BIM in Bridge Construction

Improving Production Phase Performance in Bridge Construction Through the Use of 3D BIM

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KTH Architecture and the Built Environment

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Preface

This report is result of a master thesis project carried out in conjunction with the Major Project division of Skanska Sverige AB that centres on the use of BIM in bridge construction. The thesis is carried out at the department of Civil and Architectural Engineering at the Royal Institute of Technology, KTH. I hope this paper will provide significant value to the industry in its efforts to strive for improvement.

I would like to sincerely thank my supervisors Lars Pettersson and Väino Tarandi for their continuous support throughout the whole project. I would also like to thank Skanska and all the personnel involved in the Röforsbron project for giving me the opportunity to be part of such a unique and fascinating development. It is an experience I will take with me for the rest of my life. Finally, I must give huge thanks to my family for their tireless support, especially through these last two years who have sacrificed many things to allow me to be here.

Stockholm, June 2013

Oscar Simey

Abstract

The effectiveness of Building Information Modelling, or BIM, in the construction industry has become a hot topic of debate. Used in the AEC (Architecture, Engineering and Construction) industry for over a decade now, its effectiveness to certain aspects and sectors of the industry is under constant review. Its implementation into the Swedish bridge construction sector is relatively new, especially when used during the production phase of a projects delivery. This paper aims to investigate how using a 3D BIM during the production phase can improve the performance of production, whilst exploring ways in which to improve the handling of 3D BIM for future projects. This is achieved by following the production phase of the Roforsbron project in Arboga, Sweden. The first of its kind to utilise 3D BIM tools throughout its entire production phase.

The theoretical framework focuses on the concepts of constructability, lean construction and productivity as well as reviewing a variety of literature on the benefits and drawbacks of BIM. The empirical data has been gathered through personal involvement of the Röforsbron project, where structured and semi-structured interviews with the workforce make up the bulk of the findings. Empirical observation and practical participation of activities on-site complement the opinions of the personnel. The interviews focus on individuals' experiences using 3D BIM and their opinions on its effect of the production of the Röforsbron.

The problems affecting current production performance often stem from a lack of detailed design and planning that affect constructability. Designing with a larger consideration on *how* to build and addressing constructability issues early is the means in which production can improve.

The Röforsbron project was successful where no rework was performed and attributed many of its savings to the use of 3D BIM. Extra resources and experienced personnel were also a factor in the success of the project. 3D BIM is shown to have the most beneficial effect on the reinforcement works, but also offers a broad range of tangible and intangible benefits to widespread aspects of a bridge project. It is concluded that 3D BIM provides an effective tool in which to improve constructability through facilitating a more detailed design and effective means of understanding through visualisation and communication.

Keywords: Building Information Modelling, BIM, bridge construction, production phase, Constructability, Lean, Productivity.

Sammanfattning

Effektiviteten av Building Information Modelling, eller BIM i byggbranschen har blivit ett hett ämne för debatt. Metoden har Använts i AEC industrin i över ett decennium och dess effektivitet inom olika aspekter och sektorer av industrin är under ständig granskning. Dess genomförande i den svenska brobyggarsektorn är förhållandevis nytt, särskilt när den metoden används under produktionsfasen av ett projekts leverans. Denna uppsats syftar till att undersöka hur användning av ett 3D BIM under produktionsfasen kan förbättra produktionen och att samtidigt undersöka olika sätt att förbättra hanteringen av 3D BIM för framtida projekt. Detta uppnås genom att följa produktionen vid Roforsbron i Arboga, Sverige. Den är den första i sitt slag att utnyttja 3D BIM-verktyg genom hela produktionsfasen.

Det teoretiska ramverket fokuserar på begreppen byggbarhet, lean construction och produktivitet samt granskar ett urval av litteratur om fördelarna och nackdelarna med BIM. Det empiriska materialet har samlats in genom personligt engagemang av handledarna et vid Röforsbron, där strukturerade och semistrukturerade intervjuer med de anställda utgör huvuddelen av resultaten. Empirisk observation och praktiskt deltagande av aktiviteter på plats kompletterar yttrandena från personalen, i kombination med analys av projektbudgetens ombesörjande. Intervjuerna fokuserar på individers erfarenheter med 3D BIM och deras åsikter om dess effekt på produktionen av Röforsbron.

De problem som påverkar den nuvarande produktionens prestanda härrör ofta från en brist på detaljprojektering och planering som påverkar byggbarheten. Projektera med större hänsyn till hur man bygger och att adressera byggbarhetsfrågor tidigt är medel som gör att produktionen kan förbättras.

Röforsbro-projektet var lyckat då mycket lite extra arbete krävdes för efterjusteringar etc. Detta kan i stor utsträckning tillskrivas användningen av 3D BIM. Extra resurser och erfaren personal var också faktorer av stor betydelse. 3D BIM hade störst effekt när det gällde montaget av armeringen men innebar också flera andra fördelar, både direkta och vad som kan kallas indirekta i form av sparad arbetstid etc. Slutsatsen som kan dras är att 3D BIM är ett effektivt verktyg för att förbättra byggbarheten genom att det underlättar för en mer detaljerad projektering. 3D BIM ger också mycket goda möjligheter att visualisera de olika konstruktionsdelarnas komplexitet. Genom den goda möjligheten att visualisera ges också bra förutsättningar för god kommunikation mellan projektets parter.

Nyckelord: Building Information Modelling, BIM, brobyggarsektorn, produktionsfasen, byggbarhet, lean, produktivitet

Abbreviations

2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional, 3D + Schedule
5D	Five Dimensional, 3D + Schedule + Cost
BIM	Building Information Model/ Building Information Modelling
AEC	Architecture, Engineering and Construction
CII	Construction Industry Institute
CAD	Computer Aided Design
XML	Extensible Markup Language File (File Format)
.pxy	Topocad File Format
.geo	Geographical File Format
GEO	Geodesy and Surveying Software Package
TPS	Toyota Production System
P/T	Part Time
F/T	Full Time

Contents

1 Introduction

1.1 Background

The introduction of Building Information Modelling, or BIM as it is commonly abbreviated to, into the construction industry over the last decade was designed to boost the declining productivity levels facing the industry. Product design modelling is credited as one of the catalysts' for the sharp productivity rise in the manufacturing industry over that time (Eastman et al., 2011). The positive attributes of product design modelling have been adopted into the construction industry through BIM to try to replicate this improvement in the performance of their project delivery. The digital tool combines 3D models with their physical and functional characteristics into one coherent system of computer models that supports the continual updating and sharing of project design information (Gould and Joyce, 2011).

Civil engineering companies across the globe have already benefited from the advantages that BIM has to offer in this short time. Projects in several sectors have utilised the method to good effect in various stages of its construction boasting successful outcomes. However, some industry sectors have seen the implementation of the method employed less than others. In particular, the Swedish bridge construction sector has been very hesitant in its deployment, especially through the production phase of a project, as it is unsure as to whether the use of BIM on site will aid in the projects productivity and constructability performance.

"BIM has been promoted as the solution to reduce waste and inefficiency in building design and construction. However, many organizations have taken a wait-and-see attitude about BIM, looking for evidence for return on investment it entails" (Solibri, 2013).

In order to test the applicability of BIM for use in bridge projects Trafikverket have decided to implement the tool into a pilot project that is the Röforsbron. The project is the first of its kind in Sweden to adopt the use of BIM tools throughout the whole project life, including the production phase of its construction. Röforsbron is a 100-year-old three span, concrete bridge crossing the river Arbogaån in Arboga. The bridge offers significant cultural history to the area and is to be reconstructed to replicate its existing form. The BIM design model was created by WSP before it was handed over to Skanska for the production of the bridge. This thesis will follow the use of the BIM tool through the production phase, to explore its benefits and shortcomings as it is utilized throughout its construction.

1.2 Problem Statement

The driving forces and resistors behind the use of BIM in the production phase of civil construction projects have been documented numerous times previously, (Krantz, 2012; Björk Löf and Kojadionovic, 2012; Eastman et al., 2011; Chelson, 2010). All this literature identifies how the project parties can benefit from the use of BIM and the advantages it will have on the overall project delivery. However, these studies lack the associated costs and qualitative values directly related to its use. "The technology, process and organizational investments required to implement BIM are considerable and costly, and adopting BIM requires substantial changes to how the industry has traditionally been designing and building projects" (Becerik-Gerber and Rice, 2009). Consequently, organizations are continually searching for the value of BIM to a project and its ROI.

This paper will explore the effect, if any, of a 3D building information model on the production phase of bridge projects. Specifically it will look at identifying and measuring waste during production created from errors in design, that ultimately lead to re-work and wasted resources, Shown in Figure 1. The paper attempts to quantify BIM's value to various stages of a projects delivery as well as the development as a whole. Skanska's Röforsbron project will provide the basis for the findings to the key research questions:

- How can a 3D building information model be used to improve the production phase performance of a bridge project?
- What methods can be improved in terms of handling of BIM information on the work site?
- How much time, resources and money can be saved with the use of BIM in the field?
- What are the possibilities and potential of BIM tools for the future based on what we see in the Röforsbron project?

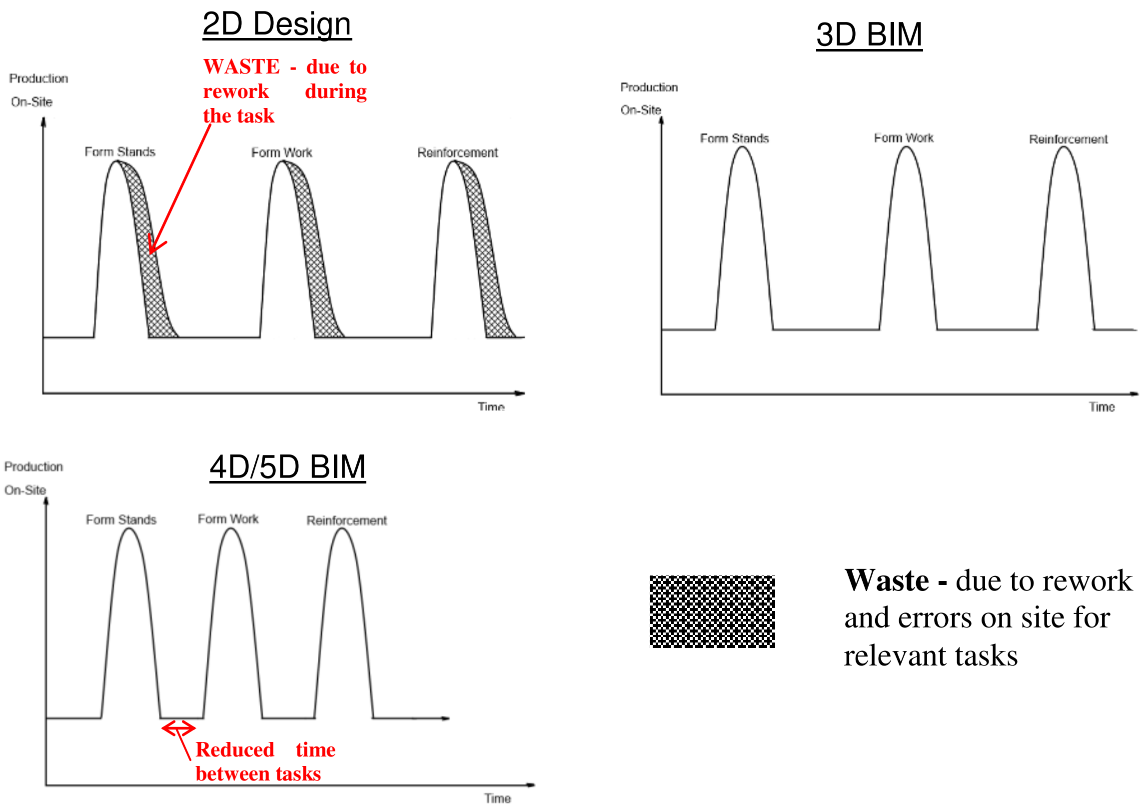


Figure 1 - Graphs to identify the production on-site against the time taken for key tasks, highlighting the proposed effect that traditional methods and various levels of BIM have on the level of waste and productivity

1.3 Purpose and Aim

The purpose of this thesis is to provide the bridge construction sector with a comprehensive insight to the value of using a 3D building information model during the production phase of the Röforsbron bridge project and how it can be applied successfully into the production phase of future bridge projects. The findings are designed to aid in the performance development of the bridge construction sector by improving constructability, lean practice and productivity during the production stage of bridge projects to save time and reduce costs in their project delivery. The paper aims to learn from the Röforsbron project and cite improvements into the handling of BIM, which will separate Skanska above its competitors. The findings will not only be limited to Skanska's benefit, but to the bridge construction industry as a whole.

1.4 Delimitation

The scope of work will focus on improving productivity in the production phase. It was found that constructability and lean construction would provide the main focus behind the theory. As the Röforsbron project was delivered using a 3D BIM, it was decided to focus on purely the attributes of using a 3D building information model. This was to avoid probing into advanced areas of BIM's utilization that would not be possible under the time restrictions

The nature of BIM as a continuously developing entity means that new areas of research and un-answered questions are constantly arising as the tools and method are utilized. During the initial stages of the project it was clear that the research would lead the author to a broader scope of exploration in which to answer the key research questions. As the production phase of the project relies heavily on the design and planning departments for its delivery, these areas were investigated further.

2 Methodology

2.1 The Research Design

2.2 Data

Due to the exploratory nature of the paper, the collection of data is taken from a wide variety of sources to try and obtain the most valid and relevant information. Interviews with personnel working on the Röforsbron project form a significant share of the research data. Interviews with experienced professionals from Trafikverket and WSP will provide another source.

Empirical observation of the key construction phases of the Röforsbron will add both qualitative and quantitative findings to the thesis. The paper also consists of a comprehensive literature review of material related to the subject. The review is based on Books, Articles, Journals, Licentiate theses, scientific research papers and online sources. In addition to these, the Röforsbron budget costs will provide an extra source of material in which to analyse.

2.2.1 On-Site Interviews

As the Röforsbron is a pilot project, there is subsequently an absence of knowledge towards the use of BIM in bridge construction. For this reason, information and opinions gathered from personnel directly involved with the production phase of the project will provide the most relevant findings. Interviews provide a great way of obtaining first hand primary research data (Ghauri and Grønhaug, 2010).

Hoepfl (1997) defines quantitative research "as a way of seeking causal determination, prediction, and generalization of findings, qualitative research seeks instead illumination, understanding, and extrapolation to similar situations". The role of the interviews is to primarily provide qualitative research data. Strauss and Corbin (1990; cities in Hoepfl, 1997) claim that qualitative methods can be used to better understand any phenomenon about which little is yet known. They can also be used to gain new perspectives on things about which much is already known, or to gain more in-depth information that may be difficult to convey quantitatively.

The interviews take place over a 14-week period during the period of 4th February 2013– 8th May 2013. During this time the project performed a large chunk of its production phase, where it installed the form stands, form work, reinforcement as well as completing the concrete casting for each of the three spans of the bridge. Interviews were conducted throughout that time with all personnel on site. Throughout this time, key personnel involved in the production were interviewed regularly, after each of those tasks were completed to establish how they assessed the value of BIM to those specific tasks. The aim of this was to remain in constant contact with the workforce, finding out their opinions immediately after the task while it was fresh in their thoughts.

The interviews themselves were semi-structured so as to ask questions that would provide responses to answer the research questions. The questions were written to avoid being leading as well as having an open nature so as to allow the interviewee to think freely and go into further detail where they felt comfortable to benefit from their experience. Commonly, further questions were spontaneously derived due to the natural progression of the interview.

The first interview performed was designed to understand individual’s opinions of BIM and its potential use in bridge construction as well as identify what, if any, experience of BIM they have had. These questions were important because actors’ attitude towards implementing BIM could have a significant affect on its success in the production phase. The following interviews were generated to provide a more direct response to actors’ assessment of the completed work using BIM.

2.2.2 External Personnel Interviews

Interviews were also carried out off-site, away from the Röforsbron project. This involved actors from other positions across the bridge construction industry. The interviews were carried out either face-to-face or through email. The aim of these interviews were to compliment the data obtained from the Röforsbron project and provide added input into answering the research questions.

2.2.3 Empirical Observation

Data for the paper is also gathered from the observation of on-site construction practices. Observation primarily takes place on the Röforsbron project. The collection of data involved direct interaction in the field, where the author observed working practice of the production phase of all parties involved. The observations are recorded from an objective viewpoint to provide an unbiased assessment of the practices that take place, specifically comprising of attendance of daily and weekly meetings, combined with observation of work procedures outside, in the field. The data collected was analysed and measured to offer both a qualitative and quantitative range of information.

Measurement

In order to quantify the effectiveness of BIM in the production phase, it is necessary to examine how the BIM tool has affected the production of the bridge. The success of a project comes down to three fundamental factors - cost, time and quality. It is the balance of these features that is the challenge facing the project managers. In an attempt to measure these factors in the Röforsbron, the performed labour, material and resources used for tasks in the project were related to the planned figures that were pre-calculated and initially used as part of the tender for the contract. The figures were based on experience from previous projects and were calculated on the assumption that BIM was not to be used in the project. The achieved figures were further compared to outcomes of previous projects to establish how the Röforsbron performed against them.

Measurement of labour productivity comes in the form of in-field observation, where practices are documented and recorded so as to provide an understanding of the daily activities that take place. The findings will be used to sight shortcomings and possible improvements in future BIM projects.

Inductive and Deductive Reasoning

When conducting inductive research, it implies that a theory is built based on the empirical observations made by the author. In comparison, deductive reasoning is the process of taking one or more theories or assumptions and testing them to confirm or reject the hypothesis. Deductive reasoning is synonymous with qualitative research, as opposed too inductive, which is commonly used as part of quantitative research (Ghauri and Grønhaug, 2010). As the paper is based on an unstructured problem where a number of hypotheses are being questioned, an inductive reasoning approach is taken.

2.2.4 Literature Review

In addition to gathering data from the Röforsbron project, a comprehensive literature review of the subject was also carried out. As the use of BIM in the production phase of bridge construction is a new concept, obtaining material on that specific subject is difficult. However, there is an ample amount of literature in the use of BIM in construction and infrastructure projects. As well as the research on BIM, the concepts of productivity, constructability and lean construction was also the main focus of the study. As with the subject of BIM, there is an abundance of information on these concepts. The purpose of the literature review was to extract and utilise relevant information from the material and apply it to providing an answer to the research questions. The sources of material from the review were from books, e-journals, articles, research papers and theses.

2.3 Criticisms of the Sources

The most significant problem with all sources of data is obtaining that which is relevant to the answering the research questions. As mentioned previously, the shear quantity of information of the subject, forces a significant amount of information to be rendered irrelevant.

The interviews will be structured to provide answers to particular areas of interest. However, due to the nature of interviews, the information gathered will seldom be void of biased opinions. Therefore, the answers obtained are put into context with the aim to offer the most objective of judgements.

As with the Interviews, the literature covers a wide variety of topics, all from relative viewpoints. When performing the review, a serious attempt is made in recording information that is from reliable sources. As BIM is very much a method in the construction industry that is in a transitional period, a lot of research papers and articles are based on theoretical findings, of which few can be attributed to fact. In addition, the areas of study for these documents are not exactly in line with the area of research for this thesis, which is taken into consideration accordingly.

Dates of publications are of key importance to the validity and relevancy of its contents. A document published 10 years ago may not be applicable to the construction industry now. The location of which content is written about is equally as important. Practice in the USA or Asia may not be valid to the European and more specifically, the Swedish construction industry. These factors will be taken into account when reviewing the sources.

The measurements attained to provide a quantitative value to the performance of BIM in the project are difficult to label as truly accurate and reliable.

2.4 Confidentiality and Anonymity

This paper is conducted in accordance with the requirements issued by Skanska Sverige AB. Skanska is a multi-national company working in different sectors across the world. It operates in an extremely competitive industry where confidential and sensitive information can harm the company's competitiveness in the market. In order to protect Skanska's right to privacy, any material or information that may be deemed confidential is not discussed in this paper. Any information or findings that are questioned as confidential are discussed with relevant supervisors before being included in the paper.

All parties involved in the thesis were offered the chance to remain anonymous in order to protect their rights. The actors would be cited as *Anonymous* throughout the paper. During the duration of the thesis, no sensitive information was obtained and all parties agreed to be identified.

3 Theory

3.1 Constructability

After a comprehensive review of literature on improving production phase performance, it was decided that constructability would be a key aspect of this paper. It is felt that by incorporating constructability principles, delivery of the project will yield lean construction and higher levels of productivity and quality, subsequently leading to an improved production phase performance, highlighted in Figure 2 (Griffith and Sidwell, 1999; citied in Motsa *et al.*, 2002).

Figure 2 - Natural progression of project performance through implementation of constructability principles, based on views in the report by Motsa *et al.* (2002)

To understand the concepts of "constructability", a definition needs to be established for the reader to understand the purpose for its use. The Construction Industry Institute (CII), which is a consortium of more than 100 leading owner, engineering-contractor, and supplier firms from both the public and private arenas defines constructability as "*the optimum use of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall objectives*" (Construction Industry Institute, 1986). The term is based on a project management technique, where construction processes are reviewed and optimised from start to finish in the pre-construction stage in an attempt to minimise the number of errors and delays that may occur when the project goes into production (Arditi *et al.*, 2002; Othman, 2011). In effect, it is the extent to which the design of a facility provides ease of construction and a way of improving construction performance (McCulloch, 1996).

The term was coined as the architectural influence on construction projects began to push the industry from a mainly mechanical approach to building, to a more aesthetic based ideology, where the look of facilities and structures took over, inducing a more complicated approach to building projects (Uhlik and Lores, 1998). It is in essence, the continuing diverging goals and lack of collaboration between the design and the construction sectors that has led to the introduction of constructability (Al-Ghamdi, 2000; Motsa *et al*., 2002).

3.1.1 Principles of Constructability

The goal behind adopting constructability principles is to make delivery of the structure easier, safer and cheaper through a more constructible design. Gambatese *et al.* (2007) attributes constructions continuous low performance to the impact of poor constructability. Successful implementation of constructability concepts requires, among other things, construction knowledge and experience from the early stages of a projects life. It relies on understanding of the construction process, the methods and information needed, as well as the limitations and constraints in order to effectively and efficiently build (Gambatese *et al.*, 2007).

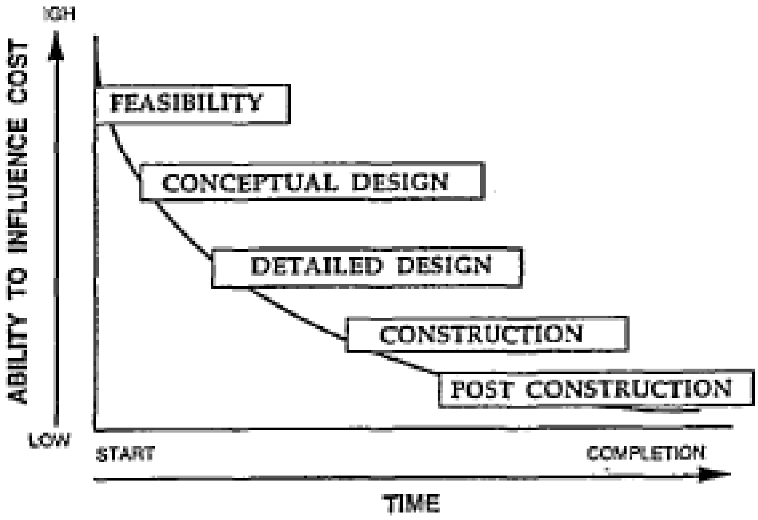


Figure 3 - Curve showing the influence of the decisions made at each stage of a projects delivery on the total cost (Griffith & Sidwell, 1999)

A constructability philosophy should be adopted through all stages of a projects life cycle from conceptual design through to the field operations (Arditi *et al*., 2002; Jergeas *et al*., 2001; Fischer and Tatum, 1997). At each stage, approaches should be made to improve constructability. The earliest stages of a project have the most significant impact on the total cost of a project, highlighted in Figure 3. Therefore, addressing constructability issues as early as possible is key to improving the overall cost of a development. The CII (1986) outlined 17 principles of constructability and categorised them into their use at each stage of a project, shown in Appendix A1. The principles have been complemented with an implementation roadmap, which identifies ways of incorporating constructability through various matrices, Appendix A2. Although the concept should be adopted throughout the life cycle, the design stages hold a significant weight of importance to its effectiveness and thus, the focus of the majority of the principles. Construction institutes around the globe have researched the concept and further added their own perceived ideas. Figure 4 is a simplified list of the principles, which are grouped together to provide the reader with a clear understanding of the core factors involved in constructability (Jergeas *et al*., 2001).

<u>Simplified List of Constructability Principles</u>

- Up-front involvement of construction personnel
- Use of construction-sensitive schedules
- Modularization and preassembly
- Standardization
- Designs that facilitate construction efficiency
- Use of innovative construction methods
- Use of advanced computer technology

Figure 4 - Simplified list of constructability principles highlighting the core aspects of the concept (Jergeas et al., 2001)

Generating a 'constructible' project requires construction knowledge, but "until the integration of design and construction knowledge is fully achieved among participants of the project development process, the practice of constructability reviews is necessary" (Gambatese *et al*., 2007). This method is one of a number of suggested ways in which to improve constructability. Wong *et al*. (2006) also include constructability reviews as one of the three common methods utilized in improving constructability- *Quantified Assessment of Designs*, *Constructability Review* and *Implementation of Constructability Programs.* An example of where these methods have proven to be effective is in Singapore, where a buildable design appraisal system must be met before the building plan is approved. Various reports citied in Koskela (2000) show that implementing constructability principles results in savings from reduced site labour, increased cost effectiveness and better resource utilisation. Other benefits reported are improved quality, safety (safety on site and performance), time (early completion) and other intangible bonuses. Improvement in industrial relations, teamwork and client satisfaction are further benefits achieved. It is also believed that incorporating principles of constructability enable better communication, planning and project management during the building process (Wong et al, 2006; Jergeas *et al*., 2001).

Constructability can be implemented to varying degrees, with projects ranging in size and complexity; the level of constructability implemented should reflect these factors (Arditi *et al*., 2002). A balance should be found where expertise is brought in where required so that resources, time and money are not wasted e.g. a highly complex project with small meticulous details might require more than one expert to aid in the design.

3.1.2 Think '*How* to Build', not just '*What* to Build'

As previously mentioned, the premise behind constructability is to generate a design that will allow production to be as easy and effective as possible. This requires designers to create plans that consider construction methods and practice. However, the parties building the product hold the knowledge and experience required to aid in the design stage. Therefore, to obtain maximum benefits, the involvement of these parties early in the project is crucial. (Jergeas *et al*., 2001; ASCE, 1991; citied in Saghatforoush *et al*., 2009; Chelson, 2010; McCulloch, 1996; Arditi *et al.*, 2002). This should not just be limited to contractors but also include the valuable knowledge of suppliers (Song *et al*., 2009), who hold a wealth of expertise on their particular practice.

Motsa *et al*. (2007) and Burati (1992) highlight this importance by suggesting that many of the decisions made in the design stages of the project life have a significant effect on the construction of the project. The expertise of contractors with construction knowledge and experience is required in the design stage to improve the constructability of a project (CII, 1993). The main problem that currently affects the design stage of developments is that there is only consideration of *what* to build and no thought on *how* (Chelson, 2010). Designing to consider methods of construction is paramount to improving constructability (Gambatese *et al*., 2007). By combining this principle with regular reviews of the building process, the design can be optimised to choose the most effective approach (Wong *et al.*, 2006).

As the different parties in the industry have drifted apart, the strict demand to complete work to tight time and quality deadlines has forced actors to focus on honing and mastering their own professional skills and thus have reduced their consideration for other actors' practices. Combined with current contract arrangements, the necessary experience and knowledge required in the early design stages of a project is not available, which in turn impedes the application of constructability into a projects design philosophy (Gambatese *et al*., 2007). Designers accept this problem and recognize their lack of knowledge of construction procedures is what hinders the progression of constructability in a project (Motsa *et al*., 2007). Designers acknowledge they need more feedback from contractors on site to aid in their designs, however this collaboration is continuously never acted on. Motsa *et al*. (2007) believe that for this collaboration to take place, calls "for a total dismantling of the traditional compartmentalization of design and construction by more widespread use of non-conventional procurement methods, which give contractors a greater role in design".

Often contractors are not invited to participate in the design activities until the end of the design stage, which limits their influence on the design (Song *et al*., 2009). Virtual planning methods have been attempted to bring all parties together from the initial procurement of the project, where all the parties sit together to brainstorm and discuss the project collaboratively. This can only aid in producing constructible designs and will benefit all parties involved.

3.2 Building 'Lean'

The main principle behind lean construction is eliminating waste. Actors have their individual definition of waste and lean production, but the concepts of each remain similar. In short, 'waste' is effectively a cost generated by actions that absorb resources but add no value to the finished product (Womack and Jones, 2003). Although the core principles of lean production are shared between actors, their goals for the approach vary, with some aiming for cost reduction and improved value, others aiming towards customer satisfaction (Pettersen, 2009). These varying goals can cause confusion when attempting to apply the concept into an organisation, as aspects for one approach may not be applicable to another. The lack of an industry wide standard definition may be the cause for this (Pettersen, 2009). In order to understand lean construction as a concept, it is important to identify its origins, principles and how it can improve production phase performance.

3.2.1 The Toyota Production System (TPS)

Building 'lean' has become a very prominent term in the construction industry over the last two decades as firms look to improve their productivity in construction through better management of waste and resources (Forsberg and Saukkoriipi, 2007). The building lean approach is taken from Taiichi Ohno's Toyota Production System (TPS), which is the system first used in the manufacturing industry to eliminate waste to improve productivity. The owners and engineers of the Japanese automotive giants founded the approach around the 1950's when they were searching for a 'ideal' production attitude where all work performed was value adding to the product (Liker, 2003). The Swedish construction industry has thus since tried to incorporate these principles from the manufacturing industry in an effort to boost their declining productivity levels (Lutz & Gabrielsson, 2002).

The TPS stems from the foundational principles of the 'Toyota Way', which was based on the culture at Toyota and is not to be confused with one another. The Toyota Way was a philosophy of management that focussed on customer value, from which the TPS was derived. It was used as a way of systematically implementing the Toyota Way into other organisations and industries. Each organisation is different, whatever industry it is in, which is why the TPS is not a set of rules but a philosophy that should be incorporated and interpreted to achieve the individual needs of each company. Likers' (2003) book on the Toyota way highlights the 14 principles of the TPS and splits them into 4 core categories: *Philosophy, Process, People and Partners* and *Problem Solving*, shown in Appendix A.3. Each category represents the key aspects of how to incorporate the TPS into a business.

The heart of the TPS is to eliminate waste in the production process. Ohno (2007) identified the seven variations of waste that increase cost, add no value to the finished products and reduce productivity. Figure 5 is a list of the seven wastes identified by Ohno that have been split into two distinct variations. By addressing these issues through proper design and planning, Ohno was able to eradicate the waste problems and improve the productivity of the manufacturing process. Ohno believed the fundamental waste was over production as it was felt that this was the cause for a lot of the other waste types. (Liker 2003)

FLOW OF MATERIALS
• **Over Production** *- Only produce what is needed. Do not produce safety or buffer stocks i.e. Just-in-time production.*
• **Correction** *- Involves reworking of processes due to errors and failure to meet specifications. All of which use up time, materials and resources.*
• **Material Movement** *- Unnecessary movement of materials from location to location across site. Materials should be delivered to their point of use for direct installation.*
• **Over Processing** *- The unnecessary steps in operations including double-checking, added communications, over handling of information, etc.*
• **Inventory** *- Holding on to excess inventory and materials. The build up of materials can really drive up costs*
HUMAN ACTION
• **Waiting** *- The periods of inactivity in a project. Involves delay, waiting for materials and equipment, etc.*
• **Motion** *- The extra steps and work performed by personnel to process errors and defects*

Figure 5 - Seven variations of waste identified by Ohno (2007) as part of the TPS

Ohno (2007) also identified the *Eighth Waste*, which were ***underutilized people.*** He believed that the creative, mental and physical skills of workers in an organisation are key to improvement. Not utilizing those abilities would be wasteful.

3.2.2 Construction vs. Manufacturing

For decades there has been a call to replicate manufacturing's successful lean approach in the construction industry. The two industries have been constantly compared in relation to their diverging levels of productivity over the last 50 years. However, this comparison could be seen as unfair as the contrast in working environments of the two industries is what prevents this seamless adoption of lean practice (Salem *et al.*, 2006). Teicholz *et al.* (2001) also believes on-site conditions in construction are significantly more varied and unpredictable. This is especially the case in bridge construction, where contractors are constantly exposed to the elements and are rarely protected from shifting weather conditions. Something that other sectors of the construction industry can occasionally benefit from. The construction industry faces a number of key distinctions between themselves and the manufacturing industry (Salem *et al.*, 2006; Chelson, 2010):

- Weather conditions make working conditions less conductive to time and quality control.
- Superior tools and equipment in a factory compared to mobile conditions on site. Larger, more expensive machines are sometimes not used due to their mobilization costs.
- Interrelationship of labour and processes from other trades cause scheduling and logistical problems.
- On site work layout varies from project to project, forcing site layout optimization difficult.
- Lifecycle of a PRODUCT is long enough to develop research and training capabilities. PROJECT life cycle is relatively short, thus more difficult to justify research and training
- Extent of operations well defined in the beginning for manufacturing. Construction has a more flexible supply chain.

Although it would be naïve to expect the construction industry to match the level of productivity achieved by the manufacturing industry, the principles entailed in improving lean production can be translated to positive effect in the bridge construction sector (Eriksson and Mehmedovic, 2012).

3.2.3 Lean Principles and their Application into Construction

The vast array of literature on lean production offers fruitful reading, with works presenting a wide range of strategies, tools and thoughts for its application. Nevertheless, applying the concept successfully into current building practice is 'easier said than done'. It is not to propose that throughout its life, the construction industry has ignored waste as a product of its practice. Of course not. Waste costs organisations money and reduces profit, a fact that all owners are very aware of and constantly looking to address. However, the industry lacks the drive to find innovative solutions to compete in the market and simply makes-do with what they currently have (Lutz and Gabrielsson, 2002).

Womack and Jones (2003) present the five principles to 'thinking lean', which form the basis to lean construction:

- Specify *Value.*
- Identify the *Value Stream*
- Continuous *Flow* of Value Steps
- Allow the customers to *Pull* the value from the organisation
- Strive for *Perfection* in all areas

Value

The customer can only specify value, as it is they who define the requirements of the finished product. It is the producers, or the contractors, who then create the value. Therefore it is key for the customers to provide a clear, concise definition of value for which the contractors to achieve (Womack and Jones, 2003). This allows firms to identify what waste is in the process of producing the finished product, so that it can be targeted and removed. Specifying value is crucial to eliminating waste

Value Stream

Once the customer has specified the value, the value stream is mapped to identify the process of activities that add-value to the finished product. This way the processes that do not add value can be removed from the stream. As identified in the following section 3.2.4, the process to produce a finished product can be split into three categories: *Value adding, indirect value adding* and *non-value adding.*

Flow

With a clear value stream identified, the aim is to make these steps flow without interruption, so that each value-adding step can run smoothly into the next without any waiting or disruptions. This means forgetting about working through departments, jobs, boundaries, etc. Instead Womack and Jones (2003) suggest “firms to form a lean enterprise, removing all impediments to the continuous flow of the specific product or product family”. Allowing a continuous flow of value steps would eliminate waste if all the people, resources and materials can work without any disturbance.

Pull

It is important to understand what exactly the customer wants. Instead of common manufacturing approaches, where products are produced and then pushed onto customers, the idea is to wait for the customer to demand the product, so that the product is made only when the customer requires it. Once the product is needed, then make it quickly. Combined with the previously stated principles of lean, the production of the product will be swift.

Perfection

Perfection stems from one of the core TPS principles where one should strive for *continuous improvement*. Womack and Jones (2003) state that as the preceding principles are put into place, the production of the product begins to yield significant benefits, where waste begins to appear during the process. From here organisations can see the theoretical ‘perfect project’. Firms should aim to continuously improve their performance by reducing any element of waste until all actions are value adding. Whether this is achievable is another question, but the premise is to strive for the best performance possible.

The lean approach should be adopted as a philosophy that fits in with the organisations culture and environment (Liker, 2003). It is not just about choosing one approach over another or a set of tools and techniques, but rather looking into the processes and management of your individual workplace to achieve the highest performance. A problem that becomes apparent when researching the lean concept in construction is that its origins stem from the manufacturing industry. Attempts have been made to 'bridge the divide'. Koskela (1992) made the first notable attempt to establish how *lean production* could be translated into construction by researching "the new production philosophy" and its applicability to the building industry, following it up with further studies (Koskela, 2000). His findings formed the basis on which *lean construction* was born, however highlighted some significant issues in its transfer of principles. Jørgensen and Emmitt (2007) cite studies by Green and May (2005) and Koskela *et al.* (2002) who indicate that lean construction is not a copy of lean production, rather an interpretation. Constructions organisations have claimed to obtain significant benefits from using lean principles in their project delivery, but documentation of these are rare (Jørgensen and Emmitt, 2007). Pettersen (2009) also concurs with this statement, stating there is scarce evidence of truly successful lean production outside of the automotive industry. Nonetheless, it is argued that the principles of lean are applicable to any industry (Womack *et al.*, 1990). As lean construction was created from lean production, its definition is still unclear, which leads to communication difficulties, complications in learning and researching the subject as well as difficulties in defining goals (Pettersen, 2009; Jørgensen and Emmitt, 2008). The 'one run', uniqueness approach to construction projects, difficulty in data collection and the hierarchical state of organisations also add to the challenge in controlling flows and improving performance (Koskela, 2000; Koskela, 1992).

The success of applying lean concepts comes from implementing them to the entire process (Fitzpatrick, 2003). This means looking at every component in the construction from start to finish. Construction projects are in essence made-to-order, but the processes entailed within them are manufacturing orientated, as they are repetitive and somewhat mass-produced (Koskela, 1992). Delving into the process of these components is the basis on which lean practice can be achieved with a focus on value and not cost. Firms should be seeking to remove all non-value adding components and improve those that do add value (Construction Excellence, 2004). The 'Get it Right First Time' approach is an ideal that is common with most lean philosophies (Sacks *et al.*, 2009) and one that the construction industry looks to achieve, as rework and defects in production are the main problems causing poor productivity (Josephson, 1998; Forsberg and Saukkoriipi, 2007; Eriksson and Mehmedovic, 2012).

3.2.4 Identifying and Measuring Waste

The identification and management of waste is the challenge facing organisations in their bid to improve productivity. Koskela (1992) points out that in order to improve your waste performance, you must first identify it. This requires searching deep into the methods of construction processes and highlighting the actions and their effects. Womack and Jones (2003) identify how each element of every task in a process can be broken down into its smallest component, then pointing out what processes are necessary and removing the ones that are not. Each task process can be classified into three actions:

- ***Value-adding*** – Work that directly contributes to the value of the final structure
- ***Indirect value-adding*** – Work that is necessary to complete the final structure, but does not directly contribute to the finished structure
- ***Non-value adding*** – Unnecessary work that has no impact on to the value of the final structure therefore is pure waste.

What is evident when analysing a construction site is the vast array of equipment, materials, machines, temporary structures and space occupied. A large amount of construction is spent building temporary structures and features that are subsequently used to build the actual finished product, but not directly. However, all of which use up resources. Because of these processes it is increasingly difficult to distinguish between what is 'value adding' and 'non-value adding' in construction. Koskela (1992) suggests that waste in construction is "invisible and inactionable", but also points out that the same situation faced the manufacturing industry before it tackled the issue (Jørgensen and Emmitt, 2007; Koskela, 1992). What is clear from the literature on *lean construction* is that waste in the industry is hidden in so many aspects of the building process. Though most literature agrees that waste on site comes in the form of rework, waiting on materials and defects (Koskela, 2000). Previous studies have been performed to try to put precise figures onto the amount of waste produced in production in an attempt to cite methods to improve the production performance (Josephson, 1998; Forsberg and Saukkoriipi, 2007; Josephson *et al.*, 2011). Reports have shown waste values equal to 30%-35% of the total production cost (Josephson & Saukkoriipi, 2005). In this example, the waste identified in the report is split into four categories:

- ***Defects and Checks,* >10%** (of production cost).
  Includes costs related to defects, checking, insurance, theft and destruction
- ***Use of Resources,* >10%.**
  Costs due to inefficient use of labour, machines and materials.
- ***Health and Safety*, ≈12%.**
  Waste linked with work-related injuries or sickness. Including rehabilitation and retirement, which increase taxes due to these actions.
- ***Systems and Structures,* ≈5%.**
  Costs incurred due to the structure of the construction industry. Include planning and purchasing processes combined with administrative and documentation issues.

Josephson *et al.* (2011) performed a similar study, analysing the actual cost of reinforcement by breaking down each activity involved in a materials life from factory to instalment. The results indicated where time and money were lost as part of this process in four different projects, documenting how every minute of activity was utilised during its installation. Wasted time was credited as 15%-45% of the total installation time. Other reports have identified 57% (CII, 2004) of work as non-value adding. Similarly, Oglesby (1989, citied in Chelson, 2010) and Levy (1990, citied in Chelson, 2010) reported that only 36% and 32% respectively, is value-adding work. Extreme figures also suggest that only 10% is value adding (Eastman *et al*., 2011).

With all these reports, it is the authors' interpretation of waste that is significant to the actual value recorded. These reports all measure their levels of waste in the production phase, which is where the non-value adding activity becomes visible. However, the emergence of waste in the production phase does not mean the cause is by the production team. Poor planning and design cause waste (Koskela, 2000). Only once the structure begins to be built is where the waste comes to surface. Literature on lean production focuses on waste in production, so it is natural for attempts of waste measurement to take place in the production phase. However, analysing the practice in the early stages of the project life is just as important as the analysis of production (Forsberg and Saukkoriipi, 2007).

3.3 Productivity

In order to understand how production phase performance can be improved, it is necessary to briefly introduce the theory behind productivity and its means of measurement.

The measure of productivity is defined as a total output per one unit of a total input. Jergeas *et al*. (2001) define productivity as a comparison of the inputs and outputs in a project. It is often presented as a percentage to signify a rate of productivity or can be calculated as a unit cost. Trafikverket represent productivity in two different ways:

$$\boldsymbol{Productivity} = \frac{Finished\ Product}{Total\ Cost}$$

$$\boldsymbol{Unit\ Cost} = \frac{1}{Productivity} = \frac{Total\ Cost}{Finished\ Product}$$

In essence, higher productivity is achieving more finished product for normal total cost, or the same finished product for a lower cost. One common misconception is that productivity is equal to production. However, a task can be productive but can be performed at a low level of productivity. An example of this is where a development requires extra personnel to complete, but the output achieved is not proportional to the input of extra personnel. It is the level of productivity that is of the most significant to projects stakeholders, as it determines the value of input used to get the desired output. Methods to improve productivity have involved the introduction of lean (Eriksson and Mehmedovic, 2012; Udroiu, 2011) and constructability (Arditi *et al*., 2002: Motsa *et al*., 2002) principles. Both have shown to have a positive effect on productivity levels in the projects they were applied to.

3.4 Measurement for Improvement

The purpose of measuring a projects performance is fundamentally to learn and improve. Progress can only be achieved and recorded if it has previous experience to compare it to (Othman, 2011; Motsa *et al*. 2007). The Swedish construction industry performs very poorly in that regard as it has little experience in learning from prior projects (Borgbrant, 2003). The lack of detailed documentation from a project is extremely low (Forsberg, 2007). Forsberg and Saukkoriipi (2007) concur with this belief and add that problems on site and the method in which they are addressed are rarely documented.

When looking at *constructability* concepts, its adoption and further improvement suffers due to the lack of structured reviews and analysis of the practice within AEC firms (Arditi *et al*., 2002). Wong *et* al. (2006) adds to this, writing that "there are very limited existing studies evaluating the success or otherwise of different approaches for improving constructability". The common methods of constructability review; *Quantified Assessment of Designs*, *Constructability Review* and *Implementation of Constructability Programs* are all aimed at improving the constructability of the project, but recordings and experience need to be stored and analyzed in which to improve future works. Wong *et al*. (2006) believe that the best way of improving a design is to quantify it, which is whey they believe a quantified assessment of designs is the best method of measuring constructability in a project, this way there are values that can provide clear markers of what areas need to be improved.

Gambetese et al (2007) points to the fact that measurement of constructability reviews are anecdotal, but refers to the study performed by Dunston *et al*., (2002) who placed a cost to benefit ratio of 2.1 and 2.29 in two American roadway projects. Regardless, they acknowledge, "placing costs and benefits to reviews will only improve efficiency of current reviews and ensure viability of future reviews".

Although implementing constructability principles into a construction project is widely regarded to provide significant improved return to all stakeholders, the methods used to assign value to these benefits is not broadly accepted (Gambatese *et al.,* 2007). It is clear that upfront investment of resources is required in order reap the advantages. The initial cost of implementing such measures is one factor preventing organisations to adopt these principles into their practice (Jergeas *et al*, 2001). However, surveys contradict that theory showing that the cost of its implementation is insignificant (Arditi *et al.*, 2002). Nevertheless, firms want quantitative proof that the concepts work and that the money they pump into a project at the beginning will significantly increase the overall profit achieved. Studies have been performed to try to assign value to its practice. Notably, Anderson and Fischer (1997) calculated that $25 was saved on a project for every $1 dollar spent on constructability analysis. This figure was also backed up by the Business Roundtable (BRT) (1982, citied in Gambatese *et al*. 2007), who reported savings of 10-20 times the cost of the constructability effort in surveyed projects. Another issue felt by designers is that there is no financial incentive for this increased effort to improve constructability (Motsa *et al*., 2007), where contractors reap the rewards for all their work.

As previously mentioned, a constructability review is a method to measure constructability. It needs a champion to oversee its implementation that emphasizes a team concept and ensures vertical and horizontal communication between actors, as well as has authority to approve plans and revisions when the review uncovers something. Reviews made at specific points during the construction depending on size and complexity of the project, by teams that contain individuals from various disciplines to identify how aspects of the process will impact the productivity.

Measurement to improve lean performance is also a key aspect to the success of the concept and is the basis in which to strive for continuous improvement (Ohno, 2007). Lean production focuses mainly on the measurement of waste to mark improvement, however Womack and Jones (2003) suggest focusing on the processes in the organization and not the numbers. With the challenge of identifying accurate values of waste in construction, it would suggest that Womack and Jones' thinking would be more applicable to the construction industry. As previously mentioned, Koskela (2000) also points to the absence of systematic waste measurement. Nonetheless, he believes that measurements "provide access to continuous improvement by pinpointing improvement potential and monitoring progress achieved".

3.5 BIM in Bridge Construction

3.5.1 What is BIM?

BIM has a different definition depending on whom you ask. Due to its continuously evolving nature, the definition of BIM in the construction industry has changed significantly over the last decade or so. No doubt it will continue to do so. Where 10 years ago, BIM was considered to be a simple digitalised model or a way of computerizing project information, it is now considered a data-rich 3D model containing all construction documents and intrinsic characteristics of the structure, that are used by all stakeholders in a project to share and extract the information they require (Gould and Joyce, 2011). To WSP (2013), "pinning down what BIM really means is easier said than done". The problem with defining BIM is that it can refer to software, a model and/or a method of construction (Chelson, 2010). What should be made clear is the difference between the model – *Building Information Model* and the method - *Building Information modelling*, which is commonly misrepresented. This paper focuses on building information modelling using the 3D BIM.

3.5.2 Why BIM?

The adoption of BIM has been slow into bridge construction because of one key question - *why should we use BIM?* Organisations across the industry are questioning what further benefit can BIM provide to a project that good planning and design cannot. BIM is credited for the time savings, waste reduction and enhanced collaboration during project delivery (Gerber *et al*., 2010). At the end of the day, the level of profit is the bottom line concern for all companies. When a project is designed and planned meticulously such as the Empire State Building in New York, USA, then delivery can be hugely successful with savings in budget and time (FHWA, 1999), all without BIM. This unique case displays the effect of good planning and design. What should be taken into consideration is the development utilised very skilled designers and planners, custom-made equipment, and well paid employees. Combined with the lack of health and safety measures that sadly cost lives, it allowed certain practices to run with fewer restrictions. This is one successful project out of millions of unsuccessful projects; nevertheless, this level of productivity is obviously attainable. The development utilised the best designers and planners at the time, but not every project in world can be blessed with such features. BIM provides a means for all “regular” professionals to achieve this level of project performance.

In the following section, the documented benefits of BIM that are of interest to production are addressed. What stakeholders look to find out is, whether these potential benefits are actually obtainable and can improve the overall value of the project. The problem with most organisations is these benefits do not seem to fit in with the practice they offer or at least come at a larger cost. This leads to case studies and reports looking to establish what relevancy and effect BIM has to their work.

Most of the theories and literature read on improving productivity, constructability and lean construction all advocate the use of integrated computer systems to aid in achieving their goals (Koskela, 1992; Gambatese *et al*., 2007; CII 1986; Eriksson and Mehmedovic, 2012; Sacks *et al*., 2009; Arditi *et al*., 2002; Jergeas *et al*., 2001). It is argued that BIM is the way in which these performance concepts could be achieved as its tools provide the means in which to incorporate the principles of each concept (Gerber *et al*., 2010). Some of the main problems in construction are due to the fragmentation in the construction industry and Koskelas’ (1992) research shows that BIM tools could aid in providing a solution. Sacks *et al*. (2010) add that visualising the flow of construction, as identified in lean construction, is very difficult under current practice and would benefit hugely from integrated computer modelling.

The introduction of BIM has reported to have a significant impact into the success of applying constructability principles, where its attributes make it easier to implement and analyse construction practice (Arditi et al, 2002). It should be recognised that BIM is not a tool to fix all construction problems. However, BIM provides the qualities to ease and improve these processes so that these problems can be prevented (Chelson, 2010). Gambatese *et al.,* (2007) believes projects would greatly benefit from “technologies that locate errors and omissions, highlight inferences and allow for time lapsed viewing of the construction process”, which is difficult to perform using traditional 2D drawing methods (Gambatese *et al.,* 2007).

Jergeas *et al.* (2001) stated that a database of constructability knowledge that can link design and construction decisions together to aid the designers in producing a structure that considers the methods entailed within it. The features of BIM make it a tool that can potentially fulfil these needs. However, a concern for designers is the responsibility of the construction methods chosen in the model. Without a standard on which to build to, there are no design specifications set (Motsa *et al*., 2007). For example, who takes responsibility for a model that considers faulty or un-favourable practice? Designer or Contractor? (McGraw Hill, 2012; Krantz, 2012)

3.5.3 Benefits of BIM in the Production Phase

BIM is regarded as the tool in which to improve construction productivity by providing an easier way of incorporating lean (Gerber *et al*., 2010) and constructability principles (Chelson, 2010) into the project delivery as opposed to traditional methods. In this section the driving forces behind implementing BIM into the production phase of bridge projects are explored. The quantity and range of literature already on the subject is well documented. The benefits of BIM depend on the level of its implementation into a project. 4D and 5D BIM draw up a vast array of further benefits to a project. A 4D BIM incorporates the schedule component of a project, where a 5D BIM adds the cost component to the 4D BIM. But due to the time restrictions of the research, 3D BIM will be the sole focus of the paper. The subsections will look at significant characteristics of 3D BIM to the production phase as well as the possible and realised benefits it provides to the delivery of a project. The Röforsbron project provides the test as to whether these benefits are obtained and what value to give to the project.

When using BIM technology in a project delivery it is important to understand each actor’s requirements. Employees on-site have differing methods in which to perform their work. Therefore, knowing what information each worker requires is important so that the necessary tools are available in which to complete their task effectively. This means eradicating any unnecessary information and actions that would slow their efficiency and cause confusion. The following benefits of BIM are designed to aid the workers in performing their task without, or with minimal problems. Though for many users, the benefits are irrelevant and could potentially disrupt the efficiency of their practice. As Chelson (2010) suggests, “The decision *whether* to use BIM is only the initial decision. *How* to use the BIM model becomes the question to achieve effective production”

3D Visualisations

3D modelling has been an effective tool in the AEC industry for many years. The tool has been especially effective in the design and tender stages of a project, where firms have used its benefits to good effect to display their proposed designs to clients and customers. The premise with BIM is to take that visualisation technology and develop it so it can be just as effective throughout a projects life cycle from tender through to handover (Eastman *et al.*, 2011).

The ability to view designs in a 3D model has a number of benefits to contractors. It allows the user to visualise the design at any stage of the process with the expectation that it will be consistent in every view (Eastman *et al.*, 2011). The ability to move and rotate the object freely, gives the viewers the ability to gain a clear understanding of how the project should look (Krantz, 2011). The traditional method of using 2D drawings to visualise a 3D object often causes misinterpretation, which is especially common when reading reinforcement drawings (Eriksson and Mehmedovic, 2012; Josephson & Saukkoriipi, 2005). The model takes away any of that thought process of translating 2D into 3D. A 3D BIM is not just a visualisation tool, but also a source for project information. Depending on the level of detail required in the design, the models can contain all material characteristics, from dimensions through to product codes (Eastman *et al.*, 2011).

Another potential benefit of the model is its ability to identify conflict and constructability problems in the design that could be recognised before entering onto site (Eastman *et al.*, 2011). This includes hard (space) and soft clashes (clearances)(Hergunsel, 2011). The latter is especially difficult to locate using 2D drawing methods. This minimises the chance for potential errors that would normally be dealt with on site, commonly resulting in delays and rework, enabling the workers to spend more time on performing direct value adding work.

Quantity Take-Offs

One of the key benefits of BIM is its ability for the user to quickly obtain detailed information about materials and parts in the model (Eastman *et al.,* 2011). Depending on the stage of the project and the complexity of the model, estimates can be made from the details stored in the model. In the early stages where the model is not as developed, general size values can be extracted, which can be used for the parametric cost estimates. Further down the project life cycle when a more mature version of the model is available, the characteristics of the materials extracted can be more specific. This is useful when making estimates and ordering from suppliers (Eastman *et al.,* 2011).

The level of detail in the model is a factor that plays a part in its subsequent effectiveness and can be improved by using contractors' knowledge of specific materials and construction methods. However, the ability to obtain quantities and measurements on materials should not simply be considered as a replacement to estimation, as an estimator plays a crucial role in providing the most accurate judgement on the cost of work, which is beyond just material costs. Analysis of unique circumstances and complexity of the task is paramount in the accuracy of the estimation (Eastman *et al.,* 2011). Furthermore, the simplicity of using a 3D BIM to provide material specifications to suppliers does not guarantee a successful order and delivery process. Thus, the skill of all persons involved in the order need also play a role (Nassar, 2010). BIM is reported as providing an increased level of precision in an estimate, however does not greatly alter the accuracy. Where the accuracy of an estimate is how far the estimated cost is from the actual cost. Precision on the other hand, describes the degree of refinement with which the estimate is made (Nassar, 2010).

Reports regularly connect effective quantity take-off to 4D BIM (Krantz, 2012: Roginski 2011), where the suppliers can easily extract the data in the model. This requires interoperability between software's for the benefits to be felt (Eastman *et al*, 2011). If a project only utilises a 3D BIM, the specifications of the materials used can be easily extracted for estimating and purchasing except without the cost values assigned.

Figure 6 - Fabrication of the SpinMaster reinforcement roll in the factory and the installation on-site. (Celsa Steel Services, 2013)

Prefabrication capabilities in a project are more achievable using 3D models as the ability to visualise the whole structure on one screen enables contractors to identify components that can be factory manufactured before they arrive on site. This allows the material to arrive on site already formed and installed directly in place, a benefit that is extremely useful with reinforcement. Prefabrication improves quality and reduces waste in materials and labour, as everything is constructed in a controlled factory environment (Gerber *et al.*, 2010). An advancement of the prefabrication in reinforcement is a unique solution developed by Celsa Steel, who has created a prefabrication product called the 'SpinMaster' or 'Rebar Carpets', shown in Figure 6. The reinforcement bars are spaced with steel and then rolled up into a cylinder. Once on site, it is rolled out like a carpet, commonly with only two men. This method allows 1.5 tons of steel to be rolled out in 10-20 minutes, which creates huge savings in labour time and resources (Celsa Steel Services, 2013).

Field Use

Traditional methods of construction comprise of 2D paper drawings from which tradesman build from. Contractors use the designs for almost all aspects of their product delivery, using the plans in-house as well as out on-site to read and understand what is to be built. BIM can utilise computer tablets for the workers to take around site. The tablets contain the 3D model with all the information that they require to perform their task. From the tablets, the model can be explored, allowing the workers to have a complete overview of the model in their hand with the capability to rotate and extract 2D drawings of certain cross-sections where needed. This eradicates the need for all those paper drawings or documents that can get lost or damaged on site, keeping all the information in one hand-held device. The tablet also provides a quick and easy means for the workers to pass on any messages or concerns to the BIM-coordinator in the office, as it has a simple message function. The tablets do however commonly rely on an Internet connection, so that issue would need to be addressed on site for the full function to be achieved.

Communication & Information Logistics

As is defined by Gould and Joyce (2011) and many others (Eastman *et al*., 2011; Crotty 2012) BIM is considered a central system combining models, intelligence and documents of a project. Any of which required by a user can be extracted to fulfil their needs. This central system is designed to make it simpler for all stakeholders to stay connected and up to date with the projects development, as all updated information is stored in this ‘core’. Barlish (2011) believes BIM “encourages the sharing of information and exchanging of information, schedule communication and organisational transformation”. This enables all parties to have a current model available instead of chasing around various actors in the project to get up to date information. BIM provides a hub for the wide variety of information in a wide range of formats, all easily accessible (Eastman *et al.,* 2011).

Dainty, Moore and Murray (2006) state that the success and high level of productivity on a project is based on effective communication. This should be adopted across all personnel, where communication is not just limited to their own workforce, but between all actors from every discipline. BIM helps in this regard by generating a more collaborative approach to the delivery (Barlish, 2011; Eastman *et al*., 2011).

BIM process aids in pre-planning by increasing design communication effectiveness by visualization and coordinating the various systems and trades that will be constructed together (Chelson, 2010). Maintaining this collaborative approach is particularly crucial when design changes are made.

4D BIM Scheduling & Simulation

Although 4D BIM goes beyond the scope of this project, it is important for the reader to be aware of its capability as its attributes are linked to successful implementation of 3D BIM.

The users of 4D BIM have the capability to benefit from its ability to perform detailed planning and visual construction simulation, where each stage of the construction is shown on the model, creating a step-by-step breakdown of the projects development (Autodesk, 2011). In effect, BIM can be used to completely construct a project digitally, before it is actually performed on-site, a so-called ‘rehearsal’ of the construction. This characteristic is one of great benefit to a project as it allows the project actors to identify any potential work flow errors and problems that could arise during actual delivery and therefore make the necessary adjustments before commencing with production. To create a simulation, every element in the project delivery needs to be considered. That includes assigning each component a construction time and duration. The benefit of which would provide the tradesman a walkthrough of the construction procedure, which in turn would allow a less skilled and experienced worker to perform the task as well as performing the task in the quickest possible time. It would also allow the designers and contractors a way of simulating variations in the construction procedure to optimize the most productive method to suit them. There is no doubt that this capability requires significantly more design time and resources. However, the rewards in production will make up for those efforts.

3.5.4 Current Drawbacks of BIM

The array of documented benefits of BIM provides attractive reading, but there are a number of factors that have stunted its implementation into the construction industry. The most obvious and documented concern is the cost of implementing the software. The use of BIM requires new technologies to be introduced and learnt, which requires a significant amount of initial investment (Motsa *et* al., 2007; Eastman *et al*., 2011; Krantz, 2012; McGraw Hill, 2012). This is not limited to cost concerns, as firms recognise that time is required to train employees on the new technologies (Jergeas *et al*., 2001, McGraw Hill, 2012). On top of that, the rather limited existing knowledge and intelligence on BIM creates a reluctance to use it (Olsson and Arvidsson, 2012), but as the tools are utilised more and more, this view would be expected to change.

This need for new technology also requires an alteration in the type of work employees will undertake. The fear of change and the theory that there is more administrative work involved with BIM is a barrier that needs to be tackled, which falls in line with the negative attitude felt towards BIM (Krantz, 2012). Firms are also aware of the interoperability issues that affect the successful application of BIM (Holzer, 2007). Designers, contractors and suppliers often work with their own software programs; this has led to compatibility problems whilst using BIM. Software manufacturers often generate programs in their own native format that cannot be read by a package from another manufacturer. Thus, when information from two programs e.g. Tekla and Civil3D are combined; the intelligence within the model is either lost or manipulated.

One of the most common reasons for the hesitancy in adopting BIM is its perceived lack of efficiency in smaller projects (McGraw Hill, 2012). Many reports study the use of BIM in large complex projects, where benefits have been clearly seen (Gerber *et al*., 2010; Barlish, 2011; Sacks *et al*., 2010), but there is a lack of evidence showing its value to smaller projects (McGraw Hill, 2012), a key factor to small/mid-sized firms. The bottom line is companies want proof that BIM is adding value to a project and that it will increase their ROI.

3.6 The Value of BIM

Although the functional benefits of BIM are widely reported throughout literature (Eastman *et al.*, 2011; Krantz, 2012; Crotty, 2012; McGraw-Hill, 2012) there seems to be a distinct lack of data providing accurate, concrete figures to its benefit. The problem facing the industry is the lack of an accepted calculation method used to place a figure on the value of BIM and the ROI for its users (McGraw-Hill, 2012; Barlish, 2011) and it is unclear as to whether BIM can be measured. Consequently, organisations must base their judgement of implementing BIM into projects on speculated gains and benefits (Barlish, 2011). Firms' hesitancy in adopting a new technology is understandable, as reports have shown application of information technology to not always provide significant monetary gains. Sacks *et al.* (2009) points to the studies by Howard *et al.* (1998), Rivard (2000) and Gann (2000) for these claims.

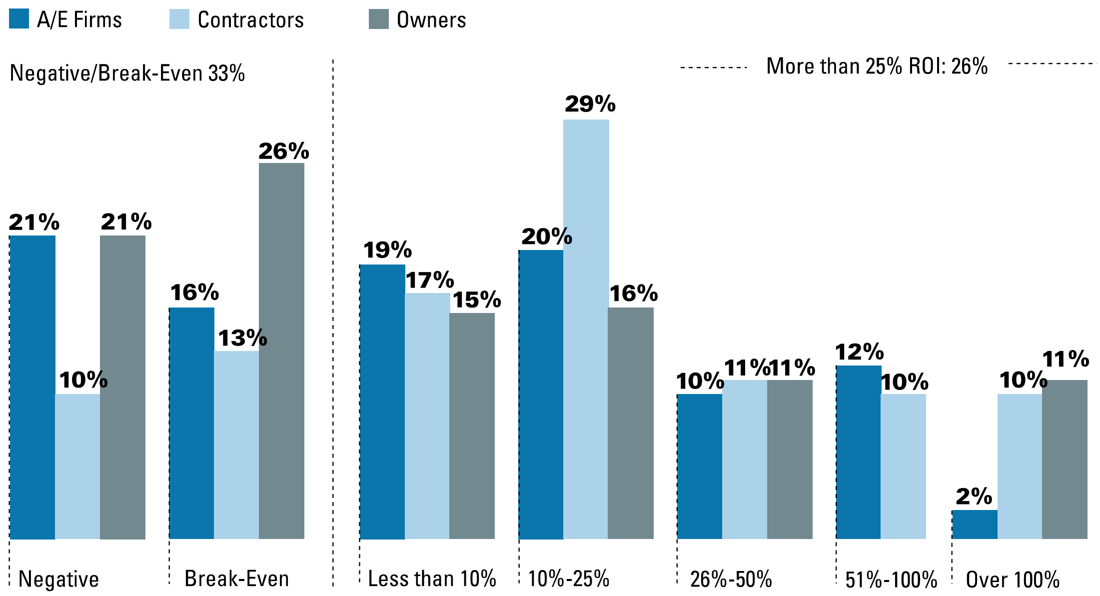


Figure 7 - Perceived ROI on Infrastructure BIM investment. Reported by McGraw-Hill to establish the business value of BIM for infrastructure (McGraw-Hill, 2012)

Due to the variety of delivery methods used in construction, establishing a ROI for each individual party is the challenge. In the traditional Bid-Build contracts where designers and contractors work autonomously, the return for each may vary. Surveys have shown up to 67% of owners observe a positive ROI, leaving up to 33% of BIM owners reporting a negative or break-even ROI, although it is unsure what percentage of that is negative (McGraw-Hill, 2012). However, the methods in which this ROI is recorded for each organisation are questionable, with approximately half reported as engaging in a formal measurement policy. Figure 7 is taken from McGraw-Hill's smart report. It identifies what actors believe their level of ROI on the BIM investment in the infrastructure sector. The thesis written by Barlish (2011) tries to measure the benefits of BIM projects in comparison to 2D projects. The case studies in her project all report savings from using BIM. Some of the projects incur larger design costs, but achieve even greater construction savings. Placing a higher concentration of time and resources in the design stage is where the industry currently falls short. Organisations believe that the cost of spending more time and money on a better, detailed and more accurate design will not yield improved savings in the production. However, this has shown not to be the case in numerous circumstances, where in fact it has shown to be quite the opposite. Savings in production have been enormous, leading to a significantly reduced overall cost and duration (Barlish, 2011). Commonly, design costs only take up a small amount of the total cost, with reports suggesting around 5% (Josephson & Saukkoriipi, 2005), whereas the production costs make up the bulk of the total cost. However, the decisions in the design stage are key to the magnitude of the production cost. Thus, the ability to identify and solve problems in this stage offers great value (Carlsson, 2012).

It is important to acknowledge that these recorded ROI figures should also be separated by the experience of the BIM users, where the most experienced users reported the largest ROI. As with any task or technology, the more you practice it, the easier it becomes to handle and the better you become at producing results.

One discussion raised among BIM users is its value to projects of varying complexity. The argument put forth is that BIM has attributes that would be beneficial to large, complex developments, where many trades and workforces are performing tasks at the same time. However, when implementing the tool into a simple and possibly smaller project, the benefits would not warrant the initial start-up and design costs. First time users commonly feel a negative impact of the technology due to the new investment and learning curve that comes with it (McGraw Hill, 2012).

BIM is introduced early into the design stage. Consequently, designers incur most of the initial costs of implementing the model. The model is handed over to the contractors who then reap the benefits of its use. In this case, the designers would feel that they are using all of their resources for the contractors gain, earning little for themselves. These costs include the adoption of the software and the extra time to produce designs, which are easier to quantify. The output gains come in so many forms and variations such that only general figures and personal opinions can define them.

Chelson (2010) cites a number of studies where BIM has been credited to positive performance figures:

- Estimated returns of 2 to 1 and approximately 10% labour savings (Carbasho, 2008)
- Design firms experienced 50% productivity gains by half of Revit users (Autodesk, 2007)
- Labour productivity 15% to 30% better than industry standards (Khanzode, 2007)
- Engineers had 47% decreases in labour hours needed to design and manage projects (Kaner, 2008)
- Case studies of projects utilizing BIM indicate field productivity gains from 5 to 40% (Chelson, 2010). Key indicators of increased productivity are RFI reduction, amount of rework, schedule compliance, and change orders due to plan conflicts

3.7 Contract Implications

There seems to be no doubt that project delivery would benefit hugely from a more collaborative approach to construction (Chelson, 2010; Arditi *et al.*, 2002; Koskela, 1992) Most of the studies performed in improving construction productivity cite current contract approaches as a key drawback in bringing all the parties together early in the projects life. Gambatese *et al.* (2007) and Motsa *et al.* (2007) also believe the current common contract delivery methods make this integration especially difficult. Finding a way of bridging this divide is proving to be very challenging.

Currently the industry adopts three common contract delivery options: Design-Build, Design-Bid-Build and Integrated Project Delivery (IPD). The latter being a more modern approach to construction where this holistic approach to project delivery is addressed.

Design-Bid-Build

This is a delivery method where clients select the design firm to generate the drawings/model, which is followed by selecting a contractor to undertake the production. This option is one of the most common as well as being the most divided of the three. The division of the actors in this case makes collaboration incredibly difficult as each party has their own contract requirements, which rarely include the consideration of other actors' practice. As the contractor enters the process after the design process, the design is not usually reviewed for constructability until then. This delays or even prevents the identification of efficient, economical construction practice. This autonomous approach to delivery minimises the possibility of reducing project time and can also lead to a breakdown in relationships (Gould and Joyce, 2011).

Design-Build

This method of delivery uses an enterprise to perform the design practice as well as the construction work. This approach generates a slightly more holistic approach to a project delivery as the departments involved in the complete delivery of a project from start to finish are part of the company. Therefore, it is in the companies benefit for its departments to work together to achieve the best possible outcome. This method promotes a better chance of performing constructability reviews and value engineering. One of the hurdles in this method is that the enterprise has the capability to perform both design and construction works, which is often not the case. Many firms are specialised in either the consulting or the contracting side of the industry.

Integrated Project Delivery (IPD)

This delivery method is becoming a more common approach as clients look to improve the value in their investment. "In the last few years IPD has gained more attention as a delivery method that contractually manages the need for increased collaboration for the purpose of solving problems in the design and construction process" (Chelson, 2010). The method adopts the most collaborative approach out of the three, where it looks to bring all parties involved into the project from day one to work together to complete the project. The aim is for all actors to come together early in the project to make informed decisions working towards a collaborative incentive rather than fulfilling their individual goals. The delivery method is designed to create a problem free delivery that improves value to the owner.

4 Empirics

4.1 Röforsbron Project

As part of Skanska's continual effort to be a market leader in civil construction, they are always looking for new ways in which to drive the industry forward. BIM is considered to be the future in which to transform the industry. However, its presence is young and requires implementation into new projects. In the bridge construction sector it is especially scarce. For this reason, Trafikverket have decided to implement BIM practice into one of its projects, Röforsbron in Arboga. The project is a reconstruction project of the original Röforsbron. It is a 100-year-old, concrete arch bridge with a total length of 63,5m over three spans, which holds a wealth cultural history to the area.

The project is the first of its kind in Sweden to adopt the use of BIM throughout its whole project life, with BIM being used in all aspects of construction, from the design stage through to completion of production. Trafikverket, the Swedish Transportation Authority, whose contract stipulated the use of a building information model, named Skanska Sverige AB general contractor for the production phase of the project. The design of the bridge was carried out by WSP Sweden, who was the creator of the model.

The production phase involved the replacement of the superstructure and strengthening of the bridge supports. The superstructure is built as an exact replica of the previous bridge, which is constructed using reinforced concrete. The bridge is expected to open on the 24 June 2013, with handover scheduled for August 2013.

The personnel on-site during production were broken down as follows:

- 1 Project Manager, P/T (Skanska)
- 1 Production Manager, F/T (Skanska)
- 1 Site Superintendent, F/T (Skanska)
- 1 BIM Coordinator, F/T (Skanska)
- 1 Project Engineer, F/T (Skanska)
- 1 Surveyor, F/T (Skanska)
- 1 BIM Bridge Designer, P/T (WSP)
- 1 Project Manager, P/T (Trafikverket)
- 6 Tradesmen, F/T (Skanska)

4.1.1 Use of BIM Tools

The Röforsbron project was a BIM project using a 3D model. *Tekla Structures* was the software used to design all aspects of the model. The model included all components of the sub-structures and super structures. The model also included all the temporary structures, which comprised of cranes, storage boxes, form stands and public pathways. These were put into the model by Skanska to aid in the production works. The fittings and finishes were also modelled.

The model was linked to the schedule, which offered a limited means of planning and tracking works through the model. The bridge model itself contained product information and material characteristics of all elements. The model was available for utilisation by all personnel on site, however to varying degrees of operability. Skanska's BIM Coordinator and WSP's designer had full operability functions, where they were able to make any changes to the model and its characteristics. All other personnel on site were limited to just the viewing version. The Tekla program *BIMSight* was the means in which all personnel viewed the model, which was operable on all computers and tablets. BIMSight enables the user to perform all functions to the model (view, rotate, select, etc.), but no changes can be made using BIMSight. BIMSight allowed the user to send messages to highlight a problem detected, but the Designer or BIM Coordinator could only make any changes.

Figure 8 - Viewing the model in the tablets on-site, through Tekla BIMSight

4.2 3D BIM in the Röforsbron Project

As the Röforsbron project utilised the 3D BIM throughout the delivery, a number of specific examples were found where BIM provided tangible and intangible benefits to the production and the effective works of the bridge in comparison to the traditional 2D drawing methods. A number of 3D BIM features were also identified, but were not fully utilised in the Röforsbron project.

4.2.1 Direct Influence of 3D BIM on the Röforsbron

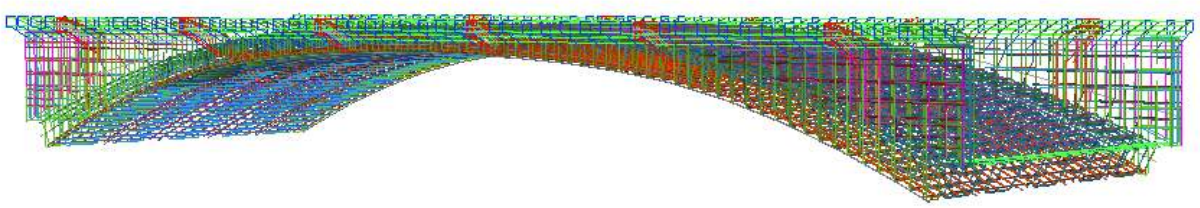
Material Order & Quantity Take-off

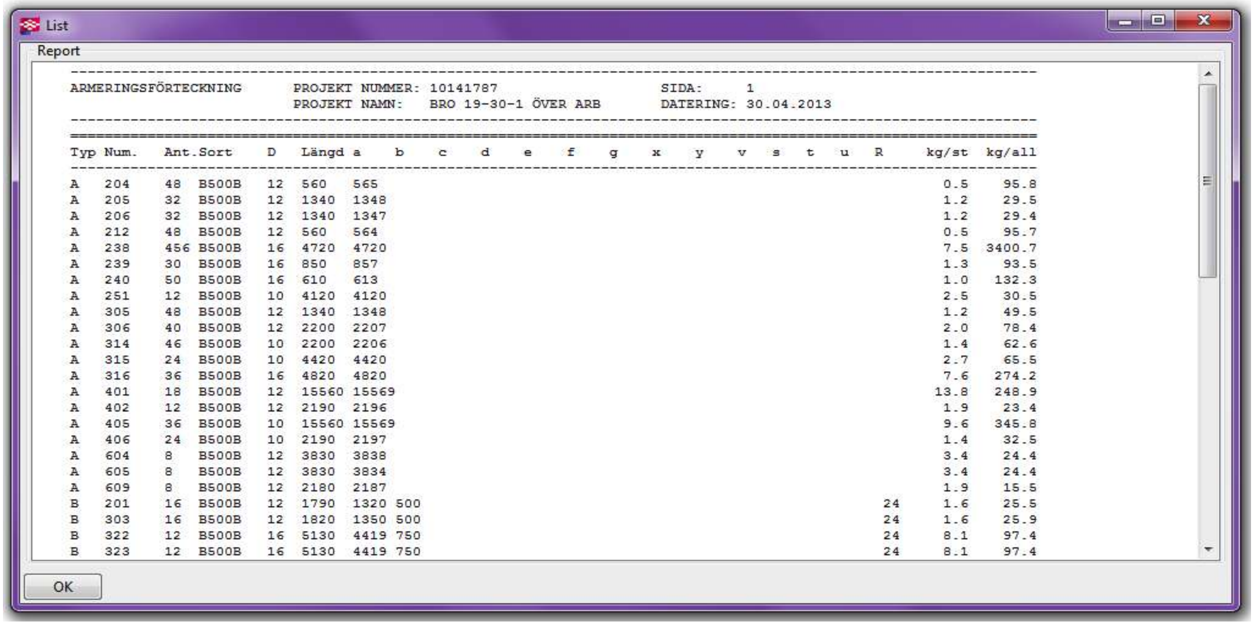
The model was used with ease to identify the material required along with the quantity, area and dimension specifications. The biggest benefit obtained using the model was the ability to extract area and sizing information (Production Manager, 2013). The model provided an easy way to easily obtain accurate and precise figures for materials to be ordered.

Formwork sizes are normally obtained through making a calculation and estimate based on 2D drawings. A calculation of the area would have to be made using a number of drawings in which to estimate the amount of wood required. The model effectively had all the information of the drawings in one single system, so it was easy to just select the area that was to be formed so that the correct quantity and size of wood could be ordered. This saved a lot time during the ordering processes.

Ordering of the reinforcement also benefited from utilising the model. Like all bridges, the reinforcement in the Röforsbron was complex which challenges the Site Superintendant in making precise estimates on order specifications. Using the model, the reinforcement required for the project was selected and extracted into a report file that was used to make cost estimates and subsequently sent over to Skanska's purchasing department for order placement. Traditionally the Site Superintendant or Production Manager would have sifted through design drawings to manually identify and register the required reinforcement. This leads to a risk of misinterpreting the data in the drawings, however the Site Superintendent (2013) added that this rarely happens with an experienced worker. Nevertheless, the savings in time to perform the material order using the model have been utilised better on other aspects of the project that add to the improvement in quality.

The Production Manager (2013) also stated that the model in the early stages of the project did not provide any benefit to an improved estimate accuracy for the costing as the model was still very raw in its detail and his inexperience in the handling of the software meant that he required continuous aid from the BIM Coordinator to extract sizing information. However, he strongly believed that now, with the experience he has gained using the tool and the level of detail entailed within it, that an improved estimate accuracy could be obtained leading to savings, something that future projects would benefit from. This requires earlier collaboration of the contractors in the design stage to achieve the best results (Production Manager, 2013).





ARMERINGSFÖRTECKNING PROJEKT NUMMER: 10141787 SIDA: 1
PROJEKT NAMN: BRO 19-30-1 ÖVER ARB DATERING: 30.04.2013

Typ	Num.	Ant.	Sort	D	Längd	a	b	c	d	e	f	g	x	y	v	s	t	u	R	kg/st	kg/all
A	204	48	B500B	12	560	565														0.5	95.8
A	205	32	B500B	12	1340	1348														1.2	29.5
A	206	32	B500B	12	1340	1347														1.2	29.4
A	212	48	B500B	12	560	564														0.5	95.7
A	238	456	B500B	16	4720	4720														7.5	3400.7
A	239	30	B500B	16	850	857														1.3	93.5
A	240	50	B500B	16	610	613														1.0	132.3
A	251	12	B500B	10	4120	4120														2.5	30.5
A	305	48	B500B	12	1340	1348														1.2	49.5
A	306	40	B500B	12	2200	2207														2.0	78.4
A	314	46	B500B	10	2200	2206														1.4	62.6
A	315	24	B500B	10	4420	4420														2.7	65.5
A	316	36	B500B	16	4820	4820														7.6	274.2
A	401	18	B500B	12	15560	15569														13.8	248.9
A	402	12	B500B	12	2190	2196														1.9	23.4
A	405	36	B500B	10	15560	15569														9.6	345.8
A	406	24	B500B	10	2190	2197														1.4	32.5
A	604	8	B500B	12	3830	3838														3.4	24.4
A	605	8	B500B	12	3830	3834														3.4	24.4
A	609	8	B500B	12	2180	2187														1.9	15.5
B	201	16	B500B	12	1790	1320	500												24	1.6	25.5
B	303	16	B500B	12	1820	1350	500												24	1.6	25.9
B	322	12	B500B	16	5130	4419	750												24	8.1	97.4
B	323	12	B500B	16	5130	4419	750												24	8.1	97.4

Figure 9 - Screen shot of the reinforcement design of one span along with the print out of the specifications of each element that would be imported into an excel file in which to place the order.

Optimisation of the Design

The Röforsbron was unique in that it was a reconstruction. The model was generated using the old original 2D drawings from the bridges' creation in 1919 as well as laser scanning. The drawings formed the basis of the 3D model, which then utilised laser scanning of the bridge to provide quality control of the shell and shape of the bridge in the model (Designer, 2013). The fixings and reinforcement were to be designed from scratch. The model allowed elements of the design to be optimised and tested with a number of variations so that the design would fit first time, effectively eliminating the need for collision control (BIM Coordinator, 2013). The

3D qualities of the model allow for easy rotation of the bridge when designing so that it can be viewed from all angles. This feature gave the designer the chance to test different shapes, sizes and locations of elements, whilst continuously checking whether they collided or provided enough cover where applicable. In small, tight, complex areas of the bridge, this was particularly useful. When questioned about the use of collision control in the model, the Designer (2013) and BIM Coordinator (2013) both stated that this limited the need for collision control further down the design process and the model was correct from the start.

As mentioned, the Röforsbron design was a replica, so there were restrictions as to what could be performed. But the Designer (2013) stated that future projects with freedom to generate designs from scratch would benefit even further from using a 3D BIM.

Quick and Easy Model Adjustment

Changes in the model during the initial design stage as well as throughout the production benefited from quick and easy adjustment of the model. In the initial stages it was very useful when making the most effective design, as the optimisation benefited from the ease at which variations could be plotted and altered.

During the production, the model did not require many alterations as it was very accurate from the beginning, but when alterations were to be made, the adjustments were made with ease. It should be noted that because the design was a reconstruction, it conformed to an already existing design so the usual design changes made on a project were not required. Though the Designer (2013) did point out that for occurring small changes, the use of a 3D BIM for small alterations did not have any significant improved impact on the design in terms of speed and quality of the alterations, but added that the larger changes did benefit from using the model. A reason for this is the interconnection between the elements in the model. As certain details were changed, their intelligent relationship with neighbouring components enabled sections to change automatically. This was utilised in the change in design of the edge beam, as the original drawings used for the model were not accurate. The alteration was simple though as the designer changed one element and the rest of the model updated automatically. As the model is one coherent system, it effectively means that all the drawings are in one place and are visualised as the model. Therefore the changes made to a certain element could be done within the model, as opposed to traditionally sorting through the array of drawings and making the adjustments to each one.

Another benefit of the model that accommodated the improved altering of the model was the ability to make certain sections visible or invisible by the touch of the button. As shown in Figure 10, where the reinforcement in the first span is visible with the concrete and edge beam deselected, the model could be used to highlight areas of interest in relation to other components in an attempt to gain an understanding of the relationships between certain details. This ability to manipulate the model provided a great benefit to workers on-site as they did not require a large number of drawings to match up together to try an understand the tasks to be performed. It was also a great communication attribute, allowing managers and workers to converse with a clearer understanding whilst also being used to present the work to external parties.

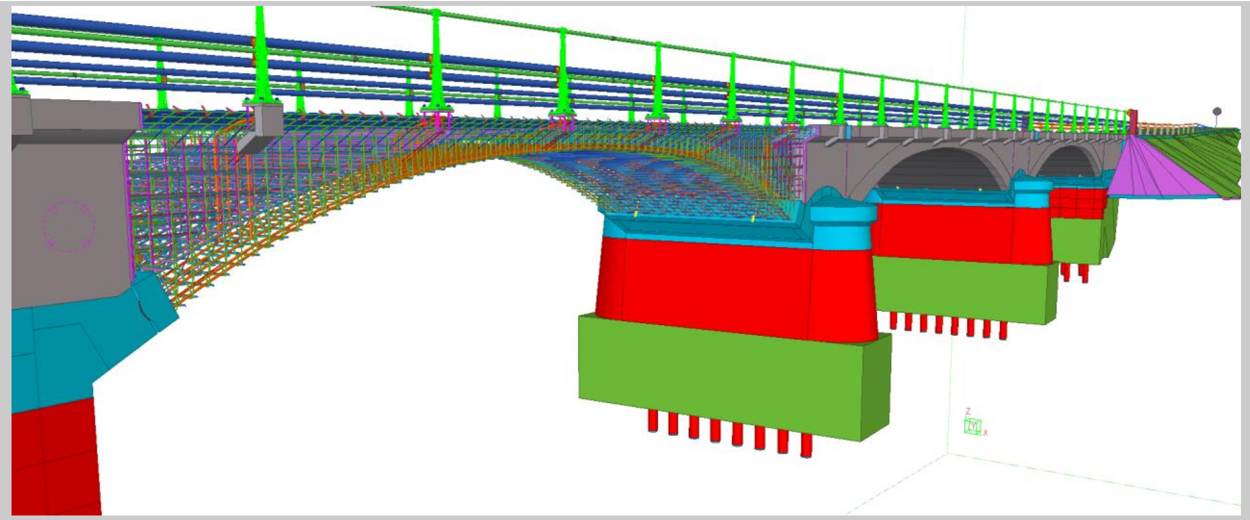


Figure 10- View of the bridge showing the ability to deselect the edge beam and concrete in the first span, whist keeping the reinforcement visible

Smart Ideas

Having the model in meetings has enabled 'smart ideas' to be put forward and utilised throughout the projects delivery (Project Manager, 2013; BIM Coordinator, 2013). When the actors sit down to discuss tasks and the project, the model has been a great tool in which to introduce new ideas and solutions to processes during production. All personnel on-site agreed that having the adjustable data-rich model in front of them allowed for ideas to be put forward and optimisations to be performed during the project delivery. The BIM Coordinator (2013) added that having the model there in a meeting allowed all actors to be on the same page whilst discussing with each other. It effectively eliminated confusion and misinterpretation between the parties. One common problem seen during construction is different parties are discussing the same aspect of a project, but their individual interpretation of that aspect is different. Without a complete model to aid in the talk, different actors think about each element in a different way. This is naturally due to their area of expertise and the way they perceive each task. Subsequently they misinterpret information from the other parties leading to disputes and problems. In the Röforsbron project, the model provided a great means of keeping everyone involved in the project on the same page.

Figure 11 - Meeting in the site office where all parties could view the model together, promoting smart ideas and solutions to specific issues

Smart Organisation

One of the benefits that have been felt by the engineers and managers on site has been the ability to keep the management of files and information in a more organised manner. The BIM Coordinator (2013) stated that having one system where the model and project data is all stored in one place has made it easier to control work files and documents. BIM promotes a smarter way of organising all work on site where less paperwork is scattered around the offices. Linking the model to construction documents is an effective way of tracking data and information associated with areas of the project. The Project Engineer (2013) also believed that the administration work he performed was easier to handle and understand. Therefore he believes he has been more productive in his work.

Easy Transfer of Setting-out Coordinates

The model contained all the coordinate information of the entire bridge. As the total stations were compatible with the GEO software used by the surveyor, the co-ordinates for the task at hand were automatically transferred into the total station for use in setting out each point (Surveyor, 2013). The Tekla model was compatible with the GEO software, which then formatted the coordinates into .pxy or .geo, for use in the total station. This saved time and reduced the risk of mishandling the data. Traditional methods would have required manual inputting of the co-ordinates into the total station. It is another way of brining design information straight into production without risking errors.

Improved Construction Attitude

The BIM Coordinator (2013) believes that BIM has changed the attitude of the workers on site. Having the model enabled the workers to see the 'bigger picture'; to be ready and aware of what is to be performed in the future, as it is easier for them to see. She noticed that the workers and managers were discussing elements of the project way in advance, recognising their sequence of events so they had all the necessary resources and documents ready for when the work was to begin.

One such element was the 2D drawings, as they required them from the BIM coordinator to print in advance, the workers developed a more forward thinking attitude. A point also agreed by the Production Manager (2013). The Project Manager (2013) added that the model allowed the workers to see how elements should be built up so that future problems are identified and addressed beforehand.

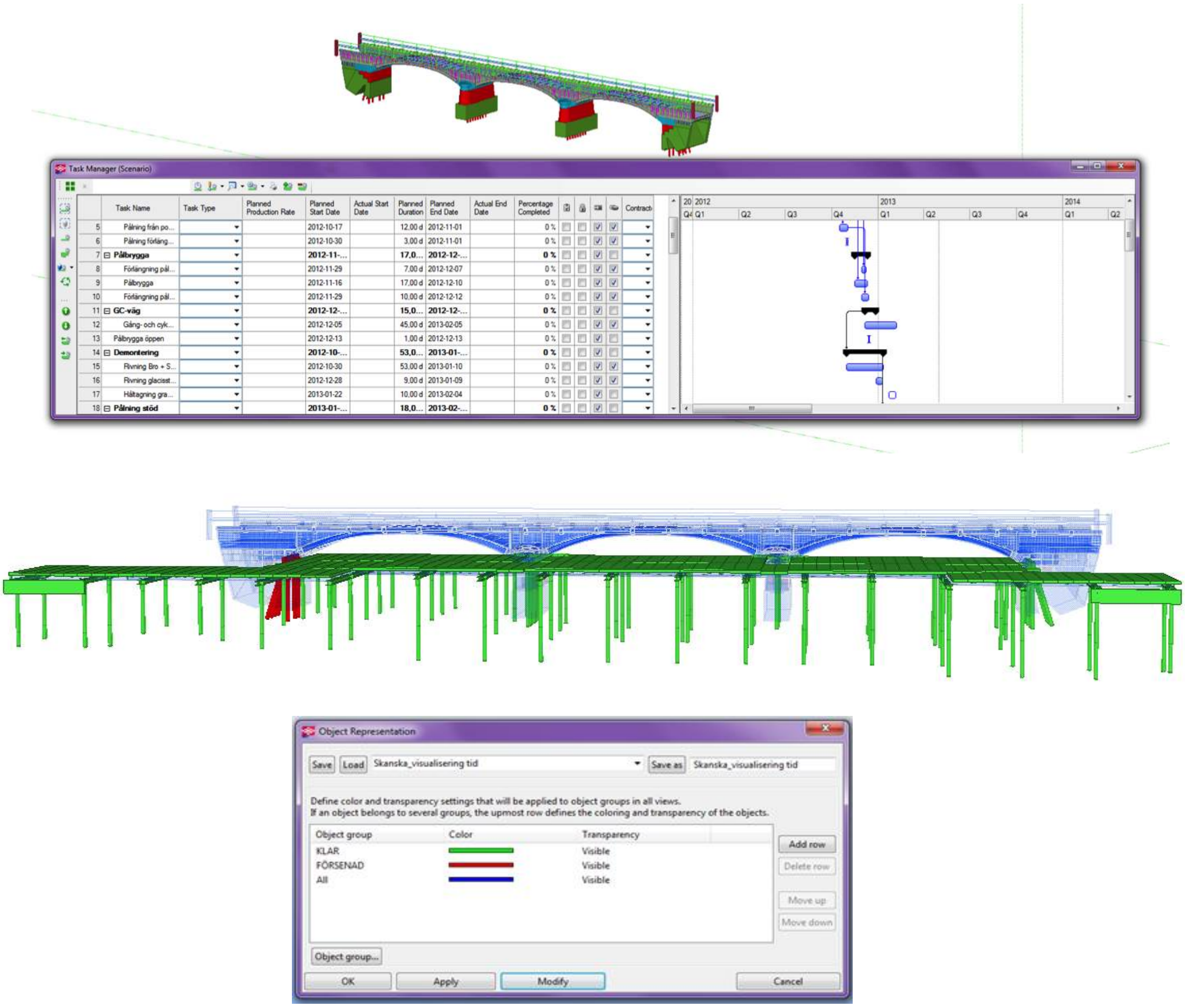


Figure 12 - Overview of the model with its link to the time schedule (Top). Bridge is colour coordinated, indicating what work has been completed and what needs to be done (Bottom)

Schedule and Model Link

Although not a detailed 4D BIM project, the schedule was linked to the model so that each element was connected with a date of installation. Traditionally, the schedule created would not have any direct link to any drawings. In the Röforsbron, the groups of elements were assigned *planned dates* and then *completed dates* so that the work completed could be tracked. These were colour coordinated to the model so that the completed and planned work could be identified in both the schedule and the model. This simple feature allowed for a clearer visual understanding of what had been completed and what needed to be done. In Figure 12 the overview of the bridge is shown with the schedule attached underneath, where each group of elements is assigned planned start and finished dates. The lower image shows the visual progress of the bridge, with green sections marking completed works and red sections marking delayed works.

4.2.2 Under-Utilised Features of 3D BIM in the Röforsbron

Collision Control

The collision control feature of BIM is one that is commonly highlighted as a significant advantage when designing structures. However, its level of use seems to be rather ambiguous. As stated in the earlier benefits, the model allows for objects to be optimised and checked during the initial design stage so the numbers of potential clashes are reduced significantly. Nonetheless, there was no strict schematic collision check on the Röforsbron model, either manually or automatically. The same outcome was reported in a neighbouring Skanska project – Slammertorp. It was found that the users were unaware how to perform the task.

For this reason, the paper considers ‘collision control’ as a specific user action performed on the model and is regarded as an underutilised feature of BIM in the Röforsbron

Site Layout and Logistics

In the Röforsbron project, the model was utilised to generate the position of cranes, temporary structures and walkways as well as delivery locations. Traditional methods of design use the 2D drawings to generate APD plans of the site to show location of safety equipment and fire escapes. Figure 13 shows both the 3D BIM site layout that includes the whole bridge model (top) and the 2D APD plan that was also used on site (bottom). The model allowed a comprehensive design of the layout and logistics during the project, but is something that is also capable on 2D drawings (Site Superintendent, 2013; Production Manager, 2013). It was inconclusive as to whether the 3D BIM really provided a marked improvement to the setting out of the site, but including all the site features into one model with the actual bridge design is not common and could have provided benefits in other aspects of the production. It should be noted that no problems during deliveries and logistics took place, which could be attributed to a comprehensive site layout model.

The Production Manager (2013) believed that on more complex projects, this capability would be hugely beneficial, especially when there are numerous trades on-site as well as construction work taking place at various locations on the site. He points out that the model can be used to highlight events that take place so that deliveries and logistics can be organised accordingly during the whole production phase. The model can also be linked to each material delivery, a scheme currently being developed by Celsa Steel.

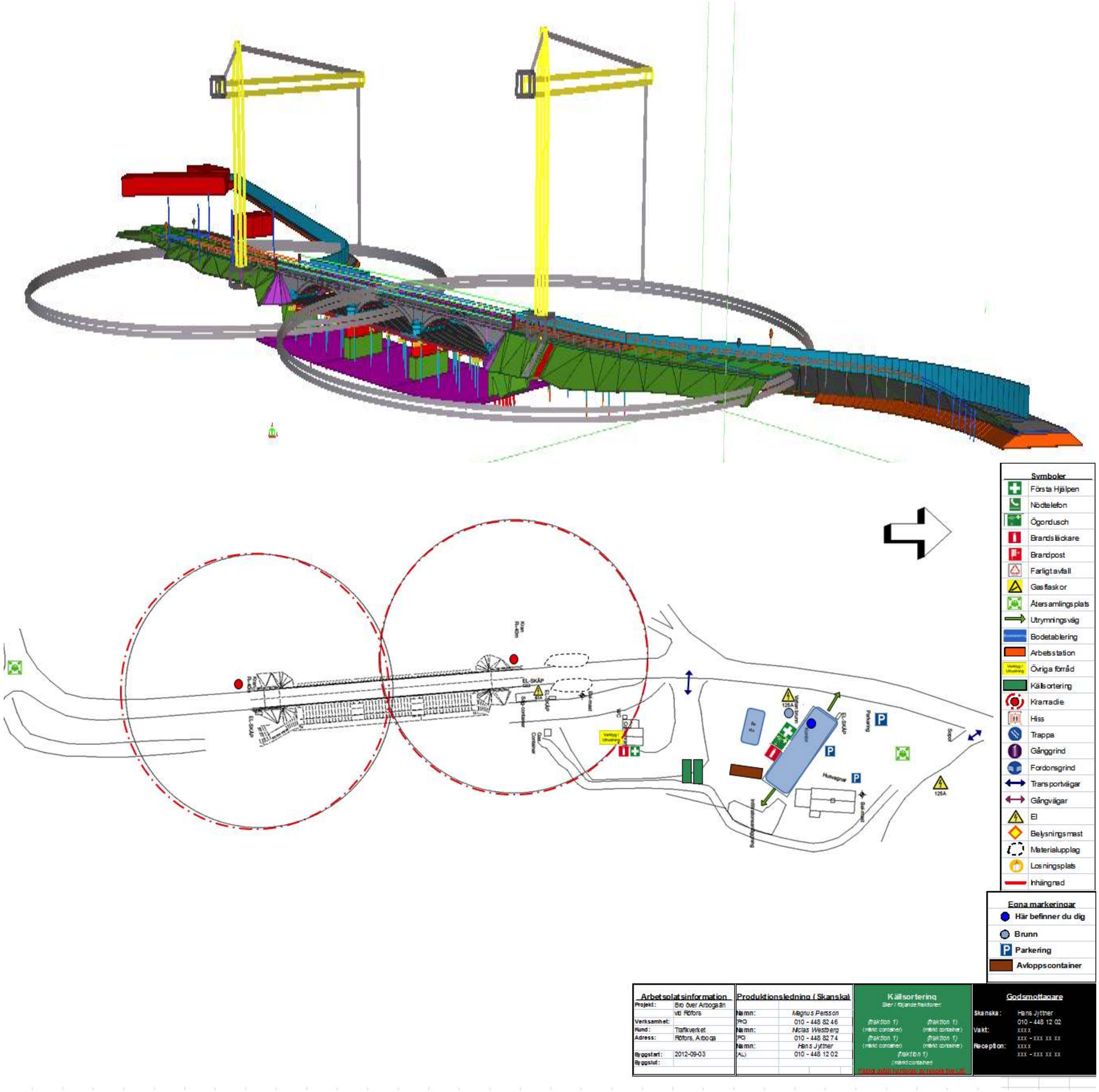


Figure 13 - Site layout overview of the Röforsbron in a 3D BIM (Top) and represented as the APD plan on a 2D Drawing (Bottom)

4.3 Problems Encountered During Production

During the production phase there was only one reported problem registered that affected the flow of construction.

Steel Reinforcement Material Order

An order for the reinforcement was placed which included the quantities and sizes for the C-bars to be used. The model was the source of material quantity and specifications. As part of the normal ordering process, the Skanska personnel on-site identified what bars needed to be ordered and sent the model and specifications required over to the Skanska purchasing department who in turn place the order with the steel suppliers in Poland.

The problem occurred at the Skanska Purchasing department, where there was a BIM software compatibility issue. The factory machines with the Polish steel supplier were not compatible with the IFC Tekla model software, which instead required an XML file. Therefore the Skanska purchaser had to manually input the Tekla model data into an XML file that could be read by the machines at the Polish steel suppliers. However, when inputting the C-bar specifications into the XML file, the purchaser misread the model and inputted the incorrect information, from which the supplier then fabricated the steel. The incorrect steel C-bars arrived on site at Röfors that were later noticed to be incorrect. Fortunately, the mistake was seen early when some of the workers went to check on another element of the project only to notice that the steel bars were wrong. The tradesmen onsite all agreed that they were lucky to identify the mistake a significant time before the reinforcement was to be used, so the new order was placed and arrived before the installation was planned.

After the problem occurred, Skanska decide to explore local steel suppliers that work with Tekla software. Subsequently they contacted Celsa Steel, a supplier situated in Västerås, Sweden. Celsa operate with BIM software to fabricate the steel reinforcement and were able to utilise the BIM model created for the Röfors to digitally extract the material quantities and dimensions with no further problems.

Analysing this problem, it can be seen that the model was not to blame for the problem as it was due to human error. However it could also be argued that BIM did not prevent the problem from occurring. The simple solution to this is to avoid the manual handling of the information, feeding the data from the model directly into the machine of fabrication.

4.4 Interviews

The initial interviews presented in appendixes A4 – A7 on site were performed during the early stages of the production. Because of this, the level of experience of each actor utilising the model at this point varied. The skilled workers were in the first few days of using the tablets. The follow up and all other interviews shown in appendices A8 – A12 were performed towards the later stages of the production, all of which were of both a structured and unstructured nature. The following section further adds opinions of personnel from the Röforsbron that have not been documented previously. The main focus of the questions is around the Röforsbron, but issues concerning other areas of construction are raised.

Technology Experience

It should be noted that all of the skilled workers on-site are extremely experienced, with all except one possessing at least 20 years' experience. One of the first questions asked to the workers was also to ascertain the level of technology experience they have concerning use of modern computer telephones and hand held devices, as well as the use of technology elsewhere in their lives. I believed their experience with technology would have an effect on their ability and understanding of using the tablets and BIMSight. The tradesman all varied in their use of technology in their lives, but it seemed to have little effect on their adoption of the use of the tablets. All individuals struggled and succeeded with the tablets to the same degree. Thus, my initial thought on 'techy' individuals finding the tablets more effective were not true.

Common Construction Problems

When discussing current problems in construction, reinforcement was a common theme in responses (Project Engineer, 2013; Site Superintendent, 2013; Tradesmen, 2013). All respondents acknowledged it as a common problem in current practice, however a number of other problems were also identified as significant. Carpenter #1 (2013) also pointed to planning issues that commonly affect the smooth flow of work, while Carpenter #2 (2013) added that delivery problems often disrupt the flow of work. Both of which are connected to a certain degree as the deliveries are based around the planning schedules. The Production Manager (2013) and one of the Tradesmen (2013) pointed out that wrong or out dated information cause work to be redone as it is installed incorrectly.

The Designer (2013) feels that communication between contractor and consultants is a big problem. Design issues are discussed but the communication to show the designers how a problem should be fixed is lacking. The Surveyor (2013) also believes that communication issues are the source of a lot of problems as information is commonly not passed on, or is lost. When asked about how BIM could benefit this issue, the Production Manager (2013) stated a 3D BIM will make it more achievable to bring in contractor knowledge into the early stages of a project as the model is a more useful form in which to communicate and discuss design decisions.

The Effect of the 3D BIM

All the tradesmen on site except one found the tool to be very useful, but their lack of experience and training means that they didn't feel they had experienced the true benefits. Because of this, they all agreed, including the Site Superintendent (2013) that more training and use of the model is required so that they become familiar with the tool. They believed the next project would be easier for them as they would be accustomed with the handling of the model. One of the 20-year old tradesman with limited experience arrived on-site midway through production. He felt that the 3D BIM helped him adapt to and understand the project much "easier and quicker" as he was able to get a clearer overview of how the bridge would look. Having all the construction details in one system with an overall model made it very easy to visualise his job from the beginning. This attribute is hugely beneficial, as projects frequently have new personnel coming in and out. The ability for workers to 'slot-in' to the production without the need for a break-in period would only improve the overall performance of its delivery.

One key point raised by the Tradesmen was to maintain the use of 2D drawings. This aspect of production is key for all of the workers as it is the basis for which they gather their information. Carpenter #1 (2013) and Carpenter #2 (2013) added that the model should compliment the traditional 2D drawings, not replace them. One problem with the Röforsbron model was that the tradesman could not just extract 2D drawings directly from the screen. They would have to inform the BIM Coordinator of the drawings they required in advance for her to manually extract and print the sections of interest.

When asked about the effect of BIM on stages of the production, its effectiveness was considered limited in various aspects. Although the Ekonomi indicated that the installation of form stands was performed under budget, the skilled workers did not credit those savings to BIM. The same was agreed for the formwork, where BIM could not be credited for its savings in cost. However they all agreed that the 3D BIM could be credited to the improvement in cost of the reinforcement work. The BIM Coordinator (2013) concurred with this finding that the Röforsbron definitely benefited in the reinforcement stage through the use of a 3D model and adds that its benefit would be felt in future smaller and larger projects, especially so in larger developments. When asked about the change in quality of work performed, they found it difficult to assess whether BIM had improved it. It should be noted that having a workforce of such experience would usually lead to a finish of high quality.

Model Design

Discussing the matter with the Designer (2013), the Röforsbron design using the BIM software did take more time to produce, but this was due to the unknown level of detail that was required in the model when beginning and how it should be represented in it. She went on to say that the alterations made during production were fewer, adding that some of the larger alterations benefited from using the 3D BIM as it utilised its ability to change the model as a whole rather than working through a number of drawings, making adjustments to each one.

The thoughts of the Designer (2013) and the Production Manager (2013) are of significance, who both stated that collaboration of contractors and designers early would make a huge difference to the project delivery. The Designer (2013) acknowledges that problems are identified, but states that input from the contractors is needed to address *how* to deal with the problem. A sentiment echoed by the Production Manager (2013), who believes one of the drawbacks from the Röfors project was the lack of collaboration with WSP during the early design stages and feels this project and future developments would benefit immensely from the collaboration. He added that the introduction of even just one contractor in his type of position would provide a valuable resource to the designers in the early stages.

When discussing future development of model design with Trafikverkets Project Manager (2013), he explained that standardisation is the key to developing correct, accurate models. Responsibility issues could then be minimised with a set of design rules and requirements. However, he believed that this would take anywhere from 10-15 years to build up and put in place.

Level of Resources

A point that was raised commonly between all the parties was the extra resources that were available to the project. Trafikverkets' Project Manager (2013) explained that the project was very much a learning exercise, so that there were no strict budget or resource requirements stipulated in the contract. The aim was to allow money to be used on areas that would be considered of interest and is the reason why the project contained such a large workforce. Trafikverkets Project Manager (2013) did continue by stating that the resources were there for a reason and not just to "fill a chair". Thus, the money spent was to improve the performance. The Project Engineer (2013) followed this with a belief that having just one BIM Coordinator was beneficial and that anymore would have actually made it harder to control information.

The Production Manager (2013) said than in a usual project of this size, the work force would probably consist of the Site Superintendent and the Tradesman on the job full-time. Maybe the Project Engineer would be there close to full-time too, or at least for parts of the project. His Production Manager position as well as the Project Manager and Surveyor positions would be part time, with a number of other projects simultaneously using their services. A BIM Coordinator would not exist and the Designer would rarely, if at all, be present during production.

This level of resource needs to be considered when evaluating the outcome of the project. The Production Manager (2013) agreed that he felt BIM played a role in the jobs success, but added that it is not just down to the 3D BIM. The extra resources were certainly influential. The BIM Coordinator (2013) added to this by raising the question as to what level of benefit in production was achieved through her presence throughout the project. This raises an interesting point.

Communication

Another benefit felt by all personnel onsite is the effectiveness of using the 3D BIM in meetings on a screen, to discuss the work that is to be performed and identify any hurdles that need to be addressed. The model enhanced their ability to detect any problems before they went out onto site, so that the issue could be dealt with before any work began. Common practice is to first see the problem once the work has begun and then deal with it out on-site, all of which lead to rework and delays (Carpenter #2, 2013). All project participants found this handling of the model particularly effective as it helped in planning the workforce and the tasks on-site as well as communicating between each other.

The Designer (2013) stated that the communication between the contractor and the consultant was very quick due to the fact that they were both on site regularly. Nonetheless, communication and decisions usually take a lot longer on traditional projects, whilst the continued interaction between the parties on the Röforsbron allowed for quicker decisions and changes to be made which saved time and money (Designer, 2013). She added that unfortunately this would probably be too expensive in a traditional project.

Contract Specifications

A Design-Bid-Build contract forces a very autonomous approach to production, which commonly leads to a lack of constructability in the design. Trafikverkets Project Manger (2013) explained that there was no stipulation for WSP to generate a model that considers construction practice. Also explained by the Designer (2013), who states the design is based purely on the old bridge and its drawings with no consideration for how it is to be built. The model however was to be handed over complete, with details down to the last bolt included. Skanska were then to perform the production with a willingness to test new BIM ideas (Trafikverket Project Manager, 2013).

Although the production phase did adopt a rather collaborative approach, there was no collaboration in the design stage between WSP and Skanska. Trafikverkets' Project Manager (2013) hopes that this mentality will begin to change and that the Röforsbron project will provide a springboard to a more collaborative approach. A 3D BIM can aid in this collaboration, as it is believed to facilitate a better way of communicating and planning early on (Production Manager, 2013).

5 Analysis

Having collected findings from the Röforsbron project as well as reviewed literature and studies on BIM, the effectiveness of BIM in the production phase is discussed. In the following sections, the key aspects of BIM in bridge construction are analysed and concluded based on the findings from the report.

5.1 Improving Constructability Through Detailed Design

One of the key points to come out of the findings from the report is the need for a good, detailed design. The production of the bridge can only be as good as the information available to construct it. This means having a detailed, accurate design that contains all the information the contractors need to build. This should be the case through whatever means of data supplied, whether through 2D drawings, building information models or construction documents. For lack of a less offensive term, the phrase 'crap in, crap out' is one that describes the importance of design well. If you provide a design that lacks the details required to build efficiently, the production process will suffer as it tries to deal with the shortfall in information.

With arguably two of the most important and influential parties in the project both acknowledging the same problem (Production Manager, 2013; Designer, 2013) and backed up by the other workforce personnel and the wide range of literature on the subject (Hammarlund & Josephson, 1991; Motsa *et al.,* 2007; Koskela, 2000; Burati, 1992), the solution would seem clear. Spending more time and resources in the early stages together would solve most of the current problems affecting the production performance. The gap in the designers' lack of constructability knowledge needs to be filled by the invaluable construction knowledge of the contractors. Bringing these two elements together will allow for a more detailed design from the beginning, allowing better plans to be implemented which will surely breed success. As pointed out by the Production Manager (2013), it does not necessarily require a large number of contractor personnel early in the design stage for it to be successful, but rather just one individual in his position to discuss constructability issues intermittently during the design stage. It is a small resource that can certainly be spared by any organisation. By doing so, the design can be generated with a stronger emphasis on *how* to build and not just *what* to build.

With this focus on *how* to build, the construction processes and methods can be designed for, effectively generating a construction specific 'IKEA Manual'. Producing a design that details what order elements should be installed would eliminate some of the misinterpretation and handling of designs. However, the question of responsibility is sure to be raised. Who would hold responsibility for these 'construction manuals'? The client would need to state that the design should consider construction methods. However, this decision would be eased with a set of standards and codes that the designer would adhere to. Thus, standardisation is an important factor in improving constructability.

Addressing this area of a project is key to providing the foundation to its success. The mentality in the industry is a big cause for the lack of action in this regard. I believe that certain actors find this level of detail in the design unnecessary for their job, but they need to recognise that the detail is not necessarily for their own use and what may seem useless to one actor is fundamental to another.

The only way to spend more time and effort in the design stage is for shareholders in a project to agree to this, even demand it. This action starts with the clients. The documented cases of very successful projects adopting a more intensive design period should provide evidence enough of its benefit (Chelson, 2010). Although the Röforsbron adopted a collaborative approach during production, it was again another case where there was no collaboration between the contractors and designers through the design stage, which makes you wonder what the possible improvements in performance could have been had that been the case? Figure 14 is designed to highlight how introducing more resources and effort into the earlier and cheaper design stage will result in a reduction in the expensive production stage, yielding a lower total cost.

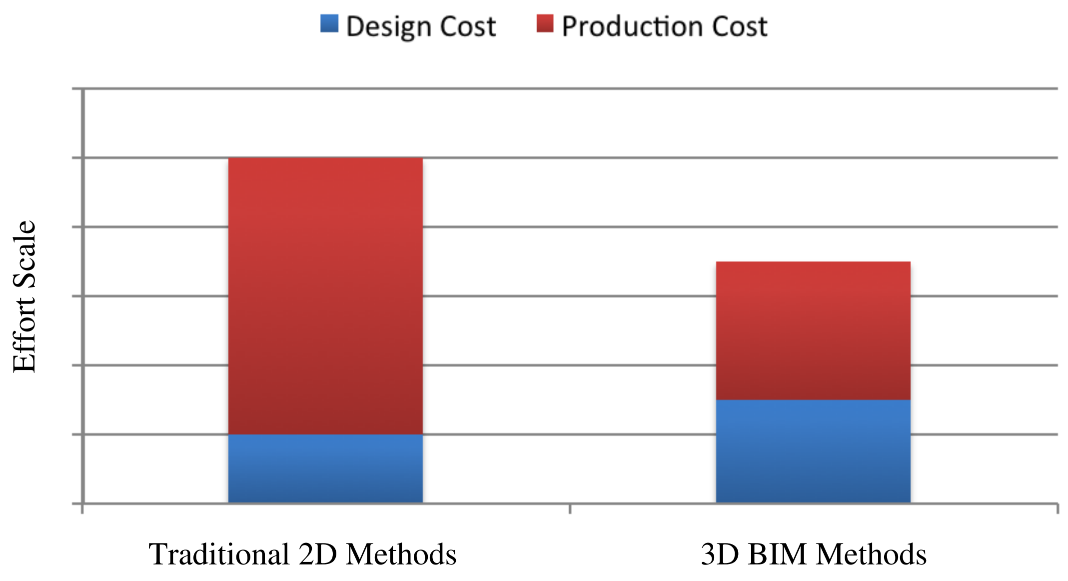


Figure 14 - Graph to show how extra effort and resources in the design stage will yield a lower production and subsequently total cost

The Röforsbron backs up previous documented projects showing that a 3D BIM can facilitate a more detailed and 'correct' design from the initial stages, highlighted by its fewer and easier alterations during production. Yes, it did take more time to design, but this was due to the level of detail built into the model from the start that clearly had a positive effect during the production (Designer, 2013). It would be common for the industry to focus on the negative aspect of this factor by highlighting the extra time spent in the design. However, it is clear that this has benefited the production where fewer alterations and no rework have been recorded. This culminates in a production work that 'fits first time', which should be the goal of any project. A 3D BIM provides the platform for these issues to be addressed and can provide a source for knowledge and experience to be stored. As believed by the Production Manager (2013), a 3D BIM can bridge the gap for a more collaborative approach through better and clearer communication capabilities.

5.2 Tackling Reinforcement Problems with 3D BIM

When looking to reduce waste in production, there is little doubt that reinforcement is the source for many of the problems and rework performed during production (Production Manager, 2013; Site Superintendent, 2013; Project Engineer, 2013). Many of the reports highlighted in the theoretical chapter of the paper confirm this belief and attempt to measure it by specifically studying the levels of waste during the reinforcement stage of production.

The most valuable aspect of BIM to the Röforsbron project was its benefit towards the reinforcement aspect of the production. The tradesmen on-site all agreed that BIM had the largest effect on that aspect, though placing a figure on to the direct savings in time and cost were not possible. However, they were in no doubt that the ability to see the complex reinforcement design in 3D provided a significant benefit, where they were able to get a clearer understanding of where and what reinforcement was to be installed. The features of a 3D BIM allow for easier and quicker identification of issues in the design before they go onto site, thus preventing incorrect work to be performed and then fixed. This was a commonly realised benefit during the Röforsbron production, which eliminated any rework and therefore wastes. Again, placing a figure onto such a benefit is not possible as there is no accurate way of calculating one, but it is clear that savings would have been considerable and more importantly, would most likely not have been spotted using 2D drawings (Project Manager, 2013; Site Superintendent, 2013).

This again falls inline with the 'fit first time' philosophy as the 3D BIM gives the workers a better chance to identify and address errors in design before entering onto site, so that the work they perform is right the first time they do it. The benefit of such a characteristic will aid not only larger projects but smaller ones as well (BIM Coordinator, 2013). Reinforcement in bridges is complex in any magnitude of project.

Generating a detailed reinforcement design is the foundation to producing the work on-site without problems. Designing 2D drawings allows for small details to be 'hopped over' as the drawings will be considered acceptable even with those missing pieces (BIM Coordinator, 2013). As the 3D model requires a significant level of detail, it promotes a more detailed design avoiding those missing elements that can be skipped using 2D drawings.

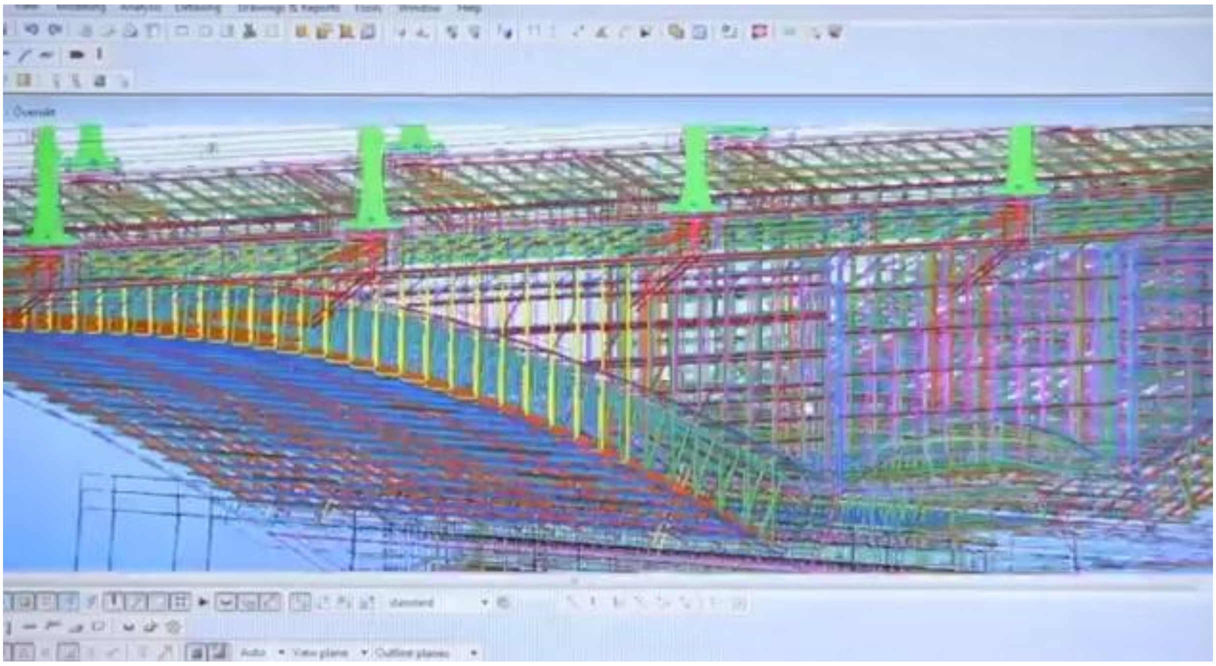


Figure 15 - Screenshot of the complex reinforcement in a section of one of the spans. Notice the variations in reinforcement colour to aid in a clearer view

Although an attribute of BIM not utilised during the production of the Röforsbron, the benefit of ***Prefabrication*** is clear. Identifying sections of reinforcement suitable for prefabrication in 2D drawings is incredibly time consuming. A 3D BIM though, provides a simple and effective way of highlighting reinforcement cages that would be suitable for prefabrication. Especially in bridge construction where reinforcement designs are incredibly dense and detailed as shown in Figures 15 and 16, the ability to prefabricate these sections would provide undoubted savings in time and cost as well as improved quality. Producing an element that can fit directly into its installation position would erase the waste in material generated from on-site sorting and cutting. All of these lead to an increase in productivity on-site (Simonsson, 2008). Prefabrication also promotes the 'fit first time' ethos, where the materials are all ready for installation as soon as they are delivered minimising the amount of manual handling of information and materials. Because of the design in the Röforsbron, the possibility to prefabricate certain elements was not possible, but was considered.

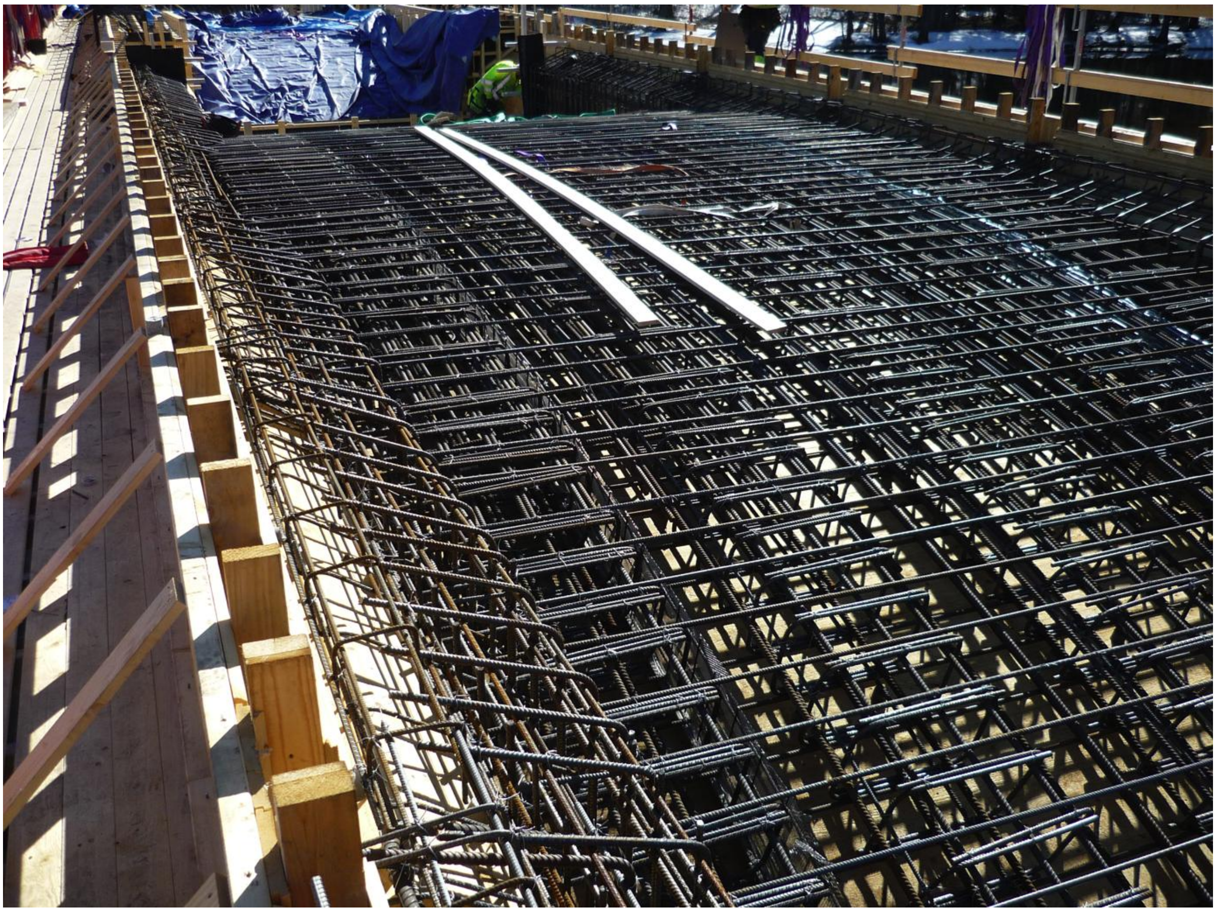


Figure 16 - Complex reinforcement in one of the spans in the Röforsbron

5.3 The Power of Visualisation

Studying the benefits obtained during the production phase at the Röforsbron, the connection between the majorities of them is the users ability to obtain a clearer understanding through the visualisation of a data-rich 3D model. Whether the benefit was designing the site layout, communication in meetings, incorporating new workers, optimising the design or having a more future-thinking attitude, the 3D BIM visualisation capability is the source to all of these benefits.

Putting a value on the benefit of this characteristic seems impossible. The Tradesmen (2013) on-site at the Roforsbron all agree with this statement. They stated that the uniqueness of every design and project is what prevents such a figure to be calculated. Nevertheless, it is without a doubt the ability to visualise the overall project that offers each individual the ability to understand and plan their work, whilst offering a communication platform that keeps participants on the same page, discussing issues with the most useful visual aid. It provides a positive effect to so many aspects during a project delivery that placing a quantitative figure on its value cannot be done. However, its positive effect can be seen through its budget performance.

The delivery of the Röforsbron has shown that extra resources in a production phase can play a key role in improving the efficiency of decisions and communication. Whether these resources are essential in improving production of future works is another question. It is yet to be seen if this will be the norm for forthcoming works. A 3D BIM however will accommodate this level of collaboration during the whole project as well as the production. The Designer (2013) pointed out that it was important to go on-site to see how the real construction is performed. Having a 3D visual representation of the model to discuss and communicate with will aid the designers in developing their ability to understand construction processes. They can hold a model capable of virtual construction that can be used to communicate with contractors and really begin to appreciate how works are performed. This is not an immediate result, but over time the 3D BIM projects will develop designers' knowledge into one of a more holistic nature.

5.4 3D BIM to Reduce Risk

When undertaking tasks during any project, there is always an element of risk involved in practices performed and decisions made. All of these are based on knowledge of the exercise and previous experience performing these tasks. Having an accurate 3D BIM that contains all the necessary construction information will provide a means in which to reduce the risk of performing wrong actions.

Looking at the Röforsbron, you have a project that contains some of the most experienced personnel in bridge construction. With this quality of workforce, there is therefore a smaller risk of mistakes occurring during production. However, with all tasks in construction, the more manual reading and transferring of information performed, the higher the risk of misreading and misinterpreting information. A point highlighted in the SBUF report by Engström *et al* (2011).

An example of mishandling information occurred during the production of the bridge, where due to the lack of interoperability, data from the model required manual input into a computer that resulted in the wrong material order. Had the material order not required the manual transferring of data, I highly doubt that any problem would have occurred. It is not to suggest that the manual handling of information will result in mistakes, but the chance of mistakes occurring are more likely. A point expressed by Chelson (2010), who concludes that BIM does not solve problems, it helps prevent them.

The features of the 3D BIM facilitate orders and deliveries to arrive on-site, ready for installation. Using the model to generate an effective site layout and plan whilst producing a detailed design so that materials, especially reinforcement can arrive pre-shaped will again limit the amount of manual handling required. Placing the materials directly into place falls into the 'fit first time' philosophy, again reducing the risk of any errors occurring during production.

5.5 The Intangible Benefits of 3D BIM

What seems to be clear when analysing the effect of a 3D BIM on production is its immeasurable influence on the project as a whole through various aspects. The specific benefits seen in the Röforsbron that were presented in the previous chapter prove exactly that. Its effect on communication, understanding, management and its ability to generate smart ideas provides an invaluable benefit. Obviously these will change from project-to-project as different issues and discussions arise during the course of delivery, but what these benefits offer is a greater ability to improve other areas of the production processes that currently suffer. Although not always easily acknowledged by production employees, the advantages that the 3D BIM provides to planning, organisation, communication, etc. plays a significant effect on other areas of the work processes.

> *Take this case for example. In a 10-hour day the site super-intendant places a reinforcement order that would take him 6 hours using 2D drawings where he would identify and then calculate the quantities and specs. Then occupy the other 4 hours by rushing through the plans for the following day. Using a 3D BIM he places the order in 4 hours where he would have saved 2 hours on that task, utilising 6 hours for more detailed, thorough planning. Although the length of the day has not changed, the influence of effort spent on the tasks has shifted so that more time can be spent on the important planning. Without acknowledging any time savings himself, he has spent more time to improve the quality and detail of the plan that the production would benefit from.*

What BIM provides is a means of improving the quality of work that currently suffers and although not necessarily improving the overall project duration, it enables the managers, engineers, surveyors, etc. to focus on details in tasks that commonly cause problems, improving their delivery so that errors do not occur in production. Speeding up usual practice that is maybe not at risk of miss handling, but is time consuming. A 3D BIM can accommodate this improvement in quality design and planning. It also leads to the action of quicker, correct decisions. This improvement in quality combined with the more forward thinking attitude generated from the model, I'm sure will yield improved production performance.

5.6 BIM improvements

As BIM is early in its life development, there are questions constantly being asked about the handling of the tool and its process as to how it can be improved. In an effort to drive the growth of BIM, the question presented by Malmkvist (2013) is "*what do we have, and what do we need?*" This is a crucially important mentality in driving BIM in the right direction, as the nature of such technologies, when not managed systematically, can lead to a solution that provides no further benefit to the industry. BIM has so many attributes and possibilities that it is important to look for solutions to the problems that are currently occurring and not 'fixing something that doesn't need fixing'.

Improve Software Inter-operability

One of the problems that have stopped BIM from achieving its full potential in the Röforsbron, as well as many other projects is the compatibility between software packages. The inability of software to communicate and transfer data between each other makes the flow of construction especially difficult to achieve. Interoperability issues were highlighted in the material order problem in the Röforbron, where it was the software's inability to read data of one another that forced the manual miss handling. Once software packages are capable of working collaboratively, the smooth flow of construction information can offer the potential to optimize all aspects of a projects delivery. This should not just be internal within an organisation, but between all parties in the industry from architects, designers, contractors and suppliers. Current efforts to address this problem are being made by buildingSMART who are developing "a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows", known as OpenBIM (buildingSMART, 2013)

Easily Obtainable 2D Drawings

Although the Röfors model provided a very detailed and effective means to view the design, it required the manual generation of 2D drawings of certain elements by the BIM Coordinator. The entire Tradesman (2013) on-site including the Site Superintendent (2013) agreed that to improve the handling of BIM, they should be able to extract 2D drawings of whatever section they require without the need to inform the BIM Coordinator in advance. This benefit would improve the flow of work with potential time and cost savings.

Working Collaboratively on a Model

Facilitating the ability to work in unison on a model would provide great benefit. In the Röforsbron project the model could only be worked on by one party at a time and then sent on to be worked by another. By having an open model, where a number of parties could work simultaneously on the model would solve communication issues and combat time restrictions. It would be especially useful in larger projects where a number of trades could design on the same model at the same time. Chelson (2010) points to the difficulty in collaborating different trade designs using 2D drawings, where a 3D BIM has the capability of achieving this.

Standardisation

One of the key areas of development required in the BIM world is the need for standardisation. One of the hurdles in BIM's effectiveness is it that there are no strict guidelines and rules in which to design the models. The models are built to Euro code standards, but there are no measures in place in which to design for constructability. In order to obtain the full benefits of BIM there needs to be rules in place for the designs to facilitate the construction process. Unfortunately, this will take time with estimates of around 10-15 years expected (Trafikverket Project Manager, 2013).

Building up a database of BIM projects and construction elements from each project will advance this solution and will only benefit future projects. The database would provide a source to extract standardised building elements from, vastly easing and improving the BIM design process. All of this will encourage repetition, which is an important factor in improving performance. Again, this will take time, as these elements need to be saved from each project, whilst also developing these features from external sources. As more projects are completed, the more can be learnt and the larger the database of design features stored.

Delivery Coordination

As pointed out earlier in the empirics, the ability to coordinate, track and sort deliveries would eliminate a number of the logistical issues currently affecting work practice. The idea by Celsa Steel to colour code and scan deliveries from loading at the factory to unloading at site would be very useful. The deliveries would be linked to the model so that the location and delivery specifications of all materials can be easily identified in the model and subsequently found on site, eliminating the need to spend time and resources searching and sorting through materials. Scanning materials from factory to delivery would increase the quality control of the production and provide a smarter management of the delivery process.

6 Conclusion, Discussion and Further Research

6.1 Conclusion

How can a 3D building information model be used to improve the production phase performance of a bridge project?

It can be concluded that a 3D BIM can facilitate a more constructible design buy enabling and somewhat forcing a more detailed design from the start. Its visualisation capabilities allow for design errors and installation processes to be established before entering onto site, thus reducing the chance of incorrect construction. 3D BIM can accommodate a better quality planning and management process as opposed to methods used in traditional 2D drawing projects. It also facilitates a more effective means of communication, where parties can discuss with a common understanding, something that seems to be currently lacking in the industry. All of which leads to reduction in waste and an improvement in productivity.

Having followed the production phase of the Röforsbron project for a number of months, the positive effects of a 3D BIM on the project have been evident, although ascertaining precise values to its impact on certain elements has proven to be futile. However, looking at the cost savings it achieved, personnel opinions as well as the smooth flow of work without errors or disruptions, it can be strongly argued that a 3D BIM did improve the production phase performance.

Looking at specific tasks in production, a 3D BIM has the most significant benefit on the reinforcement aspect of a structure. The ability to generate an accurate, detailed, correct design through optimisation and clash control early on set's a solid foundation for its successful installation. Add to that its visualisation capabilities and the workers are presented with the best possible chance to install reinforcement that fits first time.

What methods can be improved in terms of handling of BIM information on the work site?

To speed up and ease production, it is suggested to allow 2D drawings to be extracted directly from the model by all actors, so that the BIM Coordinator should not be required to manually draw up the 2D sections.

Aim to perform tasks with out any, or minimal manual handling of information. Reducing the handling of data will reduce the chance of problems occurring. This obviously requires the inter-operability of software, which is a process that needs to develop and will take time.

> *How much time, resources and money can be saved with the use of a 3D BIM in the field?*

I believe it is impossible to accurately establish how much time, money and resources can be saved from the use of a 3D BIM, as it influences so many areas of the construction process that there is no way to put direct values onto its effect. The experience of the workforce and the level of resources are just two of a number of variables that can affect the efficiency of production and further add to the immeasurable nature of 3D BIM. However, it can be concluded that a 3D BIM can save time, money and resources if utilised effectively.

As mentioned previously, it is the actions and decisions in the design and planning stages that affect the production performance. Therefore, those stages should be performed in detail utilising the model.

> *What are the possibilities and potential of BIM tools for the future based on what we see in the Röforsbron project?*

Without a doubt, BIM is a tool that has the potential to improve the delivery performance of future bridge projects from start to finish. As the tool is used further, users will become more proficient in it's handling and be far more effective in its use. The Roforsbron didn't utilise all the beneficial features that the 3D BIM had to offer, as it was unknown to most of the workforce, but much has been learnt from the project. I believe BIM can be beneficial to projects of all magnitudes, with larger complex constructions achieving the greatest benefits.

Its ability to facilitate detailed planning I believe will offer a huge benefit. As shown in Figure 1, the 4D and 5D capabilities of the tool promote an optimised plan of daily works and personnel to achieve maximum productivity. It will also offer a better visual means at which to manage and keep track of works. BIM can be used as a means of virtually constructing projects before actually going into production, a so-called 'Sim-City' approach, so that works and problems are considered virtually without having to deal with them in reality where the costs are high.

In order for BIM to develop further, it is necessary to implement its tools into as many projects as possible. As with all new technology, it needs to be used in order for users to become comfortable in its handling and gather further experience and knowledge of its practice.

6.2 Discussion

When examining the findings and conclusions of the report, I feel that the research questions have been answered, supported by strong evidence. Complimenting the findings with quantitative values was an initial goal, but it quickly became obvious that no accurate figures could be calculated. It is apparent that placing values onto BIM's effect on certain construction tasks is impossible. The ambiguous nature of the tool means that it has so many influences onto construction works. Combined with the wide range of varying factors on a project, it makes it impossible to construct direct numerical comparisons between BIM and non-BIM projects. I believe people's expectations are for BIM to directly solve specific problems in construction, which it does to a certain extent. But BIM offers so many direct and indirect benefits to the design, planning and construction of developments that it can revolutionise the whole delivery.

As concluded, BIM can help in improving production phase productivity, but it is not a one-stop solution to all construction problems. What BIM provides is a tool for constructability to be improved. By improving the constructability of a design, production will be leaner as a result, which will lead to improved productivity. There is no doubt that the construction industry has obvious problems entailed within its practice. It is constantly considered the poor performing little brother of the manufacturing industry, but I feel this comparison needs to be put into context before being frivolously thrown about. The two industries are so different, that the comparison should almost be ignored. This is shown through the findings of the report. Initial considerations and a wide range of literature focused mainly on the 'lean production' principles. I now believe this concept is not quite as applicable to the construction industry as first thought. This attention on reducing waste is of importance, but in construction waste takes so many forms that it becomes un-measurable. Instead focussing on the construction practices as a whole and the source of poor productivity is the key to improving overall production performance. That is why focussing on 'constructability' is the key to success.

One aspect of the industry that was raised regularly throughout the duration of the paper was the issue of early contractor involvement. That importance is clear, but it is now time for action to be taken. Understandably contracts act as a major hurdle in this factor, especially in design-bid-build deliveries, but I would suggest that consultants look to employ individuals with a wealth of contractor experience into their firms to aid designers. When delivery methods are not so divided, it should be a requirement for contractor representatives to be involved in the design. These are solutions for the current climate. Further utilisation of BIM and the generation of standards will enhance this cooperation between actors as well as build strong, long-term relationships between organisations.

Project performance improvement is the goal of the industry right now. BIM can definitely provide the tools for this to be achieved but it will require more that that. The industry seems to suffer from a 'make-do' attitude towards its work. Instead of accepting the first solution that becomes available, there should be an effort to continuously optimise and find the most effective solution to whatever problems arise. The thought that optimisation takes time and money is deterring this and is correct, but there seems little acknowledgement of the great benefits this will yield. Innovative solutions will be discovered where time, resources and money can be saved.

With governments around the world already setting industry standard requirements for BIM projects, I envisage that it will develop quickly over the next 5-10 years. The growth figures reported in its use also signify that who ever doesn't transfer to BIM will be left behind in the industry. This includes all actors from architects, designers, contractors and suppliers. The complaints about the cost of introducing the software seem weak as it is merely an initial cost that will be paid back the more it is used. It should be considered an investment into the improvement of the organisations practice, as well as the industries.

"Because of the way BIM facilitates green design, construction, and sustainable outcomes, the growth of green building as an accepted, widespread practice is helping to accelerate BIM adoption" (McGraw Hill, 2010)

6.3 Further Research

In an effort to develop BIM further as an effective tool in bridge construction, the area of detailed planning should be explored further. This is the 4D and 5D version of BIM, where time schedules and cost are added to the model for use in production. I believe productivity can be improved dramatically by developing this feature. This paper identified the ability to design elements of the bridge in order of construction. If detailed time schedules can be incorporated into this element of the model with visualisation and simulation features, then virtual construction can be achieved.

One of the questions raised during the project is the influence of extra resources during the production stage. It seemed to have a positive effect on the Röforsbron project and it would be useful to find out if a larger set of resources during the production stage would generate a more productive construction that would outweigh the cost of the resources.

Another area of interest is the needs for benchmarks and milestones. As conferred in the theoretical chapter, the industry lacks a drive and a means of improving its practice due to its lack of measuring standards. Actors need aims and goals so that they can measure their effectiveness against neighbouring projects. BIM has all the attributes to set and record these performances, but it certainly needs clarification and development so that it is easily understood and acted on by all parties. Investigating methods of implementing these standards would be of great benefit to the growth of BIM and the construction industry.

BIM would also benefit by investigating its use post construction. One of the key advantages of BIM is its usefulness in facilitating operations and maintenance of structures after the construction is complete. Housing a database of information and knowledge whilst storing project experiences should be an area of further research.

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Appendices

A.1 CII Constructability Principles

Conceptual Planning Phase

- A formal constructability program is made an integral part of the project execution plans.
- Early project planning actively involves construction knowledge and experience.
- Construction personnel are involved in developing the project contracting strategy.
- Project schedules are sensitive to construction requirements.
- Basic design approaches consider major construction methods such as modularization or preassembly.
- Site layouts promote efficient construction (e.g., adequate space for laydown and fabrication yards and efficient site access).
- Project team participants responsible for constructability are identified early in the project.
- Advanced information technologies such as 3D computer modelling or field notebook computers are applied.

Design and Procurement Phases

- Design and procurement schedules are construction sensitive.
- Designs are configured to enable efficient construction considering issues like simplicity, flexibility, sequencing of installation, and labour skill and availability.
- Design elements are standardised including maximum use of manufacturers' standards and standardized components.
- Construction personnel consider construction efficiency in specification development including prior review of specs.
- Modular/preassembly designs are prepared to facilitate fabrication, transportation, and installation.
- Designs promote construction accessibility of personnel, materials, and equipment.
- Designs facilitate construction under adverse weather.

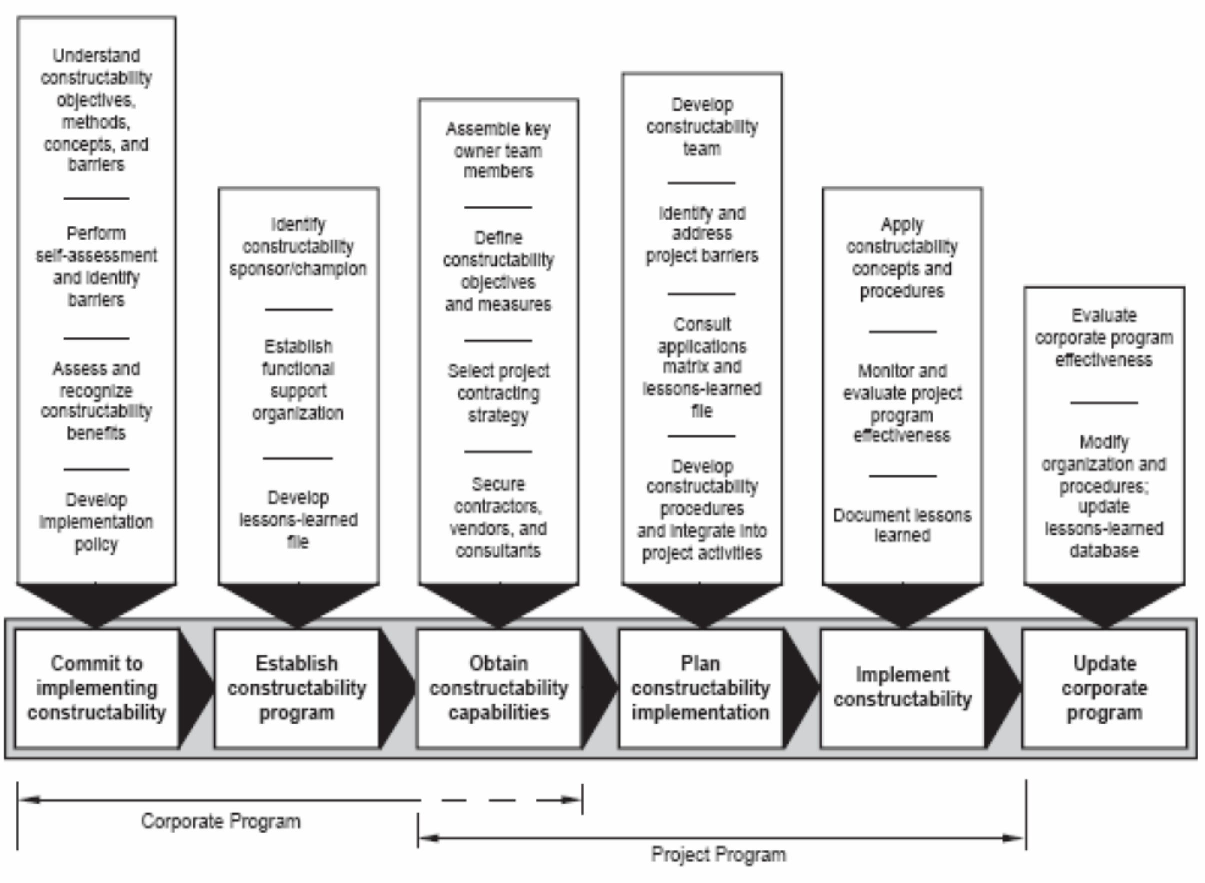
- Design and construction sequencing facilitates system turnover and start-up.

Field Operations Phase

- Innovative construction methods are used such as innovative sequencing of field tasks, or use of temporary construction systems, or innovative use of construction equipment.

(Source: CII, 1986)

A.2 Constructability Implementation Roadmap



(Source: CII, 1993)

A.3 14 Toyota Way Principles

Philiosophy

1. Base your management decisions on a long term philosophy, even at the expense of short term financial goals

Process

2. Create Continuous Process flow to bring problems to the surface
3. Use "Pull" systems to avoid overproduction
4. Level out the workload
5. Build a culture of stopping to fix problems, to get quality right the first time
6. Standardised tasks are the foundation for continuous improvement and employee empowerment
7. Use visual control so no problems are hidden
8. Use only reliable, thoroughly tested technology that serves your people and processes

People and Partners

9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others
10. Develop exceptional people and teams who follow your company's philosophy
11. Respect your extended network of partners and suppliers by challenging them and helping them improve

Problem Solving

12. Go and see for yourself to thoroughly understand the situation
13. Make decisions slowly by consensus, thoroughly considering all options, implement decisions rapidly
14. Become a learning organisation through relentless reflection and continuous improvement.

(Source: Liker, 2003)

A.4 Initial Skilled Worker/Tradesman Interview

Name: ______________________ Date: ______________

Construction and Technology Experience: ______________

1. What is your role in the Construction process?
2. How would you define BIM and what do you hope it can benefit you in?
3. What do you currently use the building information model for? *Has it helped you get a better understanding of the project and its construction process? Have you found it easier to find and address problems?*
4. (New Worker) Have you found it easier to come into a project mid way through construction and gain a quicker understanding?
5. Do you think it has a place in the production phase of civil works? More specifically bridge construction? *What benefits for you?*
6. How much prior training and experience have you had with BIM? If so, with what? *Would it be adequate for future projects?*

7. Did you have any input into the building information model during the design phase*? If so, to what extent? If not, do you think it would increase the benefit of BIM in the project?*
8. Who, in your eyes, takes responsibility for the building information model in terms of updating and sharing?
9. How is the building information model utilized during meetings? *What are the benefits/drawbacks?*
10. Is there a process in the construction procedure that tends to encounter more problems than others?
11. Finally, in general, has the use of BIM so far made the work performed and construction life of this project easier? Have you already noticed constructability benefits?

A.5 Initial BIM Coordinator Interview

Name: Date:

1. What is your role in the Construction process?
2. What is your definition of BIM and what do you hope it can benefit in?
3. What do you currently use the building information model for?
4. Do you think it has a place in the production phase of civil works? More specifically bridge construction? Benefits for you?
5. How would you describe the change in productivity levels on site over your career?
6. How much prior training and experience have you had with BIM? If so, with what? Adequate?
7. Did you have any input into the building information model during the design phase? If so, to what extent? If not, do you feel it would?
8. Who takes responsibility for the building information model in terms of updating and sharing?
9. How is the building information model utilized during meetings? What are the benefits/drawbacks?
10. Is there a process in the construction procedure that tends to encounter more problems than others?
11. Did you use the building information model to design the site layout? If so, did this provide any benefit?

A.6 Initial Bridge Model Designer Interview

Name: Date:

1. What is your role in the Construction process?
2. How would you define BIM and what do you hope it can benefit you in?
3. What do you currently use the building information model for? *Has it helped you organise your workforce/establish and fix problems/ etc.?*
4. Do you think it has a place in the production phase of civil works? More specifically bridge construction? *What benefits for you?*
5. Have you seen any benefits of using BIM for this project so far?

6. Have there been areas that BIM has had a negative effect on the project so far?
7. How much prior training and experience have you had with BIM? If so, with what? *Would it be adequate for future projects?*
8. Was the design stage more complicated and longer? *How would you weigh up the benefits of this through the production phase?*
9. How much input did you have from Skanska into the design of the model? *Would the production have benefited from more?*
10. Who, in your eyes, takes responsibility for the building information model in terms of updating and sharing?
11. Would you prefer to have another colleague in your position on site?
12. How is the building information model utilized during meetings? What are the benefits/drawbacks?
13. Is there a process in the construction procedure that tends to encounter more problems than others?
14. Has it been easy for Skanska staff to communicate any problems to you? *Have they been easy to address?*
15. Have you been spending significantly more time on fixing and modelling this project during the production phase as opposed to previously? *What did the job previously entail?*
16. Finally, in general, has the use of BIM so far made the work performed and construction life of this project easier? Have you already noticed constructability benefits?

A.7 Initial Production Manager & Site Superintendent Interview

Name: ____________________ Date: ________________

1. What is your role in the Construction process?
2. What do you currently use the building information model for? *Has it helped you organise your workforce/establish and fix problems/ etc.?*
3. Do you think it has a place in the production phase (Your role) of civil works? More specifically bridge construction?
4. How much prior training and experience have you had with BIM? If so, with what? *Would it be adequate for future projects?*
5. Did you have any input into the building information model during the design phase? *If so, to what extent? If not, do you think it would increase the benefit of BIM in the project?*
6. Who, in your eyes, takes responsibility for the building information model in terms of updating and sharing?
7. Using the model, have you found it easier to instruct (newer) workers on the project and the tasks ahead?
8. What is a common problem you've experienced during construction?
9. Did you use the building information model to design the site layout? If so, did this provide any benefit? If not, could you see a benefit from it?
10. How has BIM been utilised when ordering and identifying materials? Has it been a more effective tool?

11. Do you feel you are doing more administrative work since using BIM? *Do you feel more time has been spent away from working on the project? Has it been necessary, as the benefits it provides outweigh the administrative time?*

A.8 Trafikverket Project Manager Interview

Name: ______________________ Date: ______________

1. What is your role in the construction process?
2. How do you use BIM for your role?
3. What is background in use and experience of BIM?
4. What were your (Trafikverket) specific requirements for the project? Your brief?
5. What specific tasks/criteria did you set for:
   - WSP
   - Skanksa
6. What was the level of collaboration between parties throughout the design stages?
7. Were there any goals set in terms of productivity, constructability, lean construction?
8. Who takes responsibility for the accuracy of the model?
9. Do you have a responsibility to check the accuracy of the model?
10. Were there any design standards set?
11. What is a common problem you normally see on projects?
12. What problems, however small have you encountered thus far?
13. Did you spend more time in the design phase?
14. Was there more resources and money spent in the design phase and implementing the BIM technology into a project?
15. Do you feel the extra time and resources in the design phase are being repaid in the production phase?
16. Do you find yourself doing more administrative work on BIM projects
17. What benefits have you noticed from using BIM thus far?
18. Have you noticed any negative effects of using BIM thus far?
19. Why was a bid build contract used for this project as opposed to IPD or another more collaborative format?
20. Additional Comments?

A.9 Follow-up Skilled Worker/ Tradesman Interview

Name: ______________________ Position: ______________ Date: ________

1. Would you say that BIM played an effect in the savings for the, elaborate:
   - Form stands
   - Formwork
   - Reinforcement
   - Concrete
2. In any of the tasks, were you able to save time in one element to spend more time on another?

3. What errors/problems however small were encountered during production?
4. Did you use the tablets to communicate between personnel on site?
5. Did the tablets contain all the information you require on site?
6. Did you spend more time trying to read the tablets than 2D drawings?
7. What could be done to improve the handling for you?
8. What would you say were the biggest benefits and drawbacks of using BIM in this project?
9. Do you think any of the reinforcement could have been prefabricated?

A.10 Follow-up BIM Coordinator Interview

1. Cost savings have been made during the production phase, would you attribute this to BIM?
2. Do you think its use can be translated to any effect on bigger or smaller projects?
3. Were there more alterations and amendments made during production than would previously happen?
4. Have you saved time in some areas of your work, which has been used to greater effect in other areas?
5. Were there any specific examples where the model provided a benefit that would not have been seen, or taken significantly longer in traditional methods?
6. The term ‘Smart Ideas’ has been used on to describe the benefit of BIM during production, can you elaborate on its meaning?
7. What way has it helped in the planning of tasks and practices?
8. Did you perform any collision control checks?
9. Were there any problems encountered during production, why were they cause and how were they dealt with?
10. Has it been easier to manage your work as it is all on the computer in one model?
11. What drawbacks and improvements could be made to using BIM?

A.11 Follow-up Bridge Designer Interview

1. Did Skanska have any input into the design before production started? If not, Why? If so, What?
2. Was the model built to take into consideration construction methods/Lean construction/ Constructability?
3. Did you experience any interoperability issues during design?
4. How many changes to the model were made during the production? In particular, what?
5. Did you use the ability of clash control in the model? Was this done manually or automatically?
6. Did the BIM software enable an easier and larger scope for optimisation of the design?
7. Did Laser scanning improve the quality and speed of the design?
8. Were there any specific BIM design codes that you adhere to?
9. Is the model designed with one, or a number of software packages? What are their compatibility capabilities?

10. In future Design-Bid-Build projects, would you anticipate a reduced involvement in the production phase, or do you feel you are a required position throughout the delivery?
11. What can be done to improve the effectiveness and handling of a 3D BIM?

A.12 Follow-up Production Manager & Site Superintendent Interview

1. Would you say that BIM played an effect in the savings for the, elaborate:
    - Form stands
    - Formwork
    - Reinforcement
    - Concrete
2. Was it easier to generate a schedule from the model?
3. Did using the BIM model aid in delivery planning?
4. Has it provided any benefit when keeping control and management of costs?
5. In any of the tasks, were you able to save time in one element to spend more time on another?
6. What errors/problems however small were encountered during production?
7. What could be done to improve the handling for you?
8. What would you say were the biggest benefits and drawbacks of using BIM in this project?
9. How did material ordering differ using BIM? Did you save on material waste?
10. Did the model reduce the amount of alterations and rework during the project? If so, did it enable the changes to be made easier and quicker?
11. Was prefabrication considered for the production? If not, why?

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