer smaller amounts of larger bars which means fewer mountings, whereas some prefer larger amounts of smaller bars that are easier to handle” (DE2). This is supported by GL1 who says that “there are as many preferable ways to install reinforcement as there are reinforcement workers”. Also, DE1 states that there is a willingness among the production staff to affect the design, but at the same time they feel that they rarely get the opportunity to do so. This is explained by GL1 who says that “sometimes this is an organizational issue, due to the fact that the design is often initiated before the actual production organization has been appointed”. Also, DE2 experiences that usually the design is performed without any feedback from production. DE2 states that “in some projects when we send out referrals to production and ask if they have any feedback or objections to our design, we often receive the answer that they don’t”. DE3 further explains this by saying that “when the design is approved and production is about to start, we sometimes get the feedback that what is designed is not optimal with regards to how the task is performed. In some cases this refers to significant changes such as redesigning entire wing walls”. DE3 is of the opinion that these problems could have been avoided if the communication between design and production had been established earlier on. This is supported by all interviewees and GL1 says that “rework related to reinforcement is a result of not incorporating enough practical experience in the design”. The respondents agree on the fact that the most beneficial way of designing reinforcement is to combine the knowledge from production with design early in the project. This is illustrated by ES1 who says that “in those cases when you have involved experienced production personnel early in the design stage, they have been able to provide the kind of practical expertise that foresee problems which results in fewer collisions and more feasible solutions during production”. Moreover, ES1 concludes that “there needs to be a good communication between design and production in order to obtain an effective production process”. This communication does not only address the fact that production needs to be involved during the design
process, but also that the designers need to get feedback after production is completed of what elements of the design that could have been improved. This is supported by DE3 who says that “we rarely get feedback concerning defects in the design that results in problems that they can solve on site themselves. They only contact us if major critical problems arise”. This is confirmed by DE2 who states that “problems that they can solve on site are solved without them contacting us, unless it concerns major changes in the design that affects the bearing capacity of the structure”.

It has also been observed that another consequence of the insufficient communication between producers and designers result in information deficiencies such as drawings that present too little information (ES1). This is illustrated by ES1 who says that “when working in production, you do not always get drawings depicting exactly what you want. The designers are always under time pressure and it is easier for them to produce simpler sections as opposed to complex sections containing a lot of design information”. Furthermore, ES1 means that “as a reinforcement worker, you prefer as many sections as possible, especially if it is a complicated structure. However, in practice you often get a simple section and you are left to ponder about the details of the complex connections such as the corners”. This is confirmed by SV2 who also says that “pondering over the reinforcement drawings consumes a lot of time at the site. If instead you had a 3D model you could easily understand how the reinforcement is supposed to be configured and you would save a lot of time by not having to think over and over again”.

Late procurement

The common opinion shared by the design engineers is that the more problems that are foreseen and sorted out in the design phase, the fewer disturbances occur in the construction phase, resulting in a more cost effective project. DE1 says that in the case study, the bridge railings and the expansion joints were procured early in the design phase. This ensured that consideration was taken to the fixings of the railings when designing the reinforcement for the underlying edge beam. This early procurement is normally not done which often lead to a lot of rework for the design engineers due to the fact that the design has to be changed later on. This is supported by GL1 who states that usually the expansion joints are procured late which means that the design information from the producer of the joints is unavailable at the time for design. As a consequence of this, the expansion joints are seldom compatible with the surrounding structural components which leads to rework and adaptations on site. GL1 states that “most often, the procurement is carried out after the design of the bridge has already been approved which in some cases has forced us to for example leave out the details for the expansion joints, leaving it to the craftsmen to solve the problem on site”.

Furthermore, DE1 also states that the experience is that in those cases where it is necessary to alter the design, the referred to changes are prone to human errors as many things are affected and needed to be changed manually. When extracting 2D drawings from a 3D model, changes made can automatically be carried out for all those
2D drawings. In traditional 2D design on the other hand, changes have to be carried out manually for each drawing which increases the risk for handling errors.

**Ineffective information handling**

Considering surveying works for piling, SP1 states that it is usually the surveying personnel, alternatively the surveying manager that produces the information needed to be able to do the surveying work at site. This information is gathered from the designers usually containing of pile coordinates, inclinations and directions. It is not uncommon that this information is received as a pdf-file, or even as a paper document from which the necessary information is copied and put into list of codes used by the surveying personnel. The perception of this way of working is that there is a large potential for improvements if a 3D model could be used instead of copying information by hand. SP1 says that “a reason for this could be the fact that it is the 2D drawings that are the legal documents resulting in that finishing the 3D model properly becomes a task with lower priority”. It is also experienced that a form of inertness exists regarding the adoption of BIM and 3D models and compatible software for these. Moreover, SP1 states that even though models are shared by the designers, it is not always sure that they can be used directly without manual intervention, or even at all.

### 4.2.2 General benefits of BIM

**Automated collision control**

Automatic collision controls have not been used for any structural member in the case study project. Despite this, automated collision control is mentioned throughout the interviews as a major potential benefit related to BIM. DC1 states that in previous projects when detailed models of the structures have been created, the automatic collision control has been beneficial both considering time and cost savings. Experience from a completed tunnel project revealed that “300 potential material collisions were revealed in the design by using an automatic collision control” (DC1). Through this, extra costs and time overruns due to rework could be avoided. DC1 goes on to say that “if the bore machine, when drilling for one of the installation bolts, were to hit one of the anchor bolts, the bore would most likely have to be replaced, resulting in production delays and rework for the designer. Imagine what this would have cost for the 300 potential clashes that we could avoid through the use of automated collision control”. In addition to this, SC1 is of the opinion that collision control is an important tool to use and says that “the conflicts that usually exist in bridge construction are collisions between reinforcement bars in the structural members”.

**Reducing handling errors**

When comparing the design procedure between BIM and traditional 2D drawings it is observed that the risk for handling errors can be reduced through the use of BIM. As drawings can be linked to the BIM model, DE1 states that these drawings can be updated automatically as changes are applied to the model. This feature is said to
reduce the handling errors that else would have been a risk in traditional 2D design. A real-world example refers to the processes of changing the properties of an edge beam. DE1 states that “if a traditional 2D design would have been used, these changes would have had to be manually applied for a number of different drawings. Changing these is a time consuming process and the risk for manual insertion of incorrect digits or unintentional omission of data is quite evident”. When using BIM on the other hand, DE1 says that “the same changes would only have had to be applied once in the model resulting in an automatic update of all related 2D drawings. This is both less time consuming and a procedure that is less prone to errors”.

SV1 says that “BIM can hopefully help to eliminate some of the human errors that sometimes occur in the projects. Considering reinforcement, there is often something wrong with either the quantities or the properties of the arriving material, such as lengths or bend radii”. In a traditional design, SV1 states that these errors mostly occur due to the fact that the numbers are handled in a way where mistakes are difficult to detect, which is an opinion that is also shared by SV2. Also, SV1 says that the compatibility between the different objects is hard to check manually, especially when it comes to 2D reinforcement drawings. For example, in our case study some reinforcement cages were ordered for the concrete slabs in the mid piers. On the one hand, these cages were modeled in 3D, but due to the fact that the measurements were manually transferred for specifying, some mistakes were made. This resulted in a delivery of slightly too small cages that had to be altered at site. SV1 says that “if the reinforcement is defined correctly in model it is possible to obtain the exact material quantifies while minimizing the potential risk for human errors”. PE1 has similar experiences from BIM usage and says that “you always have to account for human factors”. In another project, PE1 has observed that even though a BIM model was used, manual intervention during quantifying resulted in errors for the ordering of materials. PE1 is of the opinion that BIM is going to reduce these kinds of errors as automatic quantifying is both possible and easy to perform with the help of a BIM model.

*Project prediction and planning*

In association with the benefits from work preparations comes also the benefit from using the model as a tool to create production adapted drawings in 3D. DE1 states that during a project where the 3D model was used as a tool during work procedure planning meetings, plots containing measurements and dimensions of the different bridge elements were created upon request by the craftsmen. Consequently, the result of this was that future work tasks could be foreseen and thought of as present work proceeded, which in turn resulted in the fact that for example material and equipment orders could be made in time. DE1 says that the experience is that this really helped the labor management in their planning and also increased the engagement of the craftsmen as it made them think “what is it that is needed from me” and “what am I supposed to do” later on.
CHAPTER 4. Findings

**BIM in meetings**

PE1 states that an experience from another bridge project is that the work procedure planning meetings were “revolutionized with the help of a BIM model”. In ordinary projects, the work procedure is planned and written down on a paper and the craftsmen are described as to “usually not be that engaged in the planning process” (PE1). But when using the model during meetings, PE1 states that the engagement level was shown to rise sharply as it, through the help of the model, was possible to visualize exactly how the structure was going to look like. The experience from DE1 regarding the same project is that the commitment rose and that “the craftsmen were spinning and turning the model, thinking and seeing potential solutions to practical problems”. According to PE1, this was also shown to “generate practical solutions”. PE1 means that someone who knows the site well can by the help of the model identify potential problems for production, such as “realizing that the wheel loader won’t be able to pass through at that location”. Additionally, PE1 states that the production manager felt that the level of commitment did rise with the help of the model.
Chapter 5

Analysis

This chapter will combine theoretical and empirical findings in order to present an analysis of how BIM applications can be used to increase production efficiency through the elimination of wasteful activities. Initially, we will present an analysis of how we have classified certain observations as waste according to lean theory. Thereafter we will present how wasteful activities can be eliminated, directly as well as indirectly, by the use of BIM applications.

5.1 Waste in construction

The first section of the analysis chapter will address waste in construction by combining empiric findings with theory. The wastes identified in the findings chapter will be related to lean theory in order to determine the underlying causes as well as for creating the prerequisites for reducing the referred to wastes.

In the theory chapter, eight categories of waste are presented. After excluding one of the original wastes and introducing an additional category, the following wastes are included:

- overproduction
- defects
- waiting
- excessive transportation
- inappropriate processing
- unnecessary inventory
- unnecessary motion
- making-do

Within the limits of this research we have been able to obtain a number of observations of different kinds of wastes occurring within infrastructure projects. These types of wastes can be classified in accordance to several of the waste categories presented above. Within the limits of this research, examples of wastes relatable to the following waste categories have been observed as empirical findings:
Therefore, the following sections will address the classification of the findings according to the categories above and argue for why our findings should be defined as wastes from a lean perspective.

**Defects**

As defined by Hines & Taylor (2000), defects, from a lean perspective, relate to finished products or services not fulfilling the requirements of the customer. Furthermore, we hereon use the broader definition of the term customer presented by Dibia & Onuh (2010) by defining that each step in the business process is considered as the customer of the previous. Consequently, each step in a business process should be considered as an internal customer that needs to be supplied with the right resources at the right time by the preceding step in the production line. Furthermore, not meeting the customer requirements leads to rework, which is another type of activity that does not add value for the customer.

When implementing lean thinking, the production process in an infrastructure project can in analogy to the definition by Laguna & Marklund (2011) presented in section 3.1.4, be seen as the process of transforming input in the form of materials and drawings into output in the form of the physical structure. In order for the production stage to carry out their work, they rely on the drawings and information produced by the design stage.

Considering the fact that the opinion of how to best mount reinforcement differs between different craftsmen (DE2) combined with the statement by GL1 in section 4.2.1, that there are as many preferable ways to install reinforcement as there are reinforcement workers, the requirements from the customer, i.e. the production stage, have to be considered in every project in order for the design to be valuable. However, we can conclude that there is often a gap between the way that reinforcement is designed and how the production crews prefer to build, due to the fact that the requirements and opinions from the specific production crew are seldom taken into consideration at the time of design (DE2, DE3, ES1 & GL1). Consequently, the requirements of the customer, i.e. the specific production crew, are not met and the design information can thus be defined as a product that does not completely fulfill the customer requirements and should therefore be classified as waste, which in its turn can lead to rework.

Figure 5.1 below illustrates a process in which the requirements of the customer, i.e. the production stage, have not been considered when generating the input in the form of design information for the production process. Consequently, this results in additional rework in order to produce the final output.
Collisions in reinforcement can also be defined as a defect considering the fact that the production steps require design information which they can build according to without there being any clashes that they have to solve on site. However, the production step often has to engage in reprocessing as collisions in reinforcement do occur (DE1 & SV2) which does not add any value for the customer, neither the production step nor the end-customer.

As presented in section 4.2.1, observations have been made that human errors can cause incorrect quantification and specification of reinforcement (DE1, DE2 & SV1). The production step requires correct amounts of material in order to perform efficiently and consequently, incorrect specifications due to human errors can consequently be seen as a defect that should be targeted for elimination.

**Inappropriate processing**

Inappropriate processing is in the theory chapter defined by Hicks (2007) as extra operations such as rework and reprocessing that occur because of defects, i.e. processing steps that are not originally required to fulfill customer requirements.

Collisions between reinforcement bars in critical areas such as expansion joints have in the findings chapter been identified as a common occurrence in production that leads to rework (DE1 & SV2). As stated in the findings chapter, one reason as to why collisions occur is that “most often, the procurement is carried out after the design of the bridge has already been approved which in some cases has forced us to for example leave out the details for the expansion joints, leaving it to the craftsmen to solve the problem on site” (GL1). In this regard, consideration during the design works is not taken to the critical reinforcement areas in connection with the expansion joints and the structural components, resulting in members not being compatible with each other. This requires efforts that are not originally required to fulfill customer requirements.
and therefore, we conclude that lack of design information leads to inappropriate processing in the form of non-value adding rework.

In those cases where human errors cause incorrect quantification and specification of reinforcement, rework is required in the forms of redoing the quantification as well as the process of ordering the correct materials (SV1). In line with the arguments above, this can be classified as waste.

**Making-do**

As defined in section 3.1.5 by Koskela (2004), the waste category denoted as making-do refers to processes that are initiated or continued without all its standard inputs required to produce the desired output.

As described in the findings chapter, procurement of for example expansion joints and bearings are sometimes conducted in late stages of the project when the design of the bridge is completed and has been approved as project documentation (GL1). This is an example of waste that can be categorized as making-do due to the fact that production is started without the necessary input in the form of design information. As described by GL1, this often results in incompatibility between structural members which causes waste in the form of rework.

**5.2 Elimination of waste**

Within the limits of this research we have observed that BIM tools can be applied in order to eliminate wasteful activities. Furthermore, we have observed that the elimination process can be classified as direct or indirect. In the following sections we will account for how we have reached this conclusion.

**5.2.1 Direct elimination**

**Human error**

In section 5.1 we have concluded that human errors lead to waste in the form of rework. As presented in section 3.2.3, BIM as a tool can be used for intelligent quantity take-off (Tekla, 2013). If the correct design information is inserted into the model, correct specifications can be obtained automatically. In contrast, 2D drawings can contain correct design information but the specifications can still be incorrect due to human errors that interfere in the process of manual translation between the drawings and the specifications. Consequently, given that the correct design information is inserted into the model, we draw the conclusion that intelligent quantity take-off can be used as tool to directly eliminate waste caused by human errors.
Clash detection

As presented in section 4.2.1, collisions between reinforcement bars are a common occurrence in production that leads to non-value adding activities in the form of rework (DE1 & SV2). In the theory chapter, it has been described that BIM-based clash detection provides an automated and highly time effective way of reducing design errors that would otherwise have emerged as cost consuming problems during production (Eastman, et al., 2011). This is confirmed as an empirical observation in section 4.2.2 based on the statement that “300 potential material collisions were revealed in the design by using an automatic collision control” (DC1). Moreover, MacDonald (2012) states that “integrating multidisciplinary design inputs using a single 3D model allows interface issues to be identified and resolved in advance of construction, eliminating the cost and time impacts of redesign”. This supports our empirical observations that collision control enables for processes with less interference due to potential problems being solved before they emerge during production.

Eastman, et al. (2011) state that traditional clash detection by 2D drawings is a really error-prone process. Given that humans can only detect clashes with the naked eye, and that computers in an intelligent way can detect all clashes, we draw the conclusion that automated clash detection is likely to detect errors which humans would not be able to. Combining these facts, we draw the conclusion that BIM in the form of automated clash detection can be used to eliminate defects in the design which otherwise could have caused the need for wasteful rework which would have lowered the level of efficiency.

5.2.2 Indirect elimination

Design-related obstacles for an efficient production process

Within the context of this research we have been able to investigate how the production process is related to the design process. Through the case study presented in section 4.1, we have carefully observed the design process of a bridge. We have also been able to monitor the production process which has provided us with a foundation for analyzing the implementation of the design. Moreover, as presented in chapter 4, we have through interviews been able to gather information from design engineers regarding the design process and also their experience of the implementation of the design. At the same time, we have been able to interview production personnel about the production process and their experience from the preceding design process. This way, we have gathered data that allows us to draw parallels between design and production and how efficiency is affected.
Through this research we have been able to identify three main design-related obstacles that limit the efficiency of the production process:

- defects
- information deficiencies
- gap between design and production

**Defects**

We have earlier established that defects are a reoccurring phenomenon in construction. This is supported by the empirical findings described by DE1 and SV2 in section 4.2.1 and also by Josephson & Saukkoriipi (2007) who state that the cost of defects in construction projects is estimated to be in the order of 6-11 % of the total project cost. Defects has been established as to cause rework (Hicks, 2007), which in its turn leads to longer lead times while not adding any value for the customer, which according to Modig & Åhlström (2011) results in lower efficiency of flow. Based on this, we draw the conclusion that defects can contribute to decreased efficiency in construction projects.

**Information deficiencies**

Late procurement of structural components such as expansion joints have in the findings chapter been described as to lead to collisions in reinforcement, resulting in rework (DE1 & GL1). This can in analogy to the reasoning presented above be concluded to lead to lower efficiency.

In addition to this, we have presented empirical findings stating that drawings suffering from information deficiencies are not uncommon in construction. Too few sections or to little details are stated to be the reason as to why the production crew has to spend considerable amount of time to figure out how to build according to the drawings (ES1 & SV2). As stated by Eastman, et al. (2011) in section 3.2.4, the occurrence of problems and errors during construction can increase the number of RFIs, unnecessarily involving people in time consuming decision making that could have been avoided. In line with the theory on efficiency defined by Modig & Åhlström (2011) in section 3.1.4, we conclude that the extra time spent on figuring out how to build, as a consequence of information deficiency, leads to decreased efficiency.

**Gap between design and production**

In section 4.2.1, we have illustrated that there is a gap between design and production in construction projects. One aspect of this relates to the fact that the production personnel have considerably more experience of how the construction work is conducted in the most practical and efficient way. In comparison, designers are not as aware of how the design affects the ease of actually constructing the referred to design (DE1, DE3, GL1 & SV1).

Moreover, we have presented empirical evidence suggesting that the communication between design and production is insufficient (DE2, DE3 & ES1). In the findings
chapter, it has also been described that different production crews do not necessarily have the same tradition of how to carry out their work in the most efficient way (DE2 & GL1). Based on this, we draw the conclusion that the design, although being correct, might not be preferred by the specific production crew which results in a less effective production process than if the production crew could affect the design early on.

In all, based on the argumentation above, we conclude that the gap between design and production can result in lower efficiency during production.

Involving construction knowledge – overcoming the obstacles

In the previous section we have presented three possible causes for design-related obstacles that hinder production efficiency. Based on the empirical findings presented in this research we have come to the conclusion that detailed planning and design involving construction knowledge can address the issue of overcoming these obstacles and thereby achieve a more effective production process. Below, we present what we have concluded to be the key benefits of engaging in detailed design involving production experience:

• reducing defects through preventive planning
• generating sufficient design information
• achieving a feasible design

Preventive planning

Based on the empirical findings presented in chapter four of this essay, we conclude that preventive planning can reduce the occurrence of defects during production. Involving production personnel in the design process is the only way to ensure that the requirements of the customer in the subsequent process, i.e. the production crew, are met. This conclusion is supported by the statements in section 4.1.4 in which all respondents involved in the design process of the case study have experienced how the combination of design and production knowledge induces a momentum within the design process that leads to reduced numbers of problems through preventive planning (DE1, DE2, DE3 & SV2).

“One good example of the planning work we did in the project regarded the piling works. Specifically the fact that the craftsmen were involved in the planning process, which gave us the possibility to address and solve a lot of potential problems beforehand” - DE1

The citation above is an example that illustrates the common opinion that by involving production knowledge in the design process, you can combine design and production experience in order to conduct preventive planning which ultimately leads to a production process with fewer errors and consequently a higher level of efficiency.
**Sufficient design information**

Another critical factor for overcoming design-related obstacles through detailed planning and design involving production experience, is to generate design information for every relevant aspect of the structure in order for the design to be implemented as efficiently as possible.

“As a reinforcement worker, you prefer as many sections as possible, especially if it is a complicated structure. However, in practice you often get a simple section and you are left to ponder about the details of the complex connections such as the corners” - ES1

The statement above illustrates the insufficiency of the design information that can arise when the gap between design and production is too big. By involving production experience early, you ensure the relevance of the produced design information. This can be derived from the fact that the production crew is given the opportunity to affect what design information that should be represented in the drawings in order to efficiently implement the design. Moreover, if production personnel are involved in the work of developing the design solution, it naturally follows they have already in the design process gained an understanding for the solution. Consequently, given that less time is spent on site trying to understand how to implement the design, this has the potential to increase the efficiency of the production process.

**Feasible design**

As described by the respondents in chapter four, the empirical evidence suggests that involving production personnel in the design process also facilitates for a more feasible design. By involving the project-specific production personnel, it is possible to jointly create a design that is optimized for the production methods preferred by those who are going to implement the design.

“*The production personnel are the ones who actually know how things are built and which way that is the most effective, especially when it comes to the design of reinforcement*” - DE1

As stated above, the knowledge of how to construct in the most efficient way resides among the experienced production personnel such as the supervisors. Consequently, involving this experience and taking consideration to preferred construction methods already in the design process has the potential to increase the overall efficiency of the production process.

**The catalyst**

In the previous sections we have described how detailed collaborative planning and design with the involvement of experienced production personnel can benefit the production process. However, based on observations presented in section 4.1.4 we believe that it is simply not enough to assemble a group of design engineers and
production personnel and expect them to overcome the obstacles for effective production by themselves. As described by DE2 and DE3 in section 4.1.4, it is unusual to engage in detailed design and dedicate as much resources for matters of detail in the same way as has been done in the case study. Though, having a design coordinator present during the design meetings has proven to be a critical success factor.

The most important function of the design coordinator is to act as a catalyst between the design engineers and the production personnel to ensure that they engage in discussions on proper matters and on the right level of detail. This is illustrated by a design coordinator in the citation below.

“The most important task is to get designers and producers to communicate. Once you get past a certain point, the dialogue seems to continue by itself” – DC1

We have observed, as described in section 4.1.4, that the absence of a coordinating role results in a stagnation of the meetings despite the fact that the proper competencies and experiences are present. Therefore, we conclude that the catalyst, in the form of a design coordinator is an essential key for experiencing the benefits of detailed design and planning meetings.

Implementing BIM applications – supporting detailed collaborative design

Detailed collaborative design

As the last link in the chain of reasoning for how BIM applications can be used to indirectly eliminate waste, we want to highlight the relationship between BIM applications and detailed collaborative design. As presented in the theory, Eastman, et al. (2011) states that BIM supports and facilitates collaboration within the project group throughout the entire duration of the project. This is supported by the findings in section 4.2.2 where PE1 states that the use of the model during meetings increased the engagement level through visualization of how the structure was going to look like. This opinion regarding the same project is supported by DE1 who says that the commitment rose and that “the craftsmen were spinning and turning the model, thinking and seeing potential solutions to practical problems”. Moreover, Dahlqvist & Winberg (2010) states that the usage of BIM increases the collaboration among the stakeholders of a project. Based on these findings, we conclude that the model can be used to facilitate and promote increased collaboration in a detailed design process.

Information richness

As concluded in earlier sections, information deficiencies can lead to lower efficiency levels in production. At the same time, as presented in section 4.1.5, DE1 states that “everything has to be drawn in detail in order to obtain a true model”. It follows naturally that a three-dimensional model contains more information than traditional
2D drawings and consequently by generating an information rich model containing all the necessary inputs you reduce the risk of the occurrence of wasteful activities that is caused by information deficiencies.

Moreover, prefabricated structural components have been proved to increase efficiency during production (Eastman, et al., 2011). However, DC1 states that “in order to prefabricate you need to maintain a very high level of detail when you generate your design”. As described above, BIM models offers the possibility to provide sufficient information and high levels of details and combining these facts, we draw the conclusion that the generation of an object-based 3D-model facilitates for prefabrication which in itself carry the potential to make production more efficient.

**Compatibility**

As stated in section 4.1.5, SC2 says that modeling in three dimensions generally results in a design containing fewer errors and that major faults and errors are more easily foreseen and avoided. In addition to this, SV2 says that it is for these kinds of problems where one can see the major benefits of BIM as it is easier to foresee production related disturbances already in the design phase. Based on the knowledge obtained in through this research, we would like to infer that compatibility is not only ensured by automated clash control, but it is also increased through the use of 3D modeling in the design process. When designing in three dimensions, you adopt a holistic approach that forces the designer to consider the compatibility between structural members. This is illustrated by an example from the case study in which the usage of the 3D model in the design phase helped the designer to see that the reinforcement bars actually fit as they were modeled with their true dimensions and not just as single lines which often is the case when designing in two dimensions (DE1). From this, we draw the conclusion that the use of a 3D model can increase the compatibility between structural members in the design which results in fewer errors and consequently a more efficient production process.

**Visualization – the catalyst**

Engelbart (1962) wrote that working with computer aided systems is working in an augmented way which is supposed to enhance the human intellect. We believe that this illustrates one of the connections between detailed design and BIM, namely that this technology enhances understanding, communication, predictability and commitment; especially when using the model for visualization. This conclusion is supported by Eastman, et al. (2011) who states that:

“Use of building models as a visualization tool is one of its most obvious uses with the clearest advantages. The 3D model of the project helps different parties to better understand the concept and especially the details of the design, forming a common mental picture and understanding far more quickly and effectively than with traditional drawings” – (Eastman, et al., 2011, p. 503)
In line with the evidence presented by Eastman, et al. in the above mentioned quote, findings stated by GE1 and SP1 in section 4.1.5 also suggest that BIM facilitates understanding. Azhar, et al. (2008) supports this by stating that communications and trust between stakeholders can be improved through collaborate 3D viewing sessions. Furthermore, Jongeling (2008) present evidence that the use of a 3D model which when used during a detailed design process results in a construction process with fewer errors. This is supported by the quote stating that BIM “helps architects, engineers and constructors to visualize what is to be built in a simulated environment and to identify potential design, construction or operational problems” (Azhar, et al., 2008, p. 1). Combining the findings presented above, we draw the conclusion that visualization through the use of a 3D model acts as a catalyst between project stakeholders that improve understanding, communication, predictability and commitment that supports a more detailed design process.

5.3 First Time Fit

In order to illuminate how BIM applications can be used to increase efficiency of the production process in infrastructure projects, we will in the following section present our theoretical model for how to achieve a production process in which structural members fit the first time, thereby eliminating the need for non-value adding rework. The guidelines presented below are based on the findings and conclusions presented throughout this research. Considering the fact that these guidelines have been derived from the findings in this research, they are consequently dependent on the context in which the research has been conducted. The purpose of these guidelines is not to establish a fixed solution, but to illuminate what we have experienced to be key factors for using BIM applications to achieve an efficient production process and thereby promote further research on the topic.

- A 3D model should be used to generate a digital representation of the structure. This is the key prerequisite for the following stages of the process. It should contain all the necessary design-related information to ensure that there is sufficient information for analyzing the compatibility between all structural members as well as to ensure that there is sufficient information during production to implement the design efficiently.
- The model should be used as a visualization tool during meetings to ensure good collaboration, communication and commitment among project stakeholders as well as facilitating understanding and predictability of the design.
- The design should be reviewed through automated clash control to ensure compatibility between all structural members.
- After having ensured design compatibility, quantity take-off and specifying should be carried out through intelligent quantity take-off from the model to eliminate the risk of human error.
• The design information should optimally be used for prefabrication to reduce the variability of the production process.
• The entire process should be carried out through detailed collaborative planning and design in order to induce a driver for continuously promoting the purpose of 
  \textit{first time fit}.

In Figure 5.2 below, we illustrate how input in the form of 3D design information is generated through collaboration between design and production in order to achieve a production process that does not contain any additional steps of rework in order to produce output in the form of the finished structure.

![Figure 5.2 - A process map in which first time fit is achieved.](image)

We believe that if the requirements of the customer, i.e. the production stage, are considered when generating the input in the form of 3D design information for the production process through collaborative design, additional wasteful rework is more likely to be avoided, thus increasing the possibility of achieving \textit{first time fit}. 


Chapter 6

Conclusion

This study has been aimed at investigate how BIM applications can be used in infrastructure projects to increase efficiency through the reduction of wasteful activities. The following chapter will present our conclusions and answer the research question.

6.1 Research question and answer

Below we present the research question followed by our conclusion.

- In what way can BIM applications be used to increase efficiency in infrastructure projects through the eliminating of waste?

BIM applications can be used to support a detailed collaborative planning and design process, which in its turn creates the prerequisites for a more efficient production process through the elimination of non-value adding activities.

Intelligent quantity take-off can be used to directly eliminate non-value adding activities caused by human errors. Automated clash detection can be used to directly eliminate the need for non-value adding rework caused by defects in the design.

The model can be used as a visualization tool that improves collaboration, communication and commitment among project stakeholders as well as for facilitating understanding and predictability of the design. The model can also be used to generate necessary input in the form of design information in order to reduce the risk of occurrence of non-value adding activities caused by information deficiencies. Furthermore, the model can be used to facilitate for prefabrication which in its turn increases the level of efficiency in production. In addition, the model can be used to increase the compatibility between structural members in the design which generates fewer errors and consequently less non-value adding rework during production.
Below we present the sub-questions followed by our conclusions.

- **What types of wasteful activities can be found in the production process of infrastructure projects?**

In this study we have found several types of wasteful activities related to infrastructure projects. Inappropriate processing in the form of rework due to reinforcement collisions, human errors, defects and making-do have been established to be reoccurring non-value adding activities in infrastructure projects that can be classified as waste. In addition to this, as presented in section 3.1.6 all of the eight lean waste categories can be found in construction, i.e. overproduction, defects, waiting, excessive transportation, inappropriate processing, unnecessary inventory, unnecessary motion and design of goods or services not meeting customer needs.

- **What are the obstacles that hinder successful implementation of BIM in infrastructure projects?**

In this study we have found a number of different obstacles that hinder a successful implementation of BIM in infrastructure projects. These obstacles have been identified to be time, cost, knowledge and training, the client, industry inertia, sub-contractors, organizational issues and technical issues. Theoretical evidence presented in section 3.2.5 concludes that, in addition to the obstacles presented above, legal issues are an obstacle that hinders successful implementation of BIM.

- **How can BIM applications be used to enable for structural members to fit the first time?**

In order for structural members to fit the first time, the following factors should be considered. A 3D model should be used to generate a digital representation of the structure. The model should be used as a visualization tool during meetings to ensure good collaboration, communication and commitment among project stakeholders as well as facilitating understanding and predictability of the design. The design should be reviewed through automated clash control to ensure compatibility. After having ensured design compatibility, amounting and specifying should be carried out through intelligent quantity take-off to eliminate the risk of human error. The design information should optimally be used for prefabrication to reduce the variability of the production process. In closing, the entire process should be carried out through detailed collaborative planning and design in order to induce a driver for continuously promoting the purpose of first time fit.
Chapter 7

Discussion

In this last chapter we will discuss conclusions and additional insights that have arisen during the process of conducting this study. Lastly, we will present our recommendations for further research.

7.1 Discussion

We have in this study presented the conclusion that the production process in infrastructure projects can be made more efficient through the use of BIM applications and detailed collaborative planning and design. Our conclusions are based on theoretical and empirical evidence. However, within the limits of the research, no measurements of efficiency in the case study have been conducted. We are aware of the fact that the reliability of our conclusions could have been increased through empirical evidence of the actual conclusions but the research problem have been addressed on a general level and therefore a larger number of case studies would have been preferable in order to make valid conclusions.

We would also like to point out that almost all of the respondents are employed by the same company and consequently, the experience shared and opinions expressed might to a certain degree suffer from bias.

A number of construction-related wasteful activities have been presented as empirical evidence after having classified them as non-value adding activities according to lean theory. Moreover, eight different waste categories according to lean theory have been presented in the referred to chapter. However, we have only been able to present empirical findings that are classifiable according to three of them. What we wish to point out however, is that we are of the opinion that all eight waste categories can be found in construction projects but the three represented in this thesis are the only ones that we, within the context of this research, have been able to document.
Consequently, we would like to infer that there is an even bigger potential for increased efficiency in construction projects than we have been able to illustrate in this research.

An additional insight that was gained during the work on this thesis is that BIM and the process of detailed collaborative planning and design are not interdependent. A detailed collaborative planning and design process does not require the use of BIM, nor does the use of BIM require a detailed collaborative planning and design process. However, we are of the opinion that, when combined, these concepts carry the potential to increase the efficiency of the production process to a far greater extent than they can do separately. Moreover, when discussing the low increases in productivity levels for the industry and the advent of BIM, we would like to illuminate that it is not the absence of BIM that has caused low productivity levels and consequently, BIM is not the answer to every problem.

Another insight gained is that the acronym BIM is ambiguous and hard to grasp. Moreover, the term has come to denote so many different elements that it in our opinion lacks real significance. We believe that this is an obstacle for implementing BIM in the industry, considering the fact that the concept is too big for decision makers to grasp. Furthermore, the concept includes many elements and many different applications and we believe that the concept needs to be divided into more distinct categories related to the order for which they should be implemented. We have observed that most benefits are attributed to the entire BIM concept instead of the specific applications from which they can be derived. If more focus was put on BIM tools instead of BIM we believe that the concept would be easier to grasp which potentially would facilitate the adoption of BIM within the industry.

Lastly, we have come to the realization that there is a big difference between “doing things right”, and “doing the right things”. As an example, it is possible produce a design of a structure not containing any clashes or errors, i.e. doing things right, which most likely should result in an efficient production. However, if consideration is not taken to level of efficiency of the production methods required to implement the design, consequently the right things have not been done. Finally, with regards to first time fit, we are of the opinion that even though all the structural members of a bridge eventually fit, efficiency resides within the processes of making them fit the first time.

7.2 Recommendations for further research

Through this research process we have come across a number of additional research topics that future research could address. With regards to the content of this thesis a number of questions could be formulated to gain further insights in the field of BIM and production efficiency.
The first recommendation for future research is to make observations from a case study in which BIM applications are used during both design and production in order to obtain stronger empirical findings related to the interdependency between the processes. In addition, we would recommend that further research is conducted for the following research questions:

- How can BIM be used to increase constructability in infrastructure projects?
- How can BIM be used to enable for automation of production works?
- What is required for reporting during production in construction projects to expose non-value adding activities?
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Appendix A

Appendix

A.1 Interview questionnaire

Name:___________________________________________

Role:____________________________________________@ ________________________

Date:____________________________________________

Mapping traditional processes – Design phase

1. Considering traditional, 2D-centric planning and design for piles;
   a. Who are usually involved?
   b. What is produced and to what level of details?
   c. Is everything always checked for errors?
      i. Please give some examples
   d. At what time of the project is most design work conducted? Are all necessary detailed documents ready in time? (the question is addressed to reflect over the difference between traditional and BIM design)
      i. Give some examples/explain why

2. Considering traditional, 2D-centric planning and design for reinforcement;
   a. Who are usually involved?
   b. What is produced and to what level of details?
c. Is everything always checked for errors?
   i. Give some examples

d. At what time of the project is most design work conducted/documents produced? Are all necessary detailed documents ready in time?
   i. Give some examples

**Mapping traditional processes – Construction phase**

3. Considering the work process for surveying during traditional design and planning:
   a. Who are usually involved?
   b. What use to be the hurdles and problems in the sense of materials, time and effort (i.e. rework and defects)?
   c. Regarding waste of material, time and effort **both in design and production**:
      i. Where does the waste occur and why? Examples/experiences?

4. Considering the construction process for piles after/during “traditional” design and planning;
   a. Who are usually involved?
   b. What use to be the hurdles and problems in the sense of materials, time and effort (i.e. rework and defects)?
   c. Regarding waste of material, time and effort **both in design and production**:
      i. Where does the waste occur and why? Examples/experiences?

5. Considering the construction process for reinforcement after/during “traditional” design and planning;
   a. Who are usually involved?
   b. What use to be the hurdles and problems in the sense of materials, time and effort (i.e. rework and defects)?
   c. Regarding waste of material, time and effort **both in design and production**:
      i. Where does the waste occur and why? Examples/experiences?
6. Considering the construction process for expansion joints and bridge bearings during “traditional” design and planning:
   a. Who are usually involved?
   b. What use to be the hurdles and problems in the sense of materials, time and effort?
   c. Regarding waste of material, time and effort both in design and production:
      i. Where does the waste occur and why?

Mapping present BIM processes

7. Considering the new BIM-centric workflow in the design and planning phase;
   a. How does BIM differ from the traditional 2D-centric workflow?
   b. Does the number of people involved change or might there be other/different people involved?
      i. Could it be that this new way of working demands a wider set of knowledge (aka. a greater variety of people) to be able to build up a detailed and accurate model?
   c. Does the level of details in the documents change? If so; in what way?

8. Considering the construction process after/during a BIM-centric design and planning workflow;
   a. What are the benefits in construction from using BIM? (in the sense of material, time and effort)

Perceptions/opinions on BIM usage

9. Regarding the hurdles and benefits with the new BIM-centric way of working
   a. What are the difficulties/hurdles with working with BIM? (in the sense of material, time and effort)
      i. Where does the waste occur?
   b. Regarding the benefits of working with BIM;
      i. Where can we reduce the waste of material, time and effort?

The value generated from BIM usage

10. Does the BIM-centric workflow bring any value to the project already in the planning and design phase? (in the sense of material, time and effort)
11. Does the BIM-centric workflow bring any value to the project in the construction phase? (in the sense of material, time and effort)

**Changes due to BIM**

12. What changes need to be made in the design phase to be able to obtain more value from BIM usage?

**Additional questions**

13. In what way can BIM be used to decrease waste of time, materials and effort in infrastructure projects?
14. What is required to achieve a construction process in which construction elements “fit-the-first-time”?
15. The increases in productivity levels have been low in construction for the last 30 years. Why do you believe that is?
16. Who has the responsibility for eliminating waste in construction?
17. Can BIM increase the quality in infrastructure projects? How?