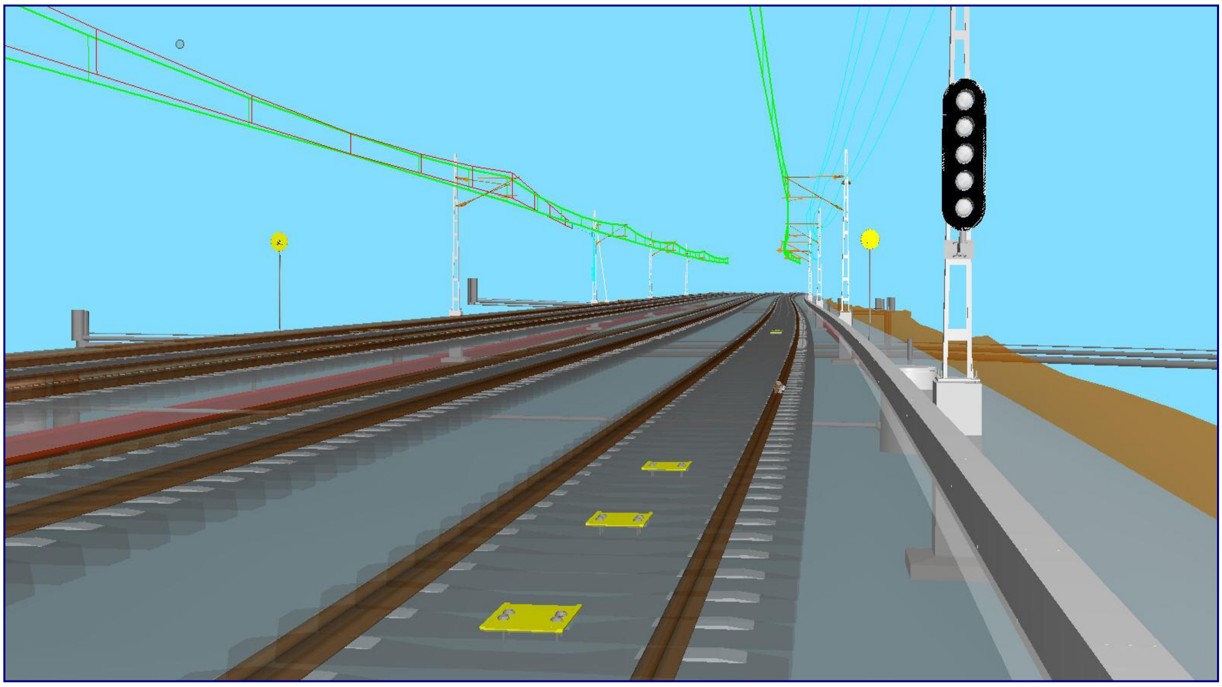


Implementing Building Information Modeling within the railway sector

Master of Science Thesis in the Master's Programme Geo and Water Engineering

ANDRÉ NORBERG

Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Research Group
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2012

Master's Thesis 2012:85

MASTER'S THESIS 2012:85

Implementing Building Information Modeling

Master of Science Thesis in the Master's programme Geo and Water Engineering

ANDRÉ NORBERG

Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Research Group
CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden 2012

Implementing Building Information Modeling within the railway sector

Master of Science Thesis in the Master's programme Geo and Water Engineering
ANDRÉ NORBERG

Examensarbete / Institutionen för bygg- och miljöteknik,
Chalmers tekniska högskola 2012:85

Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Research Group
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
3D visualization of a part of Mälarbanan generated from Bentley Navigator.

Chalmers Reproservice
Göteborg, Sweden 2012

Implementing Building Information Modeling within the railway sector

Master of Science Thesis in the Master's programme Geo and Water Engineering
ANDRÉ NORBERG
Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Research Group
Chalmers University of Technology

ABSTRACT

The AEC industry has been struggling with low productivity development for a long time. Building Information Modeling, BIM, is seen by many as the solution to this problem. It origins from the manufacturing industry and has recently spread to the civil construction sector where it is now used also in large infrastructure projects. Project Mälarbanan will be the first project for Vectura to make use of BIM for railway design at a high level. The purpose with this master thesis is to study how the different parties in a large railway project look at the implementation and use of BIM. It will describe the status of BIM within the railway sector at Vectura and identify benefits and challenges from implementing it, and analyze how different procurements affect the chances of succeeding with BIM. The information is collected from both a literature review but also several interviews with key persons from Vectura, the Swedish Transport Administration and NCC. The result shows that there is no common picture of BIM in the industry; instead the parties tend to see only to their part of the project. A deeper understanding of BIM in a lifecycle perspective is lacking, and the knowledge varies greatly both between the companies as well as within them. Object-based modeling and model-based collaboration are used in project Mälarbanan, but the level of BIM integration seems to decrease from high in the design phase, to lower in the production phase and when it comes to facility management it is absent. There are many benefits related to visualization, better understanding, design review, quality, productivity, re-use of information, time and production planning, and an increased collaboration between the participants. Challenges for the implementation of BIM include the legal status of the model, vague owner demands, technology problems related to the new BIM tools and the interoperability between them. A procurement which allows early collaboration between the participants such as Integrated Project Delivery is the most suitable for BIM projects, while more fragmented approaches like DBB cannot be recommended, since BIM both demands and encourages an early, effective collaboration.

Key words: BIM, CIM, railway, design, infrastructure, procurement, facility management

Implementing Building Information Modeling within the railway sector

Examensarbete inom masterprogrammet Geo and Water Engineering
ANDRÉ NORBERG
Institutionen för bygg- och miljöteknik
Avdelningen för geologi och geoteknik
Forskargruppen Väg och Trafik
Chalmers tekniska högskola

SAMMANFATTNING

Byggnadsbranschen har kämpat med dålig produktivitetsutveckling under en längre tid. Building Information Modeling, BIM, ses av många som lösningen på detta problem. Det kommer från början från tillverkningsindustrin, men har på senare tid spridit sig till anläggningsbranschen där det används för stora infrastrukturprojekt. Projekt Mälarbanan är det första projektet för Vectura där BIM kommer att användas på en hög nivå. Syftet med detta examensarbete är att studera hur de olika parterna i ett stort järnvägsprojekt ser på införandet och användandet av BIM. Det kommer att beskriva statusen av BIM på Vectura och identifiera villka fördelar som införandet ger, samt de hinder som finns idag. Dessutom kommer chansen att lyckas med BIM i samband med olika entreprenadformer att analyseras. Informationen är inhämtad dels från en litteraturstudie, men också ett antal intervjuer med nyckelpersoner från Vectura, Trafikverket samt NCC. Resultatet visar att det inte finns någon gemensam bild av BIM i byggnadsbranschen idag; istället ser aktörerna till hur de kan nyttja det i sin del av projekt. Vidare så är kunskapsskillnaden stor när det kommer till BIM, både mellan de olika aktörerna men också inom dem, och det saknas en helthetssyn som täcker hela livscykeln. I Mälarbanan används objektbaserad modellering och samarbetet är modellbaserat, men nivån av BIM-integrering sjunker från hög i projekteringsfasen, till låg i produktionsfasen och när det kommer till förvaltning så är den obefintlig. Det finns många fördelar med BIM; visualisering, bättre förståelse, samordning, kvalité, produktivitet, återanvändande av information, tid- och produktionsplanering och ett djupare samarbete. De hinder som finns rör främst den juridiska statusen på modellen, vaga krav från beställaren, tekniska problem rörande BIM-verktygen samt interoperabiliteten mellan dem. En entreprenadform som medger tidigt samarbete mellan projektdeltagarna som Integrated Project Delivery är mest passande för ett BIM-projekt. Mer fragmenterade entreprenadformer som generalentreprenad och totalentreprenad är inte fördelaktiga, eftersom BIM både kräver och uppmuntrar ett tidigt, effektivt samarbete.

Nyckelord: BIM, CIM, järnväg, projektering, infrastruktur, entreprenadform, förvaltning

Glossary

Bill of quantities - Mängdförteckning

Building Information Model - Byggnadsinformationsmodell

CAD Engineer - CAD-Projektör

Changes and additional work (CAW) - Ändrings- tilläggs- och avgående arbeten (ÄTA)

Consideration of permissibility – Tillåtningsprövning

Counties Agency - Länsstyrelsen

Data coordinator - Datasamordnare

Design-build - Totalentreprenad

Design documents - Bygghandling

Design phase - Projektering

Design phase manager - Projekteringschef

Design review meeting - Samgranskningsmöte

Design-bid-build - Generalentreprenad

Deviation report - Avvikelserapport

Enquiry documentation - Förfrågningsunderlag

Environmental Code - Miljöbalken

Extended collaboration - Utökad Samverkan

Facility management - Förvaltning

Feasibility study - Väg- eller järnvägsutredning

Idea study - Idéskede

Initial study - Förstudie

Laydown area - Upplagsplats

Machine-guidance - Maskinstyrning

Owner - Beställare

Plan of mass disposition - Massdispositionsplan

Procurement - Upphandling

Quantitiy take-off - Mängdning

Railroad Construction Act - Lagen om byggande av järnväg

Railway investigation - Järnvägsutredning

Railway plan - Järnvägsplan

Subcontractor - Underentreprenör

Surveyor’s assistant - Utsättare

Swedish Rail Administration - Banverket

Swedish Road Administration - Vägverket

Swedish Transport Administration - Trafikverket

Technical manager - Teknikchef

Tender - Anbud

Tenderer - Anbudsgivare

Dictionary

3D-model - Geometrical model in three dimensions; length, height and width.

4D-model - 3D-model plus time

5D-model - 4D-model plus cost

AEC - Architecture, Engineering and Construction

BIM – Building information modeling, the activity, when referring to a specific building information model the term “BIM model” is used.

CAD – Computer Aided Design

DTM – Digital Terrain Model

EIA – Environmental Impact Assessment

Contents

Preface

This master thesis is the final step in the Master's Programme Geo and Water Engineering at Chalmers University of Technology, comprising of 30 credits.

It is based on qualitative interviews with key persons from designer, owner and contractor organizations within the AEC industry. The project is carried out at the Department of Civil and Environmental Engineering, Chalmers University of Technology, Sweden. It has been performed for Vectura in Stockholm with Jan Dahlberg as supervisor and university lecturer Gunnar Lannér as examiner, both of whom I would like to thank for their advice and encouragement throughout the writing of this thesis.

The author would also like to thank all the informants from Vectura, the Swedish Transport Administration and NCC. Without your contribution this master thesis would not have been possible. A thank you is also extended to my opponent Martin Rudolphi for valuable feedback on the report.

Stockholm, June 2012

André Norberg

1 INTRODUCTION

1.1 Background

For a long time the construction industry has been falling behind other industries in terms of productivity. Statistics from SCB reveals that the Swedish manufacturing industry productivity increases at a rate of 7,1 % every year during the period 1995-2003. The productivity rate for the construction industry was for the same period -0,2 % (SCB, 2012). To address this problem the AEC industry today is undergoing a change and is evolving away from 2D-CAD and paper towards 3D digital models which contain more information and will help increase the productivity.

This new approach is known as Building Information Modeling (BIM) and is more and more used in the industry (Steel et al, 2010). Intelligent, object-based 3D models are central when using BIM and it can contain information about the construction throughout its entire life cycle, from idea to design, construction and facility management until demolition. BIM is used widely in the building sector with success but has not had the same impact in the civil construction sector, in particular the railway sector. Some aspects of BIM have been used but the full potential is yet to be seen, but this is changing now as it is more common that the use of BIM is used in larger infrastructure procurements. Consequently this means that the designers and contractors need to implement BIM in the way they work if they want to stay in the competition.

Vectura is an engineering consultant specializing in the fields of transport infrastructure and movement planning. They develop and design sustainable transport systems and offer services in the fields of investigation and analysis, design, construction and project management, and operation and maintenance. Currently one of their biggest projects, Mälarbanan, is being designed and this is a pilot project where BIM is implemented in a large railway project. Mälarbanan between Tomteboda and Kallhäll is one of the most congested parts of the Swedish railway system; therefore a higher capacity is needed. Project Mälarbanan consists of constructing two new rail tracks between Tomteboda and Kallhäll, north-west from Stockholm C. Today this stretch consists of a double-track railway but it is getting more and more clogged with the increasing number of inhabitants in the city of Stockholm. Also, the new tracks would make it possible to increase the frequency of departures, decrease the travelling time and improve the punctuality. The full distance between Tomteboda and Kallhäll is 20 km but has been divided into two parts. Vectura is currently designing the northern part, from Barkarby to Kallhäll, which is about 8 km and is the first part to be built (Trafikverket, 2012).

For Vectura this is one of the largest and most challenging projects ever to be carried out. Traffic on the railway will run throughout the whole time of construction except for some shorter stops. This leads to large risks in the work environment and makes the construction process more complicated. The process needs to be thoroughly planned in order to succeed. The idea is that the use of BIM in combination with a different type of procurement which enables early collaboration between Vectura, the Swedish Transport Administration and the contractor at an early stage will make the project more efficient.

Within railway design at Vectura, BIM has not yet been used much and there is not yet a company policy for the implementation and use of BIM. Today 3D design is not used within all the technical areas, for example within electric design which is more schematic and here 2D is still used. Other areas such as track design have used 3D modeling for a long time, and the goal is to create an information model where all the technical areas can work collaboratively. The experiences from project Mälarbanan will lead the future development within BIM at the railway division at Vectura.

1.2 Definition of BIM

There is no official definition of BIM in Sweden, thus the author needs to come up with a definition to be used in this thesis.

The definition of BIM used for this report is adopted from GSA, the U.S. General Services Administration:

"Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design."

The choice of definition will be further discussed in chapter 3, and BIM will be explained in a wider context.

1.3 Purpose

The purpose of this master thesis is to study how the different parties in a large railway infrastructure project look at the implementation and use of BIM. The report will identify the benefits and challenges from implementing BIM in project Mälarbanan and also look at the current status of the use of BIM in the railway division of Vectura.

The thesis aims at answering and analyzing the following questions:

- What is the view on BIM from the different parties in project Mälarbanan?
- What is the status of BIM use in the railway sector at Vectura?

- What are the benefits and challenges of implementing BIM in a large railway project like Mälarbanan?
- What type of procurement is most suitable for a BIM project?

1.4 Limitations

Since this study is performed by one student as a Master's thesis and consists of 30 hp (one semester's full time work) both time and resources are limited. Therefore the work is focused on BIM in project Mälarbanan and the parties involved in that project.

The master thesis will investigate how Vectura can benefit from using BIM in project Mälarbanan, and the report will focus on the use of BIM for designing railway. Comparisons will however be made to the house building sector to point out the differences.

Due to the limited time the number of interviews will be restricted, hence a selection of the most important persons for the project will be made. The selection of respondents will be further discussed in chapter 2.

With the use of BIM and digital information models instead of paper drawings certain legal issues arise. In this report the focus is not on the legal issues that come with the use of BIM, but they will be addressed briefly.

1.5 Methodology

In this study a number of different methods will be used to collect information and data. General information about the background, theory about BIM and different software applications is collected from relevant literature and digital sources. The main part of the information will however be collected from interviews with key persons involved at the different organizations, most of them directly involved in project Mälarbanan. This includes persons from Vectura and the contractor as well as construction managers. The methodology will be discussed further in detail in Chapter 2.

1.6 Layout of the report

- **Chapter 1** contains the introductory parts like the background, the working definition of BIM, purpose, research questions, limitations and also previous studies and a literature review.

- **Chapter 2** covers the methods used in this report for data collection which are mainly a literature study and a number of interviews. The choice of methodology is then discussed.

- **Chapter 3** has all the necessary theory needed to comprehend the concept of BIM and how the industry is evolving from paper-based design to intelligent BIM models.

- **Chapter 4** contains the empirical results from the interviews. The answers from the respondents are placed in a matrix, and presented in the text with quotes from the respondents.

- **Chapter 5** holds the analysis and discussion of the result from chapter 4. The theory provides a framework which is used together with the result from the interviews along.

- **Chapter 6** contains the conclusions which are based on the research questions in chapter 1.3.1, along with the theory, empirics and the authors own opinions.

1.7 Literature

There is an abundance of articles, scientific studies, and other literature sources available about the subject, and it is difficult to cover it all, since the development within BIM is rapid. Therefore it is important that the literature used is up to date. An article written five or ten years back might not be completely accurate today. Considering this, the aim has been to use as recent material as possible.

The BIM handbook (Eastman, et al. 2011) has provided much useful information about BIM theory. It is a very extensive book about the BIM approach to design, construction and facility management. The second edition of the BIM handbook is from 2011 which means that the latest progress in technology is accounted for.

2 METHODOLOGY

In this chapter the methodology will be discussed, which includes different scientific methods and techniques. Sometimes it can be hard to draw a clear line between the two. The definition of method is a scientific way to approach the subject of the study and how the subject is intended to be treated. Since the method affects how the study is being performed it is important to choose a suitable method for the study. Examples of different methods could be a simple description, make certain comparisons, form hypothesizes or make predictions (Ejvegård, 2009).

The meaning of technique is how the information is being collected, for example from interviews, surveys or experiments. The information is then used to describe, compare, make hypothesizes or predict. The method can be seen as the wider and more overall concept, while the technique is more mechanical and concrete (Ejvegård, 2009).

2.1 Qualitative or quantitative research?

Over the last decades many things have been written and a lot of discussions have taken place about the concept of qualitative or quantitative research. The difference between the two is how the collected information is generated, processed and analyzed. A quantitative research method means that statistical methods are used for the collecting and analysis of the information. A qualitative research method is more focused on the “soft” data, i.e. qualitative interviews and interpretations. The two different research methods often seem to exclude the other when practicing them, but that is not the case. They can be considered to be on opposite ends on a scale, and the main part of the research carried out today is somewhere between these two end points. What determines the choice of one or the other is how the research problem is formulated (Patel & Davidsson, 2003).

2.2 The relation between theory and empirics

The scientist’s work consists of producing theories that should give a realistic knowledge of the reality. The foundation for the theory construction is data or information about the part of the reality that is subject for the work. This material is often referred to as “empirics”. It is then the work of the researcher to relate the theory and empirics to each other. How to relate the theory to the empirics is a central dilemma within all kinds of scientific work. There are different concepts that can be used to relate theory and empirics; deduction, induction and abduction (Patel & Davidsson, 2003):

- Deduction means that a scientist works with known principles and theories and, based on those, draws conclusions about certain subjects. Hypothesis from commonly known theory are tested empirically in the research. An already existing theory determines what information is needed, how to interpret the information and finally how to relate the results to the theory. The objectivity in a deductive approach is assumed to be strengthened because the base is taken from existing theory. This means that the research process will be less colored by the individual scientist’s subjective opinions. However, there is a danger that the theory used will affect the research in a way that for example new observations are not taken into account (Patel & Davidsson, 2003).

- A scientist who works inductive can be said to follow the path of discovery. It means that the scientist can study the research object without using a previously established theory. Based on the empirics (the collected information) a theory is formulated. A risk with this approach is that the scientist does not know the range of the theory or its generality since it is based only on empirics that are typical for a certain situation, time or group of people. The scientist must discover something that could be formed into a more general theory, which means that the work is performed with open ends. Also, the scientist has own ideas and conception which inevitably will color the theories produced (Patel & Davidsson, 2003).

- Abduction is the third way to relate theory and empirics and could be described as a combination of the previously mentioned approaches. Abduction means that based on a single case the scientist formulates a theory that explains the case. This first step could be said to be inductive. In the next step the scientist tries the theory or hypothesis on other cases, which is similar to an inductive approach. The theory could then be developed and expanded to become more general. An advantage with abduction is that the scientist is not as locked as if working strictly deductive or inductive. The risk with abduction is that all scientists are colored by previous experiences and research, which means that no research is started impartially. The scientist could, without knowing it, choose the subject of study based on previous experience, and furthermore formulate a hypothesis that excludes other alternative takes (Patel & Davidsson, 2003).

Within natural science the aim is to come up with a theoretic superstructure, a system of empirically tested laws with full covering. Since this superstructure already exists to a large extent within natural science and is considered to be verified it is the deductive approach that is most common. Within other sciences it can be more of a mix between deduction, induction and abduction (Patel & Davidsson, 2003).

The methodology used in this thesis is towards the inductive approach, the work starts with a literature review and then interviews are performed to collect information, which is then analyzed and discussed. According to Patel & Davidsson (2003) it is a qualitative form of research, where the respondents' opinions about the subject have been interpreted.

2.2.1 Literature review

The literature review usually consists of all the printed material available: books, articles, reports, studies, essays etc. Information collected from the internet is also a part of the material. When looking for information it is important to use relevant key words to find the desired material. Another way of finding information is to follow a chain of references. Scientists almost always list their references in their studies and by following these new studies or books can be found (Ejvegård, 2009).

2.2.2 Survey- and interview techniques

To find out the opinion and knowledge from a population in a scientific context, surveys and interviews are used. The survey is a written questionnaire which is handed out to a number of people while the interview is consists of oral communication between the researcher and the interviewee. Surveys and interviews are used more and more frequently today for collecting information for essays and studies. These techniques, especially the interview, can be used for almost any field, since they all have their own experts. Sometimes the information from these experts cannot be found in the literature available (Ejvegård, 2009).

2.3 The interview study

The interview study accounts for most of the information collected for this report. The aim with the interview study was to investigate the view on BIM, collect experiences, and get a picture of the BIM status in the industry today. The interviews provided much valuable information about the advantages of using BIM, but also some of the challenges that come with a new work method.

2.3.1 Choice of respondents

The respondents were chosen from the different organizations involved in project Mälarbanan; Vectura, the Swedish Transport Administration and the contractor. From the start the contractor was supposed to be procured in April, but this has been delayed .Therefore another was chosen from a different railway project. By doing so, it was possible to see if the picture of BIM varied among the parties, and to catch the different opinions about BIM. The respondents were chosen from a contact list for the project Mälarbanan, with additional help from people with insight in the project.

The respondents were chosen from different levels in the hierarchy, from design engineers to specialists to project leaders. By doing so, a wider range of opinions and ideas could be anticipated from the interviews. The level of knowledge about BIM varied as well, from on one hand people who have practically never worked with BIM, to BIM experts on the other hand.

Most of the respondents were naturally from Vectura's organization since the study is performed for them. It was also practical since they sit in the same office building. Geographically the respondents range from Norrköping in the south up to Luleå in the north. These interviews have been performed by using video conference software. Most respondents however were located in the Stockholm area; see Table 1 below for a complete listing of the respondents.

Table 1: Categorization of the respondents

Category	Position
Designer	Project manager
Designer	Design coordinator
Designer	Design coordinator
Designer	Technical manager
Designer	Model coordinator
Designer	Senior CAD designer
Designer	CAD designer signalling
Designer	CAD designer track
Owner	Design phase manager
Owner	Data coordinator
Owner	Technical manager
Contractor	Project Engineer

2.3.2 Formulation of questions

The questions were formed based on the theoretic base provided by the literature review, with respect to the respondent's background and knowledge. The aim with the questions was to give background information but also to answer the research questions formulated in chapter 1.3. Many questions were the same for all respondents, as for example their picture of BIM and the benefits and challenges of implementing BIM.

A number of questions were then specially formulated considering the background and knowledge of the respondent. These questions varied and a BIM expert for example got more in-depth questions compared to a project leader.

The interviews were semi-structured which meant that the questions were written down beforehand, but during the interview follow-up questions could be asked when needed. This makes it easier for the respondents to bring up things not included in the questions. An effort was also made to keep the questions open so that the respondents could answer without being directed by the formulation of the question.

2.3.3 Performing the interview

First, an e-mail was sent out to the respondents where a presentation of the Master Thesis was made, and why their participation was important. Then a time and place was decided and at least a couple of days before the interview, an e-mail was sent to the respondents with the questions. By doing so the respondents could read through the questions before, think about possible answers and be more prepared for the actual interview.

Every interview was recorded and then typed in a text document. This was to make sure that no information from the interview would be lost. The location of the interview was mostly at the respondent's work place. In some cases the interview has been performed as a video conference due to long distances, where the respondent is located in a different part of the country. However, personal interviews are preferred since they admit a better contact with the respondent.

2.3.4 Analysis of the information

After collecting the information it is then sorted and made anonymous. A matrix where the relevant information is placed is used to make a more systematic analysis. The matrix is made with the purpose and research questions as a base. Finally the result is presented in the text.

2.4 The research process

No matter how a research problem was born and what it contains, the research process can be described in a number of steps in a logical order. The process starts with an identification of the problem area, followed by a formulation of purpose and research questions, a literature review, choice of technique for collecting information, performing the work, processing, processing and finally reporting. However this is an idealized picture of the research process. Very seldom can the steps be performed one after the other in that very order. A reason for this is that the steps sometimes overlap each other; another is that new knowledge and experience are obtained throughout the research process which needs to be added. Sometimes it can even be positive to do things in a different order. For example, when using a qualitative approach it can be suitable to wait with the literature review until after the investigation (in this case the interviews). A thorough theoretic work in the beginning of the process could hinder the discovery of new knowledge (Patel & Davidsson, 2003).

The scientific approach will affect what we do during the research process, from formulating the problem, going through the different steps to the reporting of the result. But it does not matter if the research process has been performed step-by-step or by jumping between the steps – the layout of the final report should look like the idealized chain of steps mentioned above (Patel & Davidsson, 2003).

The process for performing this study can be seen in Figure 1 below.

Figure 1: The research process can be illustrated in the above steps.

2.5 Quality in qualitative studies

The quality in a qualitative study is depending on the whole research process. When talking about the quality in a study there are two central concepts which will be explained below; reliability and validity. These will be further explained below.

2.5.1 Reliability and validity

In a qualitative study the concept validity is the ambition to discover phenomenon and describe opinions or a culture. In comparison, validity in a quantitative study is depending that the right phenomenon is studied, with a solid theoretic base and good instruments when performing the study (Patel & Davidsson, 2003).

Reliability in qualitative research is different from validity in quantitative research. For example, if the same person is interviewed several times and the same question is asked, but the answers differ, it is a sign of low reliability. In a qualitative study this is necessarily not the case, and the reason for this is that the respondent might have changed opinion, received new information or learned something since the last interview. Within qualitative research the two concepts of reliability and validity are so intertwined that scientists seldom use the concept of reliability. Instead the meaning of validity is broader. Sometimes the term understanding or authenticity is used instead (Patel & Davidsson, 2003).

As mentioned earlier the validity is not related only to the collection of data or information; it includes all the parts in the research process. Considering the collection of information the validity is linked to the ability of the scientist to get material for a credible interpretation. Furthermore the interpretation of the interviews plays a central role for the validity. Thus, each qualitative research process is unique and it is not possible to form any rules or procedures to ensure the validity (Patel & Davidsson, 2003).

2.6 Method discussion

Several measures have been done to get a good and reliable result. If we look at the collection of data first, the respondents have been given the questions in advance which should increase the reliability.

Furthermore, the interviews were recorded which means that no information will be missed from the actual interview and the transcript will be accurate. Otherwise there could problems during the transcription process which affects the information. For example, there is a difference between spoken language and written language.

It is also an advantage if the interviewer has good knowledge about the research subject when performing the interview. The literature review that was done beforehand provided the necessary knowledge.

However, time and resources are limited and it is very time-consuming to perform and process interviews. It is possible that this affects the result, since the number of interviews was restricted. With a larger number of interviews more opinions could have been collected which might have led to a different result.

Due to circumstances out of my control the contractor in project Mälarbanan was not contracted in time before the interviews were decided. Therefore a contractor from a different infrastructure project was chosen as respondent. However, it was one of the bigger players on the market, and also from a railway project, so that should not affect the result.

3 THEORY

In this chapter all the necessary theory will be given to comprehend the contents of this report. The process of railway planning and production is described, as well as the different procurements and the transformation in the industry from paper-based design to BIM models.

3.1 The process of railway planning and construction

The railway process starts with an extensive planning process, which consists of the first three phases; idea study, pre-study and railway investigation. As the process moves forward the level of detail in the design increases. The first three phases mostly consists of considerations between different public interests. Not until reaching the work- and railway plan phase, is it possible to see for example how private land owners are affected (Trafikverket, 2012a). The whole process can be seen in Figure 2 below.

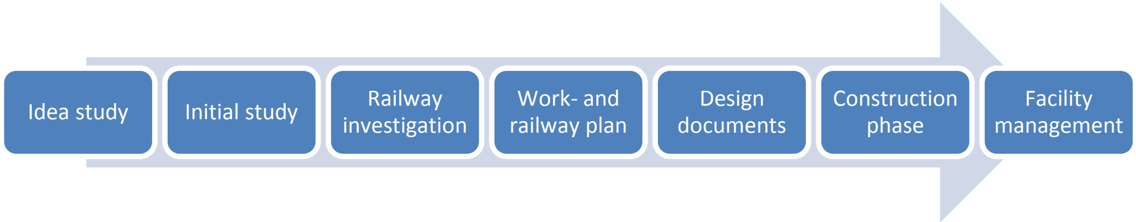


Figure 2: The different steps in the railway process (Modified from Trafikverket, 2012)

The whole railway planning process is very heavy and time-consuming which means that the time frame from idea to a finished railway is several years. The planning process follows Swedish law under "Railroad Construction Act" and "Environmental Code" (Trafikverket, 2012a). The different steps in Figure 2 are explained further below:

- **Idea study -** The railway process starts with several ideas and possible solutions being analyzed and identified (Trafikverket, 2012a).

- **Initial study -** The pre-study comprises alternate solutions and ideas and their shortcomings and possibilities are documented. Some ideas are considered not feasible, and are therefore sorted out. An important prerequisite is that an open dialogue is kept with the society. The pre-study also includes a general description of the environmental impact from the different alternatives (Trafikverket, 2012a). Depending on the size, some projects need to be approved by the government before moving on to the next phase. This means that a new railway or a new track longer than 5 km or large reconstructions of an existing railway generally have an important environmental impact and need to be approved by the government (Trafikverket, 2012a).

- **Railway investigation -** During the railway investigation phase the remaining alternatives are tested and analyzed. The purpose of this is to provide information about the final selection of alternatives which are to be chosen from. To this an EIA (Environmental Impact Assessment) is added which should be approved by the Counties Agency. It is also investigated how the alternative affects the existing road network, public transport, traffic safety and availability and the environmental consequences (Trafikverket, 2012a). Before moving on to the next phase the final alternative need the approval of the government, which is done after a consideration of permissibility.

- **Work- and railway plan -** In this phase the final design and placement is decided. It also means that the level of detail is higher compared to previous phases, so that it is clear which buildings and land are affected by the new railway. After that it is up to the Counties Agency to approve the EIA associated with the alternative. The focus lies on having a dialogue with land owners, municipalities and other agencies. Once the plan is finally approved, there is a period for appeal before the railway plan is finalized. After that the construction can begin (Trafikverket, 2012a).

- **Design documents -** This phase consists of creating the necessary design documents for the construction of the railway. The design documents include the final design with the technical specifications. Only smaller deviations from the railway plan are allowed. If larger deviations or changes are made it could be necessary to change the railway plan or make a new one (Trafikverket, 2012a).

- **Construction phase -** The construction of the railway facility is mainly done by contractors. The construction phase starts as soon as the work and railway plan is validated. Usually during construction there will be some adjustments or changes to the design documents. The reason for this is that the reality sometimes differs from the model, when it comes to bedrock levels for example. However, the changes that can be made have to be within the railway plan (Trafikverket, 2012a).

- **Facility management -** After the completion of the construction phase the railway is handed over to facility management which takes care of the long-term operation and maintenance of the railway.

3.2 The Swedish Transport Administration

The owner of project Mälarbanan is the Swedish Transport Administration (sometimes the abbreviation STA will be used in the text). They are the agency responsible for all modes of traffic whether it is on roads or railways, in flight or on the sea. STA has the overall responsibility to build, maintain, and operate all national roads and railways (Trafikverket, 2012a).

3.2.1 The different steps in a procurement

The Swedish Transport Administration is an authority which by law must endeavor to procure goods, services and contracts in competition. Trafikverket are bound to follow both the Public Procurement Act and the Act on Procurement in the Water, Energy, Transport and Postal Services Sectors. These acts are based on directives from the European Union (EU). A number of fundamental EU principles have to be observed when carrying out public procurements. All suppliers have to be treated in a similar, open and non-discriminatory way (Trafikverket, 2012b).

The procurement process starts with a need for a service or contract within Trafikverket. The chain of process can be seen in Figure 3 below. The next step is the production of enquiry documentation, which describes what is to be procured, including what requirements are placed on the tenderer and the subject of the procurement, and finally how the tenders will be evaluated (Trafikverket, 2012b).

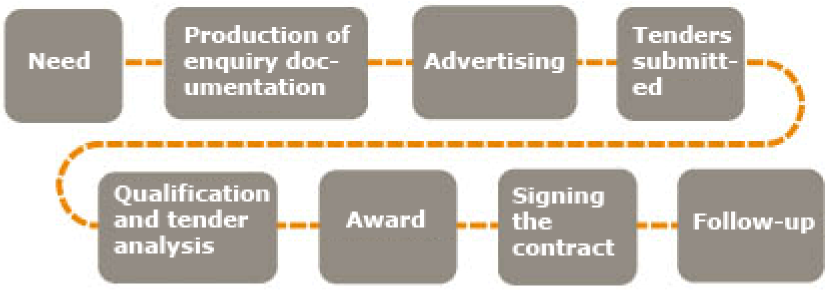


Figure 3: The process of procurement (Trafikverket, 2012b)

The next step is to advertise the procurement in a publicly accessible database and on Trafikverket’s webpage. The different suppliers send in their tenders in the right time, and after that an analysis is done by STA in accordance with the evaluation criteria set out in the enquiry documentation. Then all tenderers are notified of which supplier (or suppliers) who have been awarded the contract. At earliest ten days after the award notification the contract is signed. The contract is then continually followed up during the term of the contract (Trafikverket, 2012b).

3.3 Different procurements and BIM

The chance of succeeding with BIM at a high level in a project is depending on the type of contract method used. Some of the most common ones used are Design-Bid-Build (DBB) which accounts for about 90 % of public buildings and 40 % of private buildings in the United States. Another common contract method is Design-Build (DB) while more collaborative methods like Integrated Project Delivery (IPD) are on the rise (Eastman, et al. 2011). These different contract methods will be discussed further into detail below. The function of the different methods can be seen in Figure 4 below.

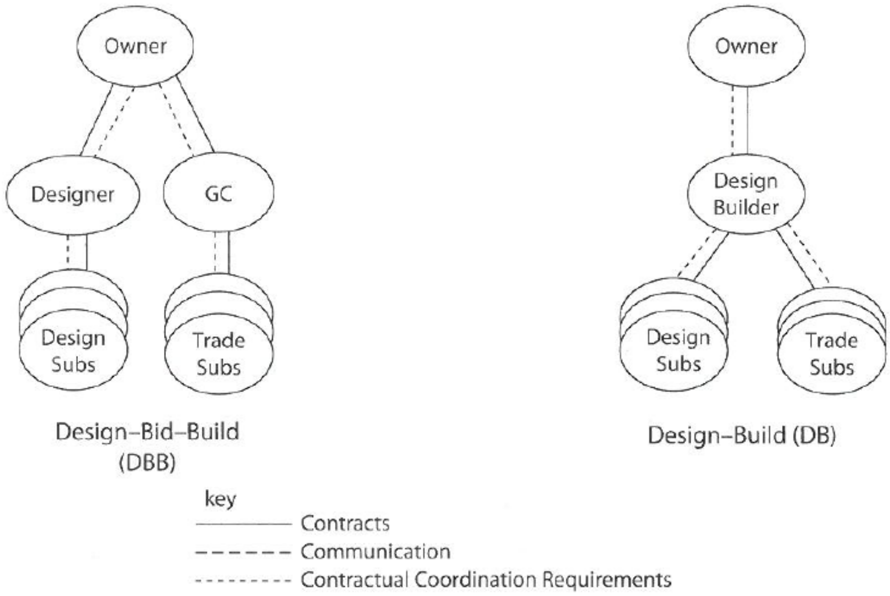


Figure 4: Schematic diagram of Design-Bid-Build and Design-Build processes (modified from Eastman, et al. 2011)

3.3.1 Design - Bid - Build

As mentioned above this is the most common contract method as of today. DBB has two major benefits; more competitive bidding to achieve lowest possible price for an owner, and less political pressure to select a given contractor.

In the DBB method, the owner hires an architect or designer, who then produces a list of the building requirements (a program) and design objectives. The final documents must satisfy local building codes and fulfill the program. Employees or external consultants can be hired by the architect to help with structural components or piping for example. These designs recorded on drawings which in the end must contain sufficient detail to facilitate construction bids. It is common that the architect chooses to include less detail in the drawings or try to restrict his responsibility because of potential liability. This often leads to disputes with the contractor when errors and omissions are found which brings an extra cost to the project (Eastman, et al. 2011).

The next stage is for the owner to obtain bids from general contractors. Each general contractor uses the quantities specified in the design documents to make a cost estimate of the project. Possible subcontractors must go through the same process. It is normal that one percent of the estimated cost for a contractor is related to compiling bids. The winner of the procurement is usually the one with the lowest bid, including work to be done by both general- and subcontractors. The winning contractor must then redraw some of the original drawings and also produce their own shop drawings which are more detailed. The shop drawings are used for actual fabrication, and if these drawings contain errors it is likely that a time-consuming and costly conflict will arise in the field.

Usually during the construction phase, many changes are made to the design as a result of previously unknown errors, construction site conditions and changes in materials available. Each of these changes requires a process in order to determine the cause, who is responsible, and evaluate time and cost additions. This has to be solved by the project team and the changes are likely to lead to legal disputes, added costs and delays. Another problem associated with DBB is when a contractor bids below the estimated cost in order to win the job. The contractor often abuses the change process to recoup losses from the bid. Using DBB requires the procurement of all material to be postponed until the owner approves the bid. This is one reason why the DBB method is not the most time - and cost-efficient approach to design and construction. The last phase is the commissioning of the building after the construction is finished; final drawings are produced and delivered to the owner along with all manuals for installed equipment (Eastman, et al. 2011).

3.3.2 Design - Build

In the DB process the owner contracts directly with the design-build team which is normally a contractor with a design capability. This method makes the contractor responsible for both design and construction as well as simplifies the owner's administration part. The DB contractor develops a building program and a schematic design that meets the demands from the owner. Then the total cost and time needed to design and construct the building are estimated. Once the potential modifications from the owner have been implemented, the plan is approved and the final budget is established. The big advantage compared to the DBB method is that the changes and alterations in the design can be addressed earlier in the process, meaning both money and time spent will be reduced (Eastman, et al. 2011).

The DB contractor hires specialty designers and subcontractors as needed, and after this point the construction begins. Any changes to the design, errors and omissions after this point are the responsibility of the DB contractor. Not all drawings need to be in detail at the time of construction start. Due to this simplification, the building is normally completed faster, cheaper and with fewer legal complications. A drawback with the DB approach is that there is not much flexibility for the owner to make changes once the initial design is approved and the contract amount is established (Eastman, et al. 2011).

3.3.3 Integrated project delivery

The IPD approach is relatively new in the construction industry but it is getting more and more popular. The reason for this is that it works well with BIM and the AEC industry learns to use this technology to support integrated teams. There are multiple approaches to IPD but the common factor is effective collaboration between the owner, the prime (and possibly sub-) designer(s) and the prime (and possibly key sub-

) contractor(s). Already at an early stage the collaboration starts, and then continues throughout the length of the project (Eastman, et al. 2011).

The key concept is that the different players work together using the best tools for collaboration so that the project will meet owner requirements at a reduced time and cost. The trade-offs that are part of the design process are best evaluated using BIM, such as cost, functionality, aesthetics and constructability. In other words, BIM and IPD go hand in hand and represent a very different approach to the previous linear paper-based exchange of information. The owner benefits the most from using IPD, but they must know what they want from the participants and how it will be achieved (Eastman, et al. 2011).

3.3.4 Which building procurement is most suitable for BIM?

Of the above mentioned procurements the least suitable approach is the DBB one since it is the most fragmented process and the contractor is not included in the design process. This means that the contractor has to make a new building model after the design is completed. However, since there are many alterations of the design-to-construction business process and also of the project team, how the team members are paid and who absorbs the risks. When it comes to the use of BIM one thing is clear though – the positive effects from using this new technology is depending on both how well the different parties collaborate and at what stage of the project they start doing so. The DB approach could provide a good platform for BIM, since one single entity is responsible for both design and construction. Of the three approaches mentioned above the most suitable for BIM is the IPD approach, since it involves a high level of collaboration (Eastman, et al. 2011).

3.4 The concept of Building Information Modeling

3.4.1 Choice of BIM Definition

It is very popular to talk about Building Information Modeling in the AEC industry today. People in the industry are generally positive and excited about the new technology, but what do the three letters stand for? Some believe BIM is just a 3D representation of a building or a facility, but there is much more to the concept. BIM can sometimes refer to Building Information Management, which is linked to Building Information Modeling. The discussions about BIM tend to be related to the practical use of 3D-models for various purposes.

But as BIM is spreading to other areas within the AEC industry, the B in BIM is somewhat misleading. Today BIM is used for design and planning of heavy civil constructions such as highways and railways, and this application is being called CIM sometimes, Civil Information Modeling (Palmer & Presley, 2009).

In Sweden there is not yet an official definition of BIM, therefore the attention was turned outside the country borders where the development has gone further. During the initial literature review a few different definition of BIM was discovered. For example, National Building Institute of Building Sciences (NIBS) defines BIM as follows:

"A Building Information Model, or BIM, utilizes cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and is intended to be a repository of information for the facility owner/operator to use and maintain throughout the life-cycle of a facility".

Jongeling, R (2008) uses the following definition of BIM in his report "BIM istället för 2D-CAD i byggprojekt":

"BIM is all the information generated and administrated during the lifecycle of a building, structured and represented by using (3D) objects, where objects can be building parts, but also more abstract parts such as voids. BIM-modeling is the process to generate and administrate this information. BIM-tools are the IT-tools used to create and handle the information. BIM is therefore not a technique, but a common generic term for how the information is created, stored and used in a systematic and quality-assured way".

The definition of BIM provided by the large owner organization GSA can be seen below (GSA, 2007):

"Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which

views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design".

The definitions are very similar with only smaller differences among them. BIM is the process of creating an information-rich model by using advanced tools, throughout the lifecycle of a building. Since there is very little that distinguishes one definition from the other, the choice between them is of minor importance. The choice of definition for this Master Thesis is adopted from the U.S. General Services Administration (GSA), which provides and maintains workplaces for over a million employees in 8500 owned or leased buildings (GSA, 2007).

3.4.2 BIM in a wider context

So BIM describes the process of creating an intelligent data model which is used during the whole life-cycle of a structure. That is the central part in the definition, but BIM extends beyond the information model and demands new processes for how a construction is being built. Moreover, BIM can also be divided into different fields which can be seen in Figure 5 below, (Succar, 2009):

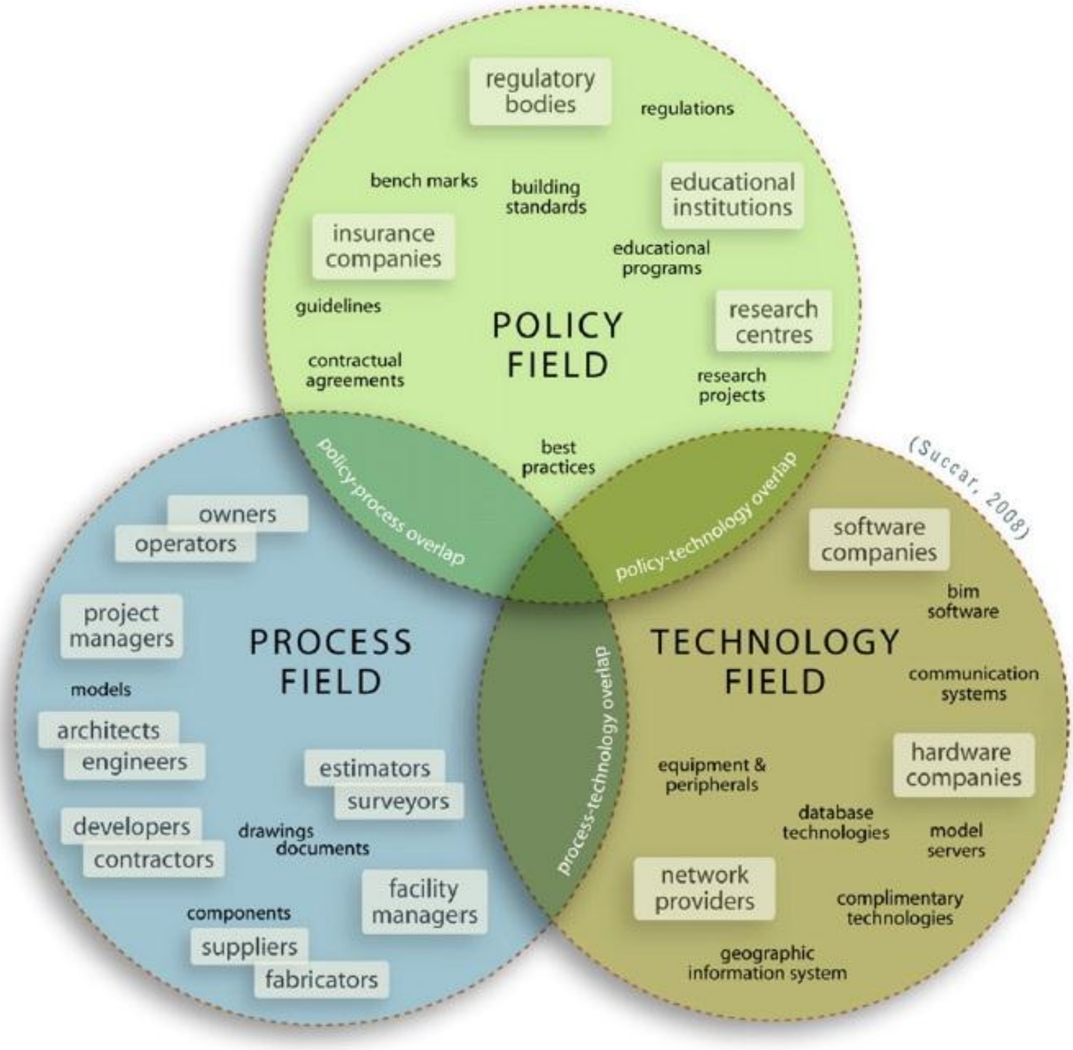


Figure 5: Describes the different fields of BIM in a Venn-diagram (Succar, 2009)

- **The BIM Technology Field:** Here is a group of players specialized in the development of software, hardware and equipment to increase the productivity and profitability in the AEC sectors. For example companies that develops software solutions applicable to the design, construction and operation of facilities.

- **The BIM Process Field:** This field clusters a group of players who procure, design, construct, manufacture, maintain and use the structures, for example owners, architects, engineers, contractors and facility managers; organizations involved in the ownership, delivery and operations of buildings or structures.

- **The BIM Policy Field:** Holds a group of players with decision-making capabilities, who focuses on preparing practitioners, delivering research, allocating risks and minimizing conflicts within the AEC industry. For example regulatory bodies, educational institutions and research centers.

3.4.3 BIM maturity

The concept of BIM maturity includes the BIM fields mentioned in Chapter 3.3.1; technology, process and policy. Other important factors to measure BIM maturity against are the data flows and the project lifecycle phases. Data flows are varied and can be structured or non-structured, compare a database to an image for example. The project lifecycle phases consist of design, construction and operations. BIM implementation will change the components of and relations between these lifecycle phases. The three BIM stages can be seen in Figure 6 below (Succar, 2009):

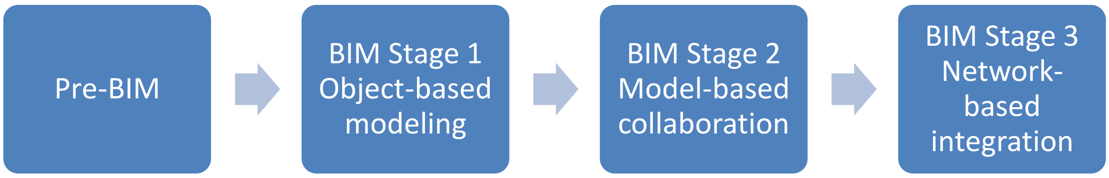


Figure 6: The different stages of BIM maturity (modified from Succar, 2009).

During the pre-BIM stage there is very much dependent on 2D documentation, even though some 3D documentation is generated is lacks intelligence and cost-estimates and quantities cannot be generated from the visualization model.

BIM stage 1 is initiated by the use of an object-based 3D parametric software tool such as Revit, where users generate models within design, construction or operation – the lifecycle phases. Collaborative practices are similar to pre-BIM status and there is no significant model-based collaboration. However, the object-based models allows for an earlier increased detail level of design and construction matters which enables faster project life-cycle phases (Succar, 2009).

BIM stage 2 is when players actively collaborate with players from other disciplines, which may occur in many ways depending on the set of BIM tools used. Model-based collaboration may occur within one or between two project lifecycle phases. Contractual changes might be needed as model-based interchanges increases.

BIM stage 3 is when integrated models are created, shared and maintained collaboratively throughout the project lifecycle phases. This can be achieved through model server technologies using proprietary, open or non-open formats. At this stage models become an nD model which means that complex analyses can be made at early stages of virtual design and construction (Succar, 2009).

According to Bilal Succar the ultimate goal of BIM implementation is to reach integrated project delivery (IPD), which integrates people, systems, business structures and practices into a collaborative process to optimize project results, increase owner value, reduce waste and maximize efficiency through all phases of design, fabrication and construction (Succar, 2009).

3.4.4 OpenBIM

OpenBIM is a development program in the AEC industry, running from 2009 to 2011. After the program was completed it was decided that OpenBIM should continue their work without a time limit. The goal with the program is to accomplish a process which guarantees participation and demands, with good architecture, good technical solutions and the lifecycle economy in focus, and to achieve a more effective construction and facility management so that, at latest, year 2013 can see a clear impact of the costs for this (OpenBIM, 2012).

To achieve the goals of the program it is necessary that the stakeholders in the program increase their participation and uses more alternative solutions which are analyzed with the help of BIM models together with consequent use of BIM for visualization, integration and automation of processes.

OpenBIM looks at real construction projects and facility management situations with an emphasis on implementation. More than 60 companies are actively participating in the OpenBIM project (OpenBIM, 2012).

3.4.5 Data exchange and interoperability

The idea of interoperability can be explained as a seamless exchange of information between different computer programs. This has been a dream since the 1970´s and a lot of effort has been put into this problem over the years. Even today we cannot be sure that data transferred 100 % correctly from software A to software B. There are many reasons for this and it is uncertain if we will ever reach 100 % interoperability. But the use of object-based CAD systems in various areas of the construction industry is improving the value of interoperability. It typically meets three different types of technical needs (Drogemuller, 2009).

- Interchange of information between different roles at a stage in a project. An example of this is CAD data and quantity take-off software.

- Continued use of information through the different stages of a project, from initial and detailed design to construction, maintenance and finally refurbishment or demolition.

- To be able to access archived data throughout the life of a facility. For example, information saved in the IGES format in the 1980's and 1990's is still accessible even if the creating software is no longer available.

IGES (Initial Graphics Exchange Specification) was a data exchange standard in the US. France used another one called SET (Standard D'Exchange et de Transfert) and Germany had their standard called VDA-FS (Verband der Automobilindustrie-Flächen-Schnittstelle). These competing data exchange standards led to problems which caused ISO (International Standards Organization) to develop a set of standards which were aimed for the manufacturing sector, known as STEP. But the development process was slow and in 1994 Autodesk formed the Industry Alliance for Interoperability which was developing Industry Foundation Classes (IFC). IFC continued to build on the technology behind STEP but was customized to suit the construction industry instead of the whole manufacturing sector (Drogemuller, 2009).

There are two major methods of exploiting BIM. The first one is to use a software suite which supports the same data exchange standard. Often this means using software from a single vendor, sometimes with add-on software from smaller developers. Naturally, this model is strongly supported by the major CAD companies. There negative side of this approach is that the range of software is restricted and the data exchange is limited by the capabilities of the file format. The second approach is to use software that supports an open exchange format, such as IFC (Drogemuller, 2009). It has the obvious advantage that any software can be used, as long as it supports the exchange format. However, the downside is that the open standards do not fully support the capabilities of the proprietary file formats.

3.4.6 IFC – Industry Foundation Classes

IFC is the main buildingSMART data model standard, and the IFC format is registered by ISO and in the process of becoming an official international standard. The IFC is a common data scheme for holding and exchanging data between different proprietary software applications. The IFCs cover the many disciplines that contribute to a building throughout its lifecycle from conception, through design, construction and operation to refurbishment or demolition (BuildingSMART, 2012). Development of the IFC was supported by Autodesk in the early years and then by the Finnish government in the VERA program; a wide range of research and development projects to create a competitive advantage for the Finnish construction sector (Drogemuller, 2009).

The fundamental idea with the IFC format is that it is open and not linked to a certain software producer. It can be used to exchange and share BIM data between applications from different software producers. As an open format it is neutral and independent of a particular software producer's development plans. The implementation of an IFC exchange should follow specific requirements which prevent uncertainty; it is important to be specific about what information is needed (BuildingSMART, 2012).

The use of IFCs in the industry was low until 2006 when GSA in the US started to demand the use of BIM models in their building design process. GSA controls the US Government office and space requirements, responsible for over 8700 buildings. This gave the IFCs a boost, and when the governments in Denmark and Singapore also gave their support the software producers had no choice but to make sure their software supported the IFC standards. Today the IAI is known as buildingSMART and they continue to develop and promote the IFC model. Currently they are working on a new IFC for infrastructure (BuildingSMART, 2012).

3.5 BIM tools and parametric modeling

What distinguishes modern BIM design applications from earlier CAD applications? The difference is a technology called object-based parametric modeling, which was developed in the 1980's for manufacturing purposes. Instead of representing objects with fixed geometry and properties, it does this by parameters and rules that determine the geometry as well as non-geometric features. The parameters and rules can be used to describe the relation to other objects, which means that objects automatically updates according to changing contexts. This is called the behavior of the object. Complex geometries can be modeled using this technique, which was not possible with the old CAD applications. Companies can make customized object libraries for a specific use, and add other attributes to the objects depending on their need. BIM design tools allow the user to mix intelligent 3D modeled objects with 2D sections for production of drawings (Eastman, et al. 2011).

Today's BIM design applications can carry out specific tasks as a tool, while at the same time providing a platform for data management within a model for different uses. Some have the ability to manage data in different models, also known as a BIM environment (Eastman, et al. 2011).

3.6 Mälarbanan – A BIM pilot project for Vectura

As mentioned in Chapter 1.1 Mälarbanan is a complex project consisting of extension to four tracks, designing and constructing 8 km of new railway. In the project new technology is used for BIM modeling purposes. Project Mälarbanan is a very important project for Vectura, since it is the first large railway project where BIM is used, and some of the tools have been modified and customized to fit the use.

3.6.1 BIM Technology

Due to its history as Banverket Projektering, Vectura has inherited the same software platform when it comes to design tools and software for railway projects. Bentley's suite of products is used for the design of the railway.

3.6.1.1 Microstation v8i

Microstation is a design software developed by Bentley and used globally as an information modeling environment in the AEC industry. It can be used as a software application for designs in 2D and 3D and to produce drawings and 3D PDFs. Microstation can also be used as a technology platform for specific purposes with applications from Bentley and other software vendors. There are specialized applications for use within the civil field such as rail design and construction, track maintenance and so forth. Moreover, Microstation can import and export DWG and DGN formats among others. According to Bentley, it is used by 47 of the top 50 ENR (Engineering News-Record) firms (Bentley, 2012a).

3.6.1.2 ProjectWise

Bentley ProjectWise is a project collaboration and information management software developed for the AEC industry. The ProjectWise system consists of several components; a schematic overview of it can be seen in Figure 10 below.

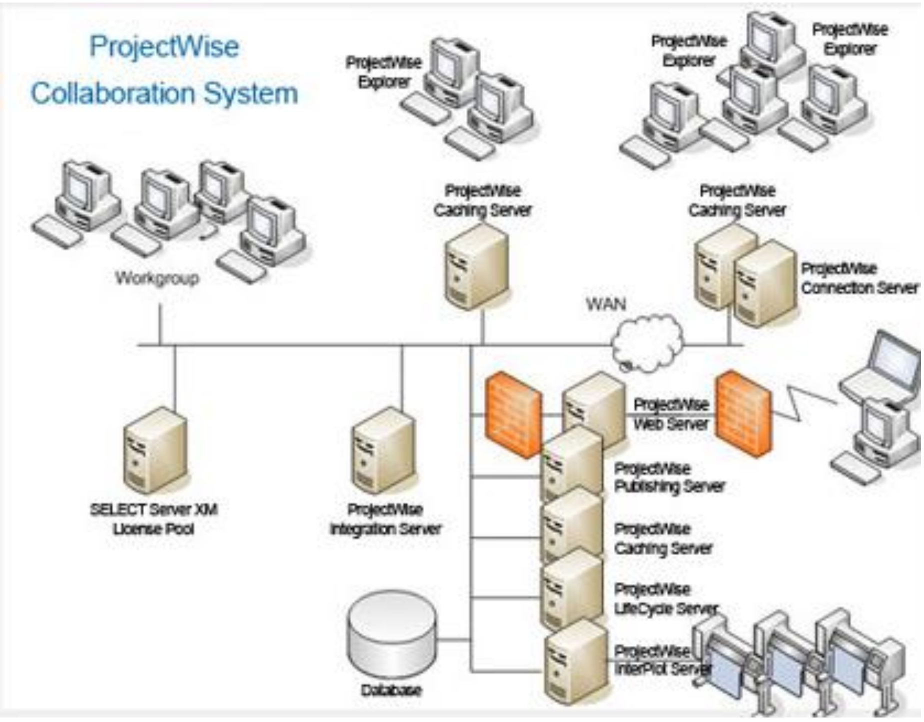


Figure 10: Shows the layout of the ProjectWise system with its components (Bentley, 2012b)

The system can be used for single offices or distributed services for a company or a team project. Bentley ProjectWise Integration server is the central component of the system, and often it is enough with just one integration server. Other servers are also needed in the system; a caching server, a web server, a publishing server and a geospatial server. However, the actual setup varies depending on the size and complexity of the project. ProjectWise Explorer and Navigator run as desktop applications for visual collaboration (Bentley 2012b).

3.6.1.3 RailTrack

RailTrack is a specialized application for preliminary and detailed 3D design of rail infrastructure. It shares the same track geometry as PROL (Power Overhead Line) and allows users to optimize horizontal and vertical track geometry to reduce project costs. It can be configured to support a wide range of international standards and is suitable for light rail, heavy rail, metros, high-speed rail and MAG-LEV projects (Bentley, 2012c). Figure 11 below shows a railway model in 3D with views of the cross section and profile.

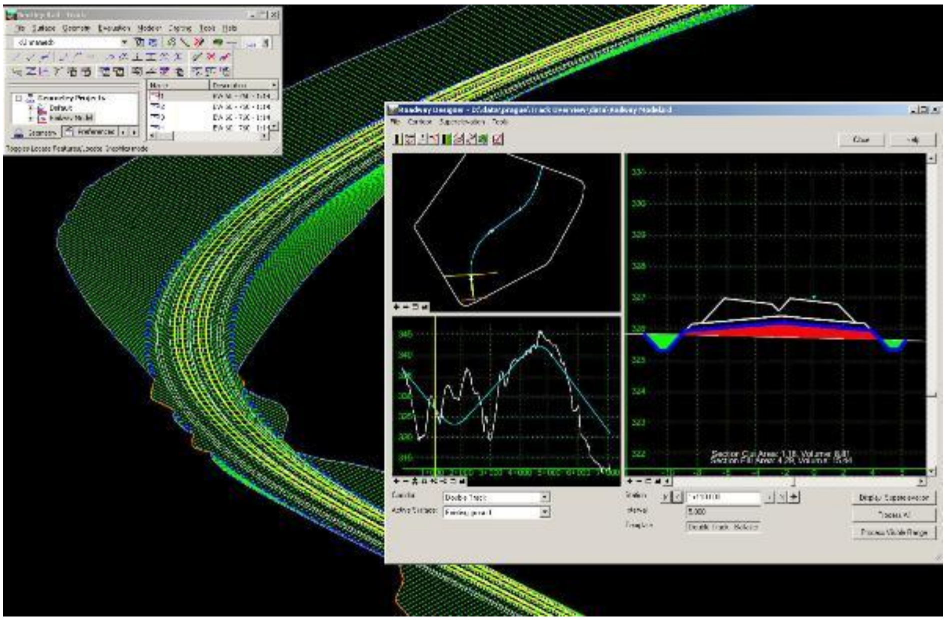


Figure 11: Shows a view of Bentley RailTrack with Roadway Designer (Bentley, 2012c)

RailTrack offers a high degree of automation to established industry workflows, which can be transformed into an increased productivity and time saving during the design and maintenance of rail projects. Railtrack is used by infrastructure owners, operating companies and contractors (Bentley, 2012c).

3.6.1.4 ProjectWise Navigator

Bentley Navigator is a standalone BIM design review tool with a 4D capability, which means a project time plan can be attached to the model. It is used by infrastructure teams to review and analyze project information. Multiple 2D and 3D design files from many sources (DWG, DGN etc.) as well as i-models can be imported to Navigator (Bentley, 2012). I-model is an extensible XML format for publishing DGN and other Bentley data, although a plug-in is also available for generating i-model data from other applications such as Revit (Eastman, et al. 2011). 2D and 3D PDFs can be produced which can be used by a wider group of stakeholders without access to Navigator. Other capabilities are reviewing of clashes, analyze schedule simulations and measure distances with high precision. Moreover, Navigator can be used to mark up designs. For instance if there are two objects overlapping each other a mark-up can be created which is saved for later (Bentley, 2012b).

3.6.1.5 PROL and Promis-e

PROL is Bentley's application for designing the overhead line and catenaries and uses the same track geometry as RailTrack. PROL can be used to generate realistic 3D models for analysis and visualization, but also accurate project drawings and deliverables for client approval and construction (Bentley, 2012d)

Promis-e is an application for control system design, solving tasks that involve electrical schematics, connection lists, panel layouts and bills of material. Promis-e integrates all these functions for a quick and efficient result. It includes a parts database that allows users to associate components in the design with specific parts information, and also enables easy generation of parts lists and other documentation (Bentley, 2012e). An adaption of this application towards railway design will make it possible to use it for electrical, signaling, and channelization purposes in Mälarbanan[1]. A library of symbols needs to be designed before Promis-e can be used in practice

3.6.2 The procurement in project Mälarbanan

This chapter is mainly based on the information from the project's contract documentation, provided by the Swedish Transport Administration.

The Mälarbanan project uses a relatively new contract method called "Extended Collaboration", which demands a specific commitment from the parties involved. Collaboration at an early stage is encouraged, which differentiates it from other, more traditional procurements like DBB and DB. The contract method is a step towards IPD which was described in Chapter 3.1.3.It also means that the owner has double roles in the project; first the normal, formal owner role as a counterpart in the project, but also as a partner in the project collaboration (Trafikverket, 2011c). In Figure 12 below a schematic picture can be seen of the overall project organization.

[1] Designer (Interview, 2012)

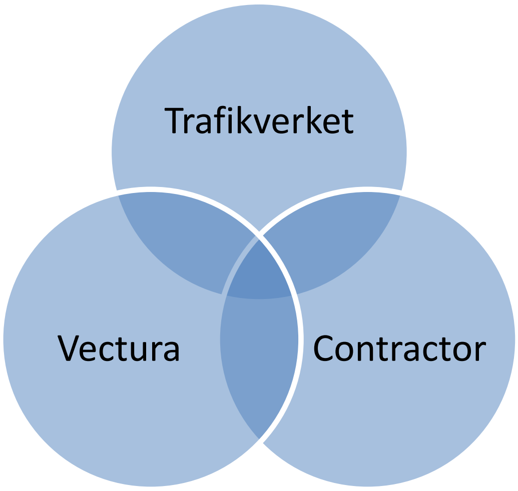
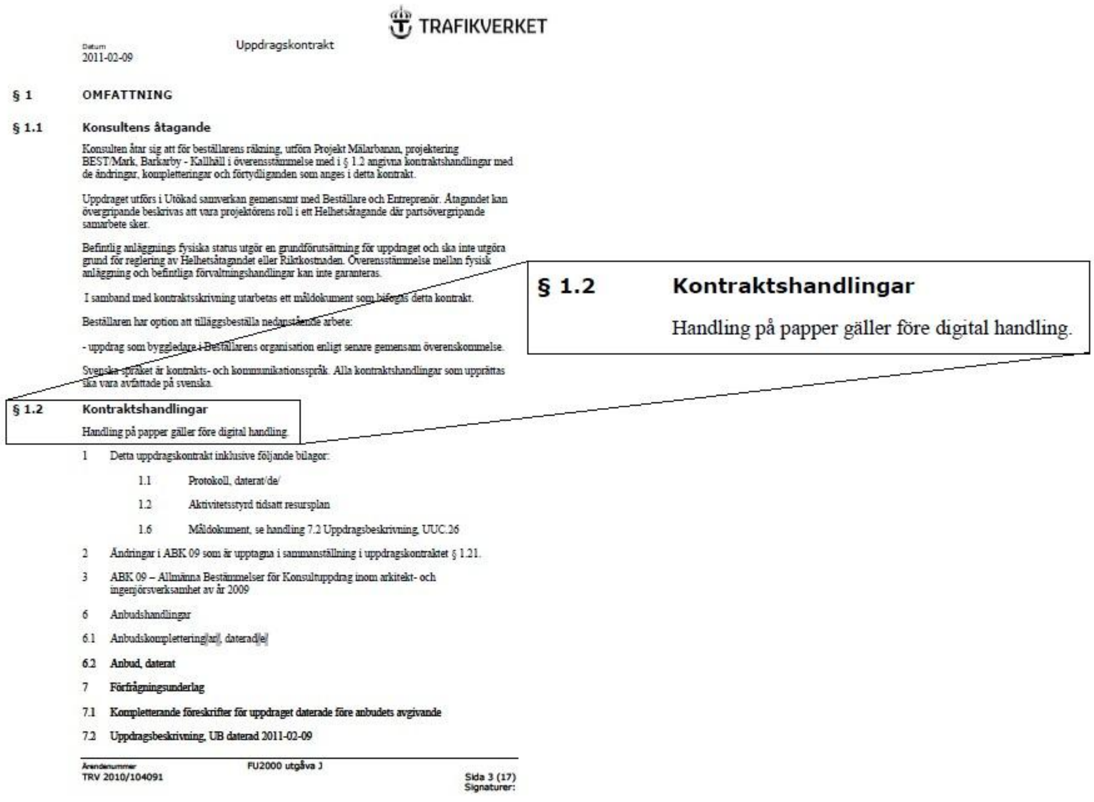


Figure 12: The project organization in Mälarbanan can be illustrated by a Venn-diagram.

The circles that represent the different parties in the project have areas of their own, and areas that are shared with one or both of the other parties. This is how the collaboration works in practice; some parts of the work are carried out in teams with one or more of the other parties, and some work is carried out separately. The idea is that the collaboration will start at an early stage in the project to get the most from it. The aim with the procurement in Mälarbanan is that all parties involved will benefit from the increased collaboration (Trafikverket, 2011c).

It is clearly stated in the contract that a paper document is valued above a digital document, which could cause legal issues later on in the project (see Figure 13 below). This will be discussed more in the analysis in Chapter 5.


TRAFIKVERKET

Datum
2011-02-09

Uppdragskontrakt

§ 1 OMFATTNING

§ 1.1 Konsultens åtagande

Konsulten åtar sig att för beställarens räkning, utföra Projekt Mälarbanan, projektering BEST/Mark, Barkarby - Kallhäll i överensstämmelse med i § 1.2 angivna kontraktshandlingar med de ändringar, kompletteringar och förtydliganden som anges i detta kontrakt.

Uppdraget utförs i Utökad samverkan gemensamt med Beställare och Entreprenör. Åtagandet kan övergripande beskrivas att vara projektörens roll i ett Helhetsåtagande där partsövergripande samarbete sker.

Befintlig anläggnings fysiska status utgör en grundförutsättning för uppdraget och ska inte utgöra grund för reglering av Helhetsåtagandet eller Riktkostnaden. Överensstämmelse mellan fysisk anläggning och befintliga förvaltningshandlingar kan inte garanteras.

I samband med kontraktsskrivning utarbetas ett måldokument som bifogas detta kontrakt.

Beställaren har option att tilläggsbeställa nedanstående arbete:

- uppdrag som byggledare i Beställarens organisation enligt senare gemensam överenskommelse.

Svenska språket är kontrakts- och kommunikationsspråk. Alla kontraktshandlingar som upprättas ska vara avfattade på svenska.

§ 1.2 Kontraktshandlingar

Handling på papper gäller före digital handling.

1 Detta uppdragskontrakt inklusive följande bilagor:

1.1 Protokoll, daterat/de/

1.2 Aktivitetsstyrd tidsatt resursplan

1.6 Måldokument, se handling 7.2 Uppdragsbeskrivning, UUC.26

2 Ändringar i ABK 09 som är upptagna i sammanställning i uppdragskontraktet § 1.21.

3 ABK 09 – Allmänna Bestämmelser för Konsultuppdrag inom arkitekt- och ingenjörsverksamhet av år 2009

6 Anbudshandlingar

6.1 Anbudskomplettering/ar/, daterad/e/

6.2 Anbud, daterat

7 Förfrågningsunderlag

7.1 Kompletterande föreskrifter för uppdraget daterade före anbudets avgivande

7.2 Uppdragsbeskrivning, UB daterad 2011-02-09

Ärendenummer
TRV 2010/104091

FU2000 utgåva 3

Sida 3 (17)
Signaturer:

Figure 13: Paragraph 1.2 in the project contract states that a paper document is valued higher than a digital document (modified from Trafikverket, 2011c)

A common economic incentive for all the parties involved in the project will increase the efficiency. At the start of the project, a total "target cost" was estimated for the planning, design and construction of the railway facility. If, at the end of the project, the sum of all costs is below the calculated "target cost" the parties share the difference. Thus, the incentive is equal to the target cost minus the sum of all the accumulated costs for the project. Of this incentive money pot, the owner receives 50 %, the contractor 40 % and the designer 10 %. So if things are done more efficiently there will be an extra reward to be shared by the parties involved (Trafikverket, 2011c).

Furthermore there are bonuses if certain critical activities in the project are done in time, which provides more motivation to do things efficiently and according to the time plan. Since the hourly pay for the consulting hours is lower compared to other more traditionally procured projects, the money to be earned is not from working many hours, but from the economic incentives. Due to this the collaboration among the parties in the project will increase further, since they all benefit from the common economic goal. But on the other hand there are risks involved, which are absorbed by the parties involved in the collaboration. For example if the design documents are delayed has to pay a fine for every week of the delay (Trafikverket, 2011c).

A common goal document contain all the general conditions for the collaboration, and all the parties have a responsibility to fulfill sub targets linked to the time-plan concerning quality, environment and economy. According to the project contract the final design documentation should be delivered at latest in the end of year 2016 (Trafikverket, 2011c).

3.7 Benefits from using BIM

Even though the AEC sector is in the early days of BIM use, there have been significant improvements compared to the old 2D CAD or paper-based practices. The advantages that will be presented in this chapter are not all in use as of today, but within a near future they can be expected to happen as the BIM technology matures. BIM is also working well alongside Lean thinking, which is to maximize the value and minimize the waste, to drive the productivity further. Figure 7 shows BIM in the center of building design and construction processes, as it meets the demands of an increased pressure on the building process (Eastman, et al. 2011).

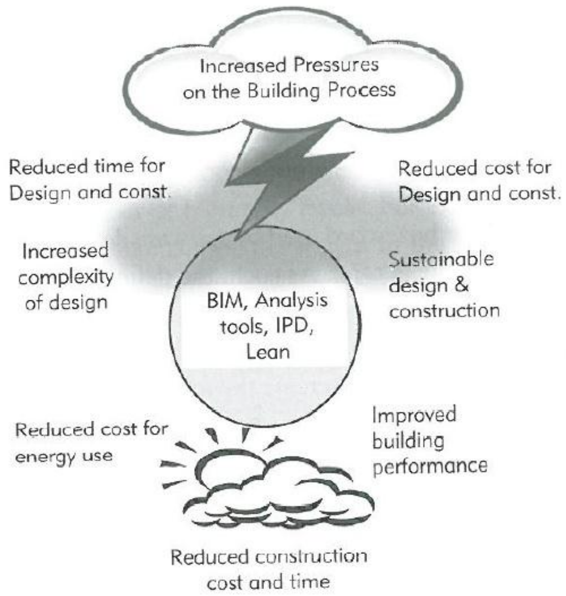


Figure 7: Increased pressure on the building process is resolved by using BIM technology (East man et al, 2011)

This leads to a reduced time and cost for design and construction, an increased complexity of design, a more suitable design and construction and an overall improved building performance It also works well in combination with Lean Production principles, aiming at eliminating all the factors in a production process that do not add value to the customer in the end (Eastman et al, 2011).

Below is a list of the benefits from implementing BIM throughout the lifecycle of a building or facility, from idea to design, from construction to facility management. Some of the listed capabilities require more development and BIM maturity but most can be realized today. They are based on chapters 4, 5 and 6 in the BIM Handbook (Eastman et al, 2011).

3.7.1 Benefits for the owner

Concept, feasibility and design benefits

At an early stage, before the owner contracts an architect or designer, it is necessary to know if a structure of a given size, quality and program requirements can be built within a given cost and time budget. If these questions can be answered with a certainty, the owner can know for sure that their goals are achievable. Finding out that a certain design is over budget after a lot of time and effort has been put in is wasteful. A BIM model linked to a cost database can be of great value in this situation.

Increased building performance and quality

Using a schematic model before a more detailed building model allows for a more careful evaluation to determine whether the building meets the demands regarding functional and sustainable requirements.

Improved collaboration using integrated project delivery (IPD)

BIM can be used at an early stage if the owner uses IPD for project procurement. This means that design and cost issues are better understood, but also that the traditional paper exchange and associated delays is avoided.

3.7.2 Benefits for the designer

Earlier and more accurate visualizations of a design

With the 3D model being designed directly, instead of being generated from multiple 2D views, it can be used to visualize the design at any part of the process.

Automatic low-level corrections when changes are made to the design

If using parametric modeling the objects are controlled by rules that ensure proper alignment, then the 3D model will be free of geometry, alignment and spatial coordination errors. Thus, the user's need to correct design changes is significantly reduced.

Generation of Accurate and consistent 2D drawings at any stage of the design

Since there is still a need for 2D drawings, these can easily be extracted from the BIM model for a given purpose. This reduces the amount of time and number of errors that are otherwise associated with the generation of construction drawings. If changes are made to the design, new accurate drawings can be generated as soon as the design modifications are entered.

Earlier collaboration of multiple design principles

Using BIM technology means that several teams can work simultaneously in different design disciplines. This reduces the design time but also the number of errors and omissions. Furthermore it gives an earlier insight to where problems might be present in a design, and also better possibilities to improve the design. It is more cost-efficient to change the design at an early stage compared to waiting until the design is almost complete, when the major design decisions have been made.

Cost estimates throughout the design phase

It is easy to generate a bill of quantities during any stage of the design phase, which means that accurate cost estimations can be made. Further into the design process there will be more detail in the quantities and more accurate cost estimation. In the end of the design phase an estimate can be based on all the objects contained in the model, which allows for a more accurate final cost estimate. It is clearly an advantage to have the contractor in the project team when using BIM for cost estimation, their knowledge is needed in terms of constructability insights and for more accurate cost estimation.

3.7.3 Benefits for the contractor

Quick reaction to design changes

When changing an object in the model, the impact can be seen and changes to the other objects will automatically update. Therefore it is easier to see the consequences of a change in the model, and clashes are avoided this way. Furthermore design changes can be resolved faster in a BIM system since modifications can be shared, visualized, estimated and resolved without the use of paper drawings which is much more time-consuming.

Discovery of design errors and CAWs before construction

If the 3D building model is the source where all the 2D and 3D drawings are extracted from, design errors caused by inconsistent 2D drawings is not an issue any longer. Also models from different disciplines can be brought together and compared systematically. CAWs (Changes and Additional Work) are identified already in the design phase rather than in the field during construction. The coordination between designers and contractors in a project becomes better, and this also speeds up the construction process and provides a smoother process overall.

Synchronization of design and construction planning

If a construction time plan is linked to the 3D objects, it is possible to simulate the construction process and see what the structure looks like at any given point in time. It will give an insight into how the structure will be constructed day-by-day, something that is not possible from paper documents. The benefit is higher if also temporary construction equipment is included such as scaffolding, cranes and other important objects, so that these also can be added to the schedule activities.

Better implementation of lean construction techniques

Using an accurate BIM model will provide an accurate estimation of the material needed for each segment of the work, and enhances the planning and scheduling of sub-contractors so that material, people and equipment will arrive just-in-time. This minimizes wasted efforts and the need to stock material on-site, according to Lean construction principles. It reduces the cost and helps improve the collaboration at the jobsite. A mobile device with the model loaded into it can also be used for material tracking, construction progress and automated positioning in the field.

Synchronization of procurement with design and construction

As mentioned before the BIM model can provide accurate quantities for all material and objects in the design. This can be useful when it comes to the procuring of material from suppliers and subcontractors. However, for this to work the object definitions for many manufactured products have not been developed. When this does happen, it will be possible to order exact quantities from the supplier, for example pre-cast concrete elements and mechanical components.

Machine-guidance

By using machine-guidance the excavation of masses is made easier, quicker and with a higher precision. The excavator is equipped with a computer which uses digital terrain models (DTMs) which can either be transmitted by wireless or simply by a USB memory stick. The excavator uses a GPS positioning system with one or two antennas for orientation. Also the buckets are equipped with sensors that register location as well as the angle of it so that the operator know both the rotation and position of both machine and bucket (Infomap, 2012). Figure 8 below shows the computer inside the machine which is operated by a touch-screen. It can hold multiple DTMs for different purposes so that the machine can work efficiently without unnecessary interruptions.

Figure 8: Shows the computer used by the operator, where the DTMs are controlled.

After calibration of the bucket, the accuracy is about 10 mm horizontally and 15 mm vertically. The small device to the left in Figure 8 indicates when the bucket is in the right location, and gives a warning if the operator excavates too deep for example. Another benefit from machine-guidance is that the need of personnel decreases (Infomap, 2012). Previously surveyor's assistants put out pegs which the operator used as indicators, now it is possible to work straight from the DTM in the computer.

The advantage with BIM is that the necessary DTM is ready to use without modification when it is delivered from the designer. That saves the time it takes for the contractor to develop their own model for machine-guidance.

3.7.4 Benefits for facility management

Improved commissioning and handover of facility information

The contractor and possibly sub-contractors collects information about materials used and maintenance information for the different systems. If this information is linked to the respective objects in the BIM model then the model itself can be used for facility management. It can also be used before the handover to check that all the systems are working as designed.

Better management and operation of facilities

The BIM model is a source of information for all the technical systems used in a facility. Analyses done earlier for example regarding control systems and mechanical equipment can be provided to the owner to verify the chosen design once the building is in operation. The information can be used to monitor the systems when the building is in use and make sure they work properly.

Integration with facility operation and management systems

The building management can benefit from an updated building model as a starting point, since it can provide useful as-built information about spaces and systems. It can facilitate monitoring of control systems and supports remote operating management of facilities. There are many possible areas where a BIM model can be useful when it comes to facility management, but many of these capabilities have not yet been developed.

3.7.5 BIM for railway design at Vectura

Vectura has had a project for the implementation of BIM in the railway division at Vectura. This chapter is based on the resulting project report (Vectura, 2012).

Vectura has adapted a "BIM-ladder" with a step by step implementation of BIM, see Figure 9 below. The first step represents the work method pre-BIM where the design was done in 2D. The next step is a 3D model but with the data in a separate system, this is not BIM either. Not until the 3D model contains intelligent object it can be called BIM, and then the level of BIM is increasing with added time planning (4D) and cost calculation (5D). The BIM model can also contain noise calculations, fire analysis and energy simulations, in the future depending on how far the development reaches.

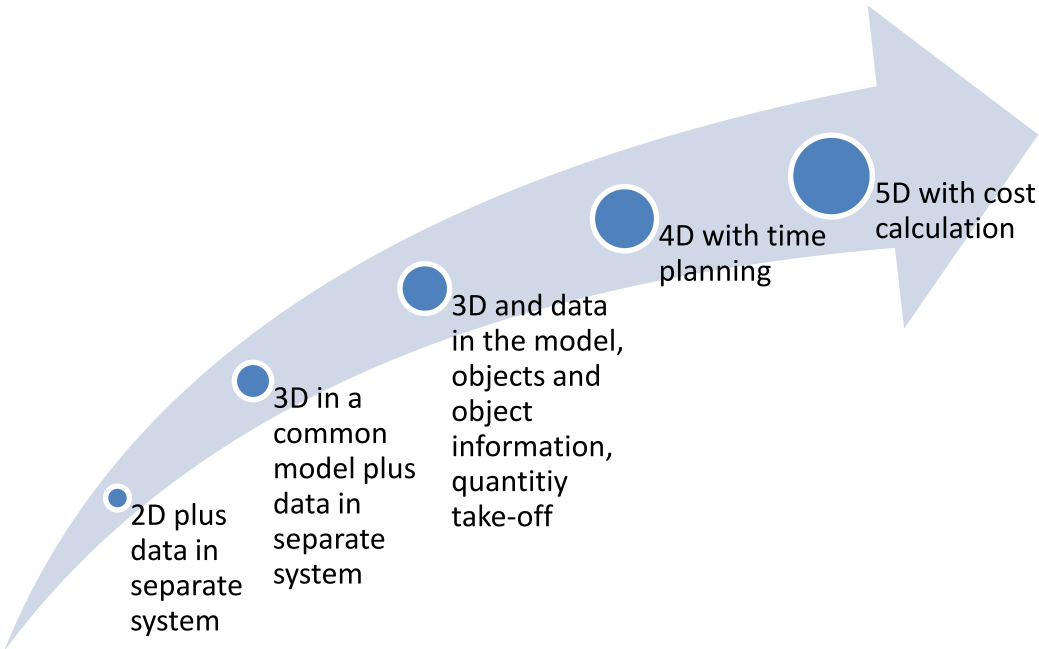


Figure 9: The different stages in the "BIM-ladder" with an increasing level of BIM to the right.

Benefits for Vectura identified from the project:

- A better understanding for the railway facility since all CAD designers can see the common 3D model at an early stage in the project

- Better review of object placement, everything is in a 3D environment. A condition is that all technical areas work in the same model.

- Design material in a digital environment can facilitate visualization, simulation, quantity take-off, time planning, cost calculations etc.

- Re-use of data through different stages in the process.

- Better quality and timesaving through a more effective work method.

- Fulfillment of new industry standards for upcoming procurements

3.8 Challenges for BIM implementation

It is easier said than done to embrace the use of a new technology which also requires new processes and changes to be implemented for each part of the design and construction phase. Inevitably this leads to challenges and problems that must be identified and solved.

3.8.1 The designer does not benefit most as the key adopter

The benefits for the owner in a BIM project are easily seen, it allows for design optimization, fewer construction errors and fewer design coordination issues. The contractor also benefits from production planning and reduced fabrication costs. However, for designers the economic benefits are less apparent. The designer has to invest in new hardware and licenses for software and train the staff, and unless the designer receives shares of the economic benefits this is a significant obstacle to the implementation of BIM. Furthermore BIM can increase the potential liability of the designer, but new business models are developing slowly to address this problem (Ashcraft, 2009).

3.8.2 Collaboration challenges

BIM works as a platform for increased collaboration, which means that issues arise regarding the development of effective project teams so that access to the model information is achieved. For example, if the designer is using traditional paper-based drawings, then it is necessary for the contractor to build a model that can be used for construction planning, estimating and coordination. And if the model is created using BIM, then the level of detail might be an issue if it is too low, or if it has inadequate object definitions. This might also require a new model for the construction. Another collaboration problem might occur if the members of the project use different modeling tools. To move the model from one environment to another, or to combine models might in this case require more tools for doing so, errors might occur while doing so. IFC could be a solution to these problems (Eastman, et al. 2011).

3.8.3 Legal status of the model

Another problem is the legal status of the model. The current practice uses several models to communicate the design and construction intent for a project. This means that the complete design is not visualized until they are imported to a viewing program. Usually the models do not contain all the necessary details for construction, therefore additional 2D information is added to the model. Then there are the permitting agencies that are not ready to view digital information and require traditional submissions of printed drawings. Another question is regarding how to stamp the model. Currently these issues are solved by using a printed submission as the contract document, even though the work up until then has been digital. But what is the legal status of the model if it is not a contract document? This question has a few different answers, the first one is that the model is a "co-contract document" used between the parties in the project, but not used for permissions by agencies. With this view, the question of inconsistencies handling needs to be stated in the contract (Ashcroft, 2009).

3.8.4 Changes in practice and use of information

By using BIM the integration of construction knowledge will start earlier in the design process. This will benefit integrated design-build firms capable of coordinating all phases of the design. Contract methods like IPD that require good collaboration will provide better advantages to owners with the use of BIM. However, the most significant change for firms that implement the use of BIM is the use of a common, shared building model during the design, and a set of building models as a basis for the construction (Eastman, et al. 2011).

3.8.5 Implementation issues

The change when going from a traditional 2D or 3D CAD environment to a building model system involves much more than only acquiring software, upgrading hardware and training the staff. An effective use of BIM requires that changes are made to almost every aspect of a company's business practice, and not just doing the same things in a different way. A basic understanding of BIM with its related processes is needed and a plan for the implementation. What the changes will be is depending on the specific company and their activity in the AEC sector. However, there are some general steps that need to be considered, which can be seen below (Eastman, et al. 2011).

- Top-level management need to develop a BIM adoption plan which covers all aspects of the company's business and how the changes will affect both internal departments and external partners and clients.

- Create a team with key managers responsible for implementing the plan, with cost, time and performance budgets to guide their performance.

- Start using BIM in one or two smaller projects in parallel with existing technology and produce traditional documents from the building model. This will help reveal where there are missing building objects, deficits in output capabilities and in links between programs. This way the company can also develop modeling standards and determine the quality and detail level of models.

- The initial results can be used to educate and guide the continued BIM adoption of software as well as staff training. Keep senior management updated on the progress, insights etc.

- Continue to integrate BIM capabilities into more aspects of the company's functions. Reflect the new business processes in contractual documents with business partners and clients.

- Look back and observe the implementation process, reflect on the benefits and problems observed so far. Set new goals for performance, time and cost and continue to extend BIM-facilitated changes to new locations and functions within the company.

4 RESULTS AND EMPIRICS

This chapter will present the result from the interviews. The information from the interviews has been placed systematically in a matrix according to the question and respondent.

4.1 The picture of BIM

The picture of BIM varied both within the different organizations but also among the respondents from the same organization. Some have very limited knowledge about BIM while others have been working with it for several years, and therefore has a wider understanding of the concept.

4.1.1 Vectura

A CAD designer[2] at Vectura pictures BIM as a tool to produce 3D designs, but also for information. A quote from another CAD designer[3] shows a more extended view on BIM:

"Many people think that BIM is merely a 3D model, but it is more than that. It is a whole process where you work in a digital information model with intelligent 3D-objects with attributes, links to type sections, article numbers and more so that quantity take-offs can be made by a single click on the button"

A senior CAD designer[4] comments that BIM is not something widespread within the infrastructural area of the industry. He thinks that BIM is something more related to house building where it has been used frequently for a longer time. The use in the infrastructural area has not yet reached there.

A model manager[5] sees BIM as something useful starting from an early phase in a project and all the way through planning and construction to facility management:

"There are benefits from using BIM, depending on the phase you are currently in, all the way from the initial study to the management of the facility. My picture of BIM is the process of getting as much information along from the first stroke of the pencil to the finished product"

Another comprehension is that even though the word BIM is something rather new, some of the activities associated with it are known and has been used for a long time, for example modeling in 3D. This can be underlined by a quote from the project manager[6]:

"The word BIM, Building Information Modeling, was something completely new to me. BIM for me today means 3D, it is just a word. 3D plus the time axle is 4D and

[2] Designer (Interview 2012)
[3] Designer (Interview 2012)
[4] Designer (Interview 2012)
[5] Designer (Interview 2012)
[6] Designer (Interview, 2012)

that is also a part of BIM, and then material lists can be added. Right now it is an object in 3D that we can add attributes to"

If working and communicating with models in the railway sector is a new phenomenon, consultants working with road resign have more experience in this field. Vectura designs both roads and railroads and a design coordinator[7] who used to work with road design says that they have been working with models for 10 years. However, it is not until later years that the model has been coordinated with respect to all the technical areas. He is quoted[8]:

"Road design is ahead of railway design when it comes to the use of BIM. We have had 3D-visualization for a long time"

This shows that there is not just a different BIM maturity and picture among the different players on the market, but also differences between technical areas within one organization. DTMs have been used for road design for a long time, and also clash detection[9].

A technical manager[10] at Vectura has visited user conferences and exhibitions and there BIM has been a popular topic the last couple of years. But the people visiting these exhibitions tend to be on the frontline of the development. It is difficult to say if there are only specific projects that are ahead in the use of BIM or if that is true for the whole infrastructure sector[11].

4.1.2 The Swedish Transport Administration

The Swedish Transport Administration (STA) is the biggest owner of railway and road projects in Sweden. At the moment the STA has several large pilot projects within infrastructure that use BIM in order to develop new work methods. At the moment they are unsure which way they should go, and that is what these projects will determine in the future. Currently the projects have not reached the construction phase and therefore it is too early to draw any conclusions from them.

It is clear that the level of BIM knowledge varies within the organization. One design phase manager has not yet worked with a BIM project but he is very excited and positive about this new approach to design[12]. He sees benefits such as less paper drawings in the future, and that collisions and colliding objects are detected earlier in the design process.

A data coordinator[13] suggests that BIM is used to make the work and planning process more effective. In other words this means that the STA as the owner not only receives drawings, but a more intelligent model file that can be used for many purposes, for example machine-guidance.

---

[7] Designer (Interview, 2012)
[8] Designer (Interview, 2012)
[9] Designer (Interview, 2012)
[10] Designer (Interview, 2012)
[11] Designer (Interview, 2012)
[12] Owner (Interview, 2012)
[13] Owner (Interview 2012)

A technical manager argues that his opinion that the STA are slow to adapt and embrace BIM[14]. The STA sees a great development potential with BIM, but the driver behind this is the market, and not themselves. He says[15]:

"There are a couple of BIM pilot projects, but in my opinion we don't have a strategy for how we should proceed. Instead we are listening to the market. This is because we want to take both designers and contractors into consideration"

The STA is currently looking to hire a BIM strategist, who can coordinate and guide the organization in BIM-related decisions. At the moment the pilot projects are pointing out different directions, each with specific technical solutions[16].

4.1.3 Contractor

NCC Construction Sweden builds everything from housing, schools and sports facilities to roads, railways and power plants. They are organized in four regions: Southern, Western, Stockholm - Mälardalen Region and Northern Sweden (NCC, 2012). They are currently building a new logistics center in Rosersberg outside Stockholm. The project engineer[17] for this project claims that they have been using BIM in infrastructure projects for at least 15 years. He gives an example of when they built runway 3 at Arlanda airport some years ago[18]:

"It wasn't called BIM at the time, but we had a digital 3D model over the airport, and that is BIM. On the other hand, maybe we didn't have all the drainage pipes in 3D but the surface was in 3D, and you knew exactly the gradient of the runway as well as the surface run-off areas and slopes. It is not something new"

NCC has had a BIM strategy for 4 years, but the use and level of BIM varies greatly from project to project, and also depending on the region within the company. They have state of the art projects where BIM has been used at a high level, with both 4D and 5D for time planning and calculations, but also projects where BIM has not been used at all. NCC's BIM strategy is to use a high level of BIM in their "own" projects, which means projects where they have control over the design phase. The project engineer[19] is quoted:

"We are not allowed to start such a project without BIM, where we can affect, or be in charge of the design"

By using BIM in a project it sharpens the requirements for the CAD designer in the design phase, that he produces a correct model without errors. Previously it was enough if the designer made a 2D drawing where the depth in the Z-axis was not included and type sections or normal sections was used. Now it has to be very exact

[14] Owner (Interview 2012)
[15] Owner (Interview 2012)
[16] Owner (Interview, 2012)
[17] Contractor (Interview, 2012)
[18] Contractor (Interview, 2012)
[19] Contractor (Interview, 2012)

according to the surroundings where the connections are between the model and the existing objects.

4.2 From 2D to 3D: The status of BIM implementation

BIM originates from other industries such as manufacturing and industrial design, where the need to control information from the design of a product all the way to manufacturing was vital. Then the BIM concept spread to other industries such as the AEC sector, and primarily within house building. Within heavy civil construction like railways the use of BIM is not as widespread. According to a technical director the prioritized focus areas of BIM should be production and facility management[20]. One of the biggest costs is the long-term maintenance of a railway facility. He is quoted[21]:

"It is easy to focus on the investment cost and forget the cost for long-term maintenance. By minimizing the need for maintenance the initial cost could be higher but you would still benefit in a longer perspective"

If the cost for the design phase only is around 10 % of a project's total budget it means that adding more hours of planning in the design phase does not affect the project budget all that much, and money could be saved in the production and facility management phases.

4.2.1 BIM maturity differences in the AEC industry

BIM within house building is more developed since they started earlier and this has several reasons. The B in BIM stands for Building, and the need to use BIM within house building was identified earlier[22] there. They realized the advantages from using BIM such as clash detection which is more useful within complex buildings where many subcontractors are involved as well.

A railway is flat, and very long-stretched. It is not built vertically like a tall building so there is not the same need to express the design in 3D. This is another reason why the need for 3D modeling was bigger within house building compared to railway projects where 2D has dominated for long[23], and this has driven the BIM implementation further within house building.

The railway sector is very traditional, in a way that makes it slow to react to and embrace new technologies[24]. This could be a reason for why BIM is not as widespread within infrastructure according to several of the respondents. There is an "old way of thinking" in the railway sector, which makes the process slow when adapting to a new

[20] Designer (Interview, 2012)
[21] Designer (Interview, 2012)
[22] Designer (Interview, 2012)
[23] Designer (Interview, 2012)
[24] Designer (Interview, 2012)

technology. First, the need must be identified, and this has happened now. A CAD designer is quoted[25]:

"There are a lot of public investments within the railway, and they are stuck in their huge organizations. It is difficult and takes long time to carry through changes, but now the wheel is in motion and I think it will go faster"

A technical manager at the STA[26] argues that the reason for the slow change process within infrastructure is due to the large and heavy organizations. When a change is made there are many thousands of people who need to be "aboard the boat" as he expresses it. Within the private sector it is easier to fund and implement these kinds of strategic changes.

Furthermore there is another owner and facility management structure within the house building sector. An owner who builds a house is usually also responsible for the facility management[27]. In that case it is easier for the owner to demand what documentation is needed for the operation of the building. In the railway sector, these are separate functions within the STA organization. From a facility management point of view the demands are currently not clear, this is something that is under investigation at the STA according to the data coordinator[28].

4.2.2 Education and BIM courses

Most of the respondents answered that they had got information or some form of education or course about BIM. Some of the CAD designers at Vectura have had a basic course about BIM design, which was aimed at learning the fundamentals about track and ballast design and how to use the BIM tools. Others have got information from Bentley's user conferences with a strong focus on their range of BIM products.

A design coordinator who has had several courses about BIM design says[29]:

"Most people know about BIM as a way to work, but these courses are aimed at implementing it in the design"

Another design coordinator has not received any specific education or course about BIM. Instead he points out project Mälarbanan as a driver for further BIM implementation and knowledge, for example on the project meetings where there are discussions about the subject.

None of the organizations have a BIM strategist, although STA is currently looking to hire one as mentioned before. The STA also has a BIM development project which

[25] Designer (Interview, 2012)
[26] Owner (Interview, 2012)
[27] Owner (Interview, 2012)
[28] Owner (Interview, 2012)
[29] Designer (Interview, 2012)

was started about a year ago[30]. But so far there are no real results from this project according to the respondents.

4.2.3 Changes in the work method for CAD designers

The implementation of BIM means that the CAD designers need to acquire new skills to be able to use the new tools. Depending on if you work with track design or signal design it is very different. A signal CAD designer previously worked only in 2D, since most drawings are schematic and there has not been any need to make the design in 3D. But with the new tools in project Mälarbanan, PROL and Promis-e this will change. Now everything will be designed in 3D, which means that they place objects such as catenary masts with foundation in the model along with object information. A senior CAD designer[31] is quoted:

"For some technical areas there will be some new things, but not so much for us designing the track. But for those working with signaling who are used to working more schematic, it will be a totally new way to work"

A track CAD designer means that there is no real difference in the work method[32]; they are using RailTrack as always. However they do use some new functions in the software which has not been used pre-BIM. He also thinks that there will be a larger workload for the CAD designers when working with BIM since more information needs to be added to the BIM model.

Previously 2D models have been used during project meetings, but this will be changed once all the design is made in 3D[33]. For example during a design review meeting for signaling, a large printed drawing was used and not a computer model. Changes also mean that everything will be according to scale when it is done in 3D[34]. There will also be an increased number of review meetings to ensure the quality of the model. The collaboration and coordination between the different technical areas will be improved and also the quality of the model[35].

According to a design coordinator[36] there will be changes once the contractor joins the project. Then more specific discussions will follow about which documents the contractor needs for example. So far Vectura is still making traditional design documents. Designing intelligent models in 3D means that the CAD designer needs to put more thought into the design, according to the contractor[37]. Previously with designs in 2D the z-axis didn't matter but now it has to fit with the surrounding environment and objects. Therefore a higher level of detail is needed during the design phase.

[30] Owner (Interview, 2012)
[31] Designer (Interview, 2012)
[32] Designer (Interview, 2012)
[33] Designer (Interview, 2012)
[34] Designer (Interview, 2012)
[35] Designer (Interview, 2012)
[36] Designer (Interview, 2012)
[37] Contractor (Interview, 2012)

4.2.4 BIM development projects

Vectura has had an internal project about the implementation of BIM in the railway division[38]. A couple of the respondents have been participating in this project, which is completed as of today. However there have been discussions about a continuation. The project described the situation within the railway division at Vectura today, and the most important conclusions were:

- Vectura can make a 3D model with today's tools, we have a manual and we aim to improve the method as the tools are developed. We can use Promis-e to place objects and cables for all technical areas.

- The tools need to be developed so that a common BIM 3D model can be generated.

- There is a need for a project to further monitor BIM-related questions, support a common BIM-strategy at Vectura and decide the upcoming "BIM-steps".

- Monitor the facility management possibilities at the client.

Vectura is also participating in a BIM group with the STA and other engineering consultants in the industry[39]. The experience gathered from Mälarbanan will form a base for the development of a new BIM standard at Vectura.

Furthermore, there is the OpenBIM group which is developing BIM use in the AEC industry. Both Vectura and the STA are participating in this program together with many other companies in the industry.

4.3 BIM in Mälarbanan

A first step towards BIM is to start working with the tools in 3D, and to have visualization models in 3D, according to a technical manager[40]. This will provide a better understanding of the railway facility. Then there will be a significant advantage if the model can be connected to a time axis, which would make the planning easier. Mälarbanan is a project divided into several stages, and the idea is that the model corresponds with the different stages of construction[41].

4.3.1 The ambition with BIM

"The goal with BIM in Mälarbanan cannot be set too high, even though we have some previous experience from another project. We can't get everything at once"

The quote is from the model manager, and the use of BIM in the project means that Vectura can plan the design and construction phase well and include the contractor

[38] Designer (Interview, 2012)
[39] Designer (Interview, 2012)
[40] Designer (Interview, 2012)
[41] Designer (Interview, 2012)

early[42]. By doing so it is easier to come up with common solutions which can make the project cheaper. It is important not to produce unnecessary design documents, since that will make the project more expensive – and therefore a dialogue with the contractor is important[43]. The technical solutions should work well and be cost-effective at the same time as they need to meet the quality demands.

Many elements during the construction will not be done based on models. For example track, signaling and the overhead line will still use lists on paper. Standardized drawings from the STA are used for the mounting of certain objects. However, when it comes to the earthworks the model will be very useful and can be used for machine-guidance[44].

In the information flow from Vectura to the contractor and owner the "Create Markup"-function will be very important[45]. As soon as there is something not right in the model a comment will be made. This will make the information clearer and in combination with a priority the mark-up can be assigned to a responsible CAD designer.

4.3.2 3D object library

The object library is taken from another railway project, Hallandsås, and then adapted to suit Mälarbanan. There were some initial errors and problems with the library, and at the beginning it didn't work properly with PROL or Promis-e. When placing 3D objects a point of insertion is needed, a so called hook point. This helps the spatial placement of the objects in and around the railway. Then additional information is added such as article numbers, material type and coding. This information is placed in a database and is a condition to retrieve material lists automatically. When the railway is completed the aim is that all the objects should be included in the object library[46].

4.3.3 Common data sharepoint

An important feature in the use of BIM in Mälarbanan is the common sharepoint called Projectwise. This means that the CAD designers will work from the same data source as the contractor receives his design documents from. The interface will be common between different projects, and the map structure will be the same even though modifications are possible to better suit the actual project. The key is that the designer and contractor have different authorizations so it is impossible for the contractor to start construction from a model file that is not yet completed[47].

[42] Designer (Interview, 2012)
[43] Designer (Interview, 2012)
[44] Designer (Interview, 2012)
[45] Designer (Interview, 2012)
[46] Designer (Interview, 2012)
[47] Designer (Interview, 2012)

The files in Projectwise have a certain status depending on the project phase. After the files have passed the internal review it can be accessed by the contractor. However, this can be adjusted to suit the project depending on the agreement[48]. A technical manager is quoted about Projectwise[49]:

"It will be a significant advantage if all the consultants are working in the same system where the material is continuously updated to the latest version."

Having a common "BIM-server" in a project will make collaboration easier and faster. How this is supposed to work in practice is illustrated in Figure 14 below:

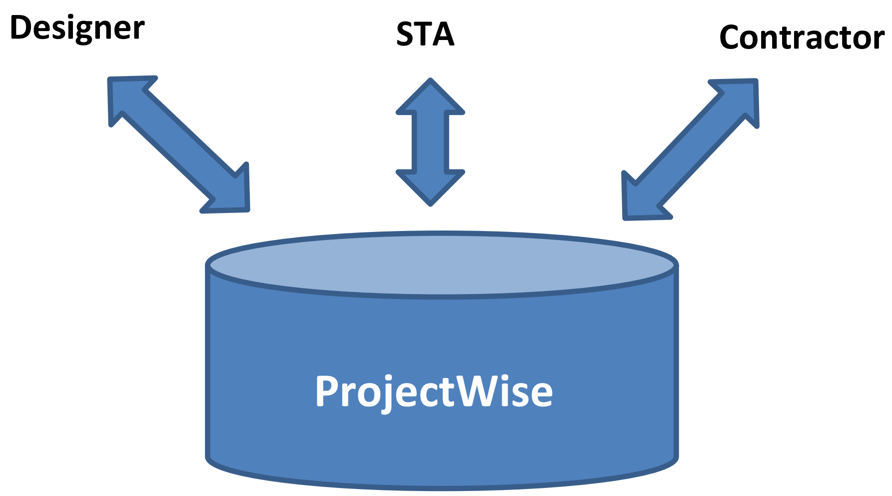


Figure 14: A schematic picture of the ProjectWise solution used in Mälarbanan.

4.3.4 Expectations of the new BIM tools

To facilitate the need for intelligent 3D design within all technical areas of railway design, a set of new BIM tools have been launched for use in Mälarbanan. Even though some areas, like track design and subgrade design has used 3D models for long, it was a new feature for other areas such as signaling. CAD designers with no previous experience from 3D design find it hard to make the work in 3D compared to 2D[50]. It takes a period of trial and error before the new work method is learned. Another CAD designer has the same opinion, that it

The general opinion about the new BIM tools is that people are enthusiastic about working with them, even though there will surely be some bugs and minor software-related errors in the beginning[51].

The model manager[52] sees other advantages with PROL and Promis-e than just using them for the spatial placement. Lists of material can be extracted which means that

[48] Designer (Interview, 2012)
[49] Designer (Interview, 2012)
[50] Designer (Interview, 2012)
[51] Designer (Interview, 2012)

orders can be placed well in time before construction, and an earlier estimation of the quantity take-off is possible.

4.3.5 Facility management data

The facility management is an important economic post when looking at a railway in a lifecycle perspective[53] but today it is unclear if the BIM model is to be used for this stage in project Mälarbanan. There are possibilities to do this however, but it needs to be coordinated with the facility management at the STA, and their practice today does not include handling models[54].

A CAD designer[55] means that it is a difficult question; today most of the facility management data is delivered in the XML- and PDF-format, but in the future it would probably be enough to deliver the BIM model only. The project leader[56] means that there are visionaries that want to change the structures around the facility management and use the BIM model for this purpose. However this is something that demands a deeper level of BIM before it is feasible.

The use of BIM models as deliverables for facility management is an important question for the STA as an owner. A technical manager is quoted[57]:

“We are still at a stage where we deal with plastic originals, and it is not an advantage when we are about to implement BIM that we aren’t working with digital data yet. We update the facility management data continuously but there are still plastic originals left”

Around the country there are numerous signal boxes with plastic drawings over the signaling system. The problem is that large investments are needed to transform the data from analogue to digital form[58]. Today this only happens during a reconstruction, which means that there is still a long way to go.

The contractor argues that it is up to the owner to demand what kind of data they need for the facility management, and that this is very different from project to project depending on the owner[59]. They are currently working with a large hospital project where the owner has come far in terms of BIM use[60]:

“They chose a system from the start where everything is in 3D all the way to facility management, but at the same time another owner doesn’t have a clue”

---

[52] Designer (Interview, 2012)
[53] Designer (Interview, 2012)
[54] Owner (Interview, 2012)
[55] Designer (Interview, 2012)
[56] Designer (Interview, 2012)
[57] Owner (Interview, 2012)
[58] Owner (Interview, 2012)
[59] Contractor (Interview, 2012)
[60] Contractor (Interview, 2012)

He also means that Finland is ahead of Sweden on the owner-side[61], they started earlier with BIM and have developed more within this field in terms of demands and regulations.

In the future there will most likely be more focus on the operation and maintenance part of the BIM, since there is a big advantage to have a well-documented railway facility to manage maintenance efforts[62]. An example from the technical manager highlights this was when a delivery of defective isolators was discovered. By the time of the discovery they were already assembled across the county, and they had to be identified manually which took a lot of time. This would probably have been easier if BIM practices had been used also for the facility management[63].

4.4 Owner demands of BIM

The interviews showed that that the demands regarding BIM from the owner are very few, or non-existing. Most of the CAD designers were not familiar with any demands at all regarding BIM, but they knew what they were expected to deliver[64]. A senior CAD designer[65] argues that the owner demands 3D or BIM models in some projects, but that the requirements are diffuse about what the model should contain. A technology coordinator[66] means that there were no demands at all from the STA during the procurement for Mälarbanan. Instead it was Vectura's initiative to use BIM and set the standards for the project. He continues[67]:

"I haven't seen it yet during procurement, but it won't be long until it comes. For example the Norwegian Public Roads Administration in Norway demands the use of BIM in their procurements, and has done so for years"

Mälarbanan is not a specific BIM development project, as for example Bypass Stockholm, and therefore the STA were clear about the fact that they do not have any demands regarding the BIM use[68]. The STA understands that this is a new technology and that it will take some time before everyone is ready to use it. Instead of having a list of demands they rather have a wish-list, aware that everything might not be possible to include in the BIM model with the current design tools[69].

Also the respondents from the owner organization show the same picture, that there are no demands regarding BIM yet. Instead they have a handful of pilot projects which will help develop measures for the future. A technical manager[70] is quoted about the BIM demands:

61 Contractor (Interview, 2012)
62 Designer (Interview, 2012)
63 Designer (Interview, 2012)
64 Designer (Interview, 2012)
65 Designer (Interview, 2012)
66 Designer (Interview, 2012)
67 Designer (Interview, 2012)
68 Designer (Interview, 2012)
69 Designer (Interview, 2012)
70 Owner (Interview, 2012)

"We are not yet there, we haven't placed any demands on either designer or contractor, and instead we have given them freedom to come with suggestions. Vectura has presented a package that they think is good and which we use for now, but as soon as the contractor comes that might have to be revised"

The construction manager at NCC means that the demands are very different depending on the owner organization, where some are very far ahead in the development compared to others who don't have a clue[71]. He also argues that it is better now when the Swedish Rail Administration and the Swedish Road Administration has merged into the Swedish Transport Administration, saying:

"Previously you could have one construction manager at the Swedish Rail Administration, and one at the Swedish Road Administration, each with different demands and with different content in the enquiry documentation. And sometimes they have external consultants in charge of the design, which is also a problem"

4.5 Benefits from using BIM

4.5.1 Owner

It is generally the owner who gets the most benefits from using BIM in a project[72], given the respondents' answers. There are some capabilities that are mentioned more frequently than others, including visualization, quality and cost cutting.

Visualization

BIM allows for earlier visualizations that can be used for different purposes[73]; project communication, review meetings, communication with the public. A design coordinator is quoted[74]:

"With BIM the owner can more easily see what is to be built, and they are usually not experts but if they can see a 3D model of the structure it is easier for them to gain understanding"

By using a BIM model less technically skilled persons can better understand the difficulties in a project. In that way the participation increases from the owner during the project phase[75]. Anyone interested can see and really understand what it is they are looking at. The model will make it possible to render advanced views, the model manager says[76]:

"You will be able to stand in the back garden and see the train pass, or you can look out from the train window and see the landscape as it looks in the reality"

[71] Contractor (Interview, 2012)
[72] Owner (Interview, 2012)
[73] Designer (Interview, 2012)
[74] Designer (Interview, 2012)
[75] Designer (Interview, 2012)
[76] Designer (Interview, 2012)

Higher quality

Another important advantage with BIM is that the quality increases, both during planning and construction. The CAD designers have to put more effort in the design, they have to solve problems earlier and there will be fewer errors in the model once it is delivered[77]. A higher quality on the design documents means that fewer errors will be made during construction, and there will be fewer deviations to be solved on-site.

The owner will also be able to see if a design is feasible early in the project, with a given budget. This is due to a higher detail level and security, which makes it easier to plan the project[78].

Communication and information

The 3D model can also be used for communication between the owner and the public at an early stage in the planning process, for example to decide between alternative designs of the railway[79].

Working and communicating with models also means that there will be less information on paper. It makes the distribution of information both faster and more accurate. The model will continuously be updated throughout the project so that access to the latest version comes automatically. The owner, designer and contractor will work from the same shared space in ProjectWise which means there will be fast access to the information[80].

4.5.2 Designer

When BIM is implemented there will be more work to do for the CAD designers since they are the ones developing the BIM model. Compared to the old work method, the design phase will take up more time, which also means more income for the company. But it has several advantages as well, and many of the respondents think that Vectura will be a more attractive as an employer on the market with the use of BIM, since it becomes more fun to work with[81]. This way younger people with computer skills can be attracted to the AEC industry how might have gone to the IT industry otherwise.

Better understanding

A better understanding between the different technical areas is another benefit for the designers. A senior CAD designer is quoted[82]:

"When working with models, it is easier to see what the other technical areas are doing, and what effects it has, but also how you affect the others"

---

[77] Designer (Interview, 2012)
[78] Designer (Interview, 2012)
[79] Owner (Interview, 2012)
[80] Owner (Interview, 2012)
[81] Designer (Interview, 2012)
[82] Designer (Interview, 2012)

Improved design review meetings

During the design review meetings it will be easier to see changes in the model when viewed in 3D using Navigator, and by creating mark-ups to mark clashes. Previously a 2D model has been used for the meetings which make it difficult to understand what is shown, since symbols, lines and shapes are overlapping each other. A design coordinator is quoted about the pre-BIM practice during these meetings[83]:

"During a design review meeting all the layers in the 2D design file are active and it is very difficult to see what you are looking at. All model files from the different technical areas are mixed together in one plane; therefore a 3D design review model is needed where everything is clearer"

Using a 3D visualization model for these meetings would make them simpler and more efficient. It would even be possible to use conference software like Communicator and the meetings would take less than half an hour for a design review meeting compared to a few hours today[84].

4D-modeling

A 4D model is a useful tool for project planning, and this is something that will be used in project Mälarbanan. As soon as the contractor is procured there will be discussions about a practical solution for how to use the 4D model for time- and production planning. According to the project manager the logistics is a very important part in a project of this size[85]. If the time dimension is added to the existing 3D model it would facilitate a more effective project planning.

Better multi-discipline collaboration

With the new work processes that come with BIM there will be better collaboration within the project group. If the different technical areas all work in the same model there it will be easier to detect clashes for example[86]. There is potential to improve the design review meetings with a common model, and also understanding among the CAD designers[87].

In order for BIM to succeed at a high level, it demands that the collaboration improves. This is not always the case though, and a design coordinator has experience of this and mentions a partnering project where everyone thought that things would go a lot easier. Instead the contractor wanted more than what was included in the design documents[88]. In project Mälarbanan the BIM server (see Figure 14) will work as a digital repository which will improve the chances of an effective collaboration.

[83] Designer (Interview, 2012)
[84] Designer (Interview, 2012)
[85] Designer (Interview, 2012)
[86] Designer (Interview, 2012)
[87] Owner (Interview, 2012)
[88] Designer (Interview, 2012)

Re-use of information

Even though the design and construction process between different projects may vary, there are always a number of elements of construction that are similar from project to project[89]. Yet new design documents are being developed and reviewed for every single project. A technical manager[90]:

“During railway construction, you excavate down to a certain depth which is the same no matter which project you look at, and also overhead power lines, tracks and switches are the same more or less”

BIM can easily facilitate the use of old designs, since all information is stored in a central project- or BIM server. For repetitive elements in the design and construction process, this could save time and increase the efficiency.

Increased interaction designer-contractor

It is easy to change a design early in a project when nothing is determined. Later on when there are more objects and details in the model it becomes harder. If the contract form allows it the collaboration and interaction between designer and contractor will become vital in order to come up with optimal solutions. BIM will work as a driver for increased collaboration between the parties through the models.

4.5.3 Contractor

Production planning

With a time-plan linked to the BIM model it is possible to see the railway being built virtually and according to the time schedule. This is a powerful tool which can be used to control the production phase. The 4D simulation will be used in project Mälarbanan and the project manager is quoted[91]:

”4D and production planning is something we will discuss with the contractor once they are hired; how we should do it in practice. We mustn’t forget that during a construction like this the logistics plays an important role”

Logistics in a large project where the access to nearby laydown areas might be restricted since there already is a built environment around the existing railway. If we can make a better planning before the construction start we can be more efficient. The material needs to arrive in time so that the production is not interrupted[92].

The contractor has used 4D in some projects, even though it is not so common today. It is very different from project to project, and is generally applied on larger infrastructure projects[93].

[89] Owner (Interview, 2012)
[90] Owner (Interview, 2012)
[91] Designer (Interview, 2012)
[92] Contractor (Interview, 2012)
[93] Contractor (Interview, 2012)

Higher production efficiency

There will be a higher efficiency in the production phase, which in the long term means a better profitability. A design coordinator[94] mentions a road project which has the same contract method as Mälarbanan – if they could design and build it cheaper than the estimated cost they share the profit – and he claims they save a lot of money from using BIM in this project.

Fewer errors

There will be fewer errors and deviations (CAWs) in a BIM project compared to a traditional project. With better and more detailed design documents the number of "resolve on-site"-problems will be fewer[95]. By using a 3D model of the structure it is easier to see the errors in the model instead of during construction.

Quantity take-off and bills of quantities

When all objects in the model are listed with attributes in a database, it is easier to extract bills of quantities. With BIM the quantities will be more exact, and they can be extracted earlier on in the design phase[96]. Different designs can be tested and evaluated, and cost estimations can be made from the bills of quantities. The material is an important parameter in the budget for the project[97]. If the quantities are more exact it means that the right amount of material is bought.

Machine-guidance and mass optimization

Previously the surveyor's assistant has been given plan and profile drawings from the designer and from those documents developed a DTM for machine-guidance[98]. Now the model is provided by the designer. Sometimes the model needs to be modified before it can be used for machine-guidance, but the idea is that it should work straight from delivery. Once loaded into the on-board computer the machine can work more or less non-stop, this makes the use of machines more effective[99].

Mass optimization is about minimizing the transport of masses, and in a large railway project this is very important for the economy in the project. At some stretches there is a surplus of masses, which could be used as fill material for other stretches where there is a shortage. The project engineer is quoted[100]:

"We cannot move around masses, as soon as there is an extra transport of misplaced masses we lose the economy in the project since the margins are so small"

The longer the railway or road (it works pretty much the same way) the longer the transports become and the more important is the mass optimization. For larger

---

[94] Designer (Interview, 2012)
[95] Designer (Interview, 2012)
[96] Designer (Interview, 2012)
[97] Designer (Interview, 2012)
[98] Designer (Interview, 2012)
[99] Contractor (Interview, 2012)
[100] Contractor (Interview, 2012)

projects (above 50 million SEK) the contractor uses specialized software for this purpose[101].

4.6 Challenges

Always when a new technology is introduced there are issues to overcome, and from the interviews a number of different challenges have been identified. Some are related to the technology, while other are related to legal matters, processes and roles.

4.6.1 Technology related challenges

To be able to design a detail-rich model in 3D all objects need to be available in the database, or object library. At the moment the process of completing the object library is undertaken. Today there are still some objects missing[102].

Another problem is the level of detail in the BIM model. Since Mälarbanan is the first BIM railway project for Vectura it is up to them to set the standard[103]. According to a CAD designer it was hard to decide the level of detail, should bolts be included etc. This led to a high level of detail, where bolts are included in the model.

A design coordinator[104] claims that BIM is easier to implement in road projects rather than railway projects since they don't have the schematic technical areas electricity, signaling and telecommunication. Moreover, when constructing a road there are not as many objects around the road compared to a railway.

4.6.2 Interoperability challenges

There are risks with the data management and interoperability as well. Mälarbanan is a long project with more than 15 years until completion, and the technical manager at The STA is concerned about this[105]:

"This is a very long project, and the question is whether the systems we use today will still be in use when it is finished, we have to see to that there is a compatibility between old and new so that we can make use of the information in the future"

Previously there were a lot of software-related issues with the different file formats but now it is not as bad. Today the formats are more compatible with each other even though the model still needs to be perfected manually by us[106].

Another problem that is of concern is that the current BIM pilot projects within infrastructure have different outcomes; that they point out different directions and standards[107]. Different projects use different BIM technology and solutions, and it is difficult to decide which technology to use.

---

[101] Contractor (Interview, 2012)
[102] Designer (Interview, 2012)
[103] Designer (Interview, 2012)
[104] Designer (Interview, 2012)
[105] Owner (Interview, 2012)
[106] Contractor (Interview, 2012)
[107] Owner (Interview, 2012)

In a railway project today the dominating design software used is Bentley's Microstation environment. Some technical areas use AutoCAD, for example bridge design, and there could be some problems when transferring files from one system to the other. Generally Microstation is better at importing AutoCAD files than the opposite[108]. There have been discussions about developing a neutral XML-based format for overhead power lines. Some technical areas such as track use the landXML format[109], which today has become an ISO standard.

The IFC format is interesting but currently it is not developed for railway projects. In order for IFC to be suitable for a railway facility a complete model of the facility needs to be developed – how should it be designed and what attributes should be assigned to the objects[110]. If all the systems had the same database model it would be easier, but that is not realistic, according to a technical manager[111].

4.6.3 Structural challenges

Since BIM still is in the early days within the civil construction field, old practices are still used which sometimes can oppose the positive effects from using it. One of the fundamental benefits with BIM is that you create the data once, but you can use it multiple times for different purposes. An example of when this didn't work is from Mälarbanan[112], where a 3D-model was developed by another design company at an early stage in the project. But the STA used old practices and received a PDF of the model, without the intelligence of a model file. So when Vectura started working with the project they had to re-construct the model, spending many hours to re-do something already done before[113]. The design companies in the industry are a long way ahead of the owner in the se of BIM. The project manager is quoted[114]:

"If the owner has the right to material from the designer but doesn't know what kind of material is needed, then something is obviously wrong"

Another concern is that the largest owner, the STA, lacks necessary competence about the implementation and use of BIM. Some experts within the organization have top skills and knowledge, but the over-all level of knowledge is low[115]. There are also variations of knowledge within the designer and contractor organizations, the project engineer at NCC says[116]:

"Certain designers are far ahead in terms of BIM in some projects, but in others they are behind. Certain persons have super skills, but in the office next to his, it is virtually on a Stone Age level"

---

[108] Designer (Interview, 2012)
[109] Designer (Interview, 2012)
[110] Designer (interview, 2012)
[111] Designer (Interview, 2012)
[112] Designer (Interview, 2012)
[113] Designer (Interview, 2012)
[114] Designer (Interview, 2012)
[115] Designer (Interview, 2012)
[116] Contractor (Interview, 2012)

There are also problems related to the differences between the road- and railroad divisions within the Swedish Transport Administration and inferior communication between the two. Instead of one vision they have two different[117].

A few of the respondents claim that the implementation of BIM is hindered by the older generations within the AEC industry, which can be underlined by this quote from the technical manager at the STA[118]:

“Before we can succeed with a high level of BIM we need to wait for a generation change at the Swedish Transport Administration, but also for the designers and contractors”

The older generation still wants to look at paper drawings; they don’t want to look at a computer screen[119]. During the owner’s review of design documents for example, more than half still want to see a paper.

The implementation of BIM has organizational impacts as well. New roles within the projects need to be defined[120], such as a BIM coordinator. The BIM coordinator will be a key person in a project, someone with expert skills and knowledge, who can help the contractor with the model for example.

Another important problem is that the owner is not clearly demanding BIM in infrastructure projects.

4.6.4 Juridical challenges

When dealing with models instead of paper drawings in a project it will raise questions about the legal status of the model. In the project contract for Mälarbanan it is clearly stated that a paper document is valued over a digital document like a model file for example. In a procurement the STA currently uses paper drawings and not model files[121]. They want to change this practice and lawyers are currently looking at the matter. The problem with model files is the version of it, which is easier to handle with a paper drawing with a stamp. There are ways to deal with this, for example in Microstation you can use a function called “Design History” which can be used to track the version of a model file. 3D-PDF’s with stamps is another solution[122].

According to a model manager[123] this is not a big issue in Mälarbanan due to the collaborative project organization, where the aim is to work towards a common goal. Vectura and the contractor together find out what documents the contractor needs to build from and the Swedish Transport Administration have no demands on the design documents, contrary to DBB procurement. He is quoted about another project[124]:

[117] Designer (Interview, 2012)
[118] Owner (Interview, 2012)
[119] Owner (Interview, 2012)
[120] Designer (Interview, 2012)
[121] Owner (Interview, 2012)
[122] Owner (Interview, 2012)
[123] Designer (Interview, 2012)
[124] Designer (Interview, 2012)

"Yesterday I was at a meeting in a different project which was procured in a traditional way, and they had big problems with the legal issues around the model"

The meaning of traditional procurement suggests that DBB or DB methods are used. There are solutions to this problem already today, and OpenBIM has a contract for digital design deliveries that can be used for this purpose[125]. This contract determines what the digital model should include, and its juridical status compared to the paper document. NCC has used this for their DB projects where they can control the design, but the STA has not used this yet according to the project engineer[126]. But with the model file valued over a paper drawing the problem occurs again with different versions. The project engineer is quoted about versions and machine-guidance[127]:

We had problems with this in the beginning, that model files are changed. They have the same names but contain a different model. This could be dangerous, especially when the model is transferred to the machine, how is the operator supposed to know?"

4.7 BIM depending on the procurement

The general opinion among the respondents is that BIM is possible with all types of procurements, although there are differences in the chances of succeeding with BIM at a high level. It is important that the parties involved in a project start the collaboration early and that they are at the same level. This can be emphasized by a quote from a CAD engineer[128]:

"I believe it's good for the project to get the contractor's opinion early. In all projects there is collaboration between the designer, the owner and the contractor and if we want BIM to work then it has to be on a level that is reasonable for all three"

If the contractor can use the model and build straight from it, then the production of paper drawings can be skipped, meaning that time and money will be saved. It is about communication between the parties involved[129].If there are three parties in a project and one of them hardly knows the meaning of BIM, it is quite clear that there will be problems. Also the technical manager at the STA agrees on this and means that there is a big advantage if the contractor joins the project early[130]. He sees advantages with BIM especially in a collaborative project during the spatial placement of the objects on and around the track[131]. Since the design is more variable at early stages it is easy to see how one change affects the other objects. He is quoted[132]:

"During procurements where the contractor has a chance to affect the design early on in a project, there are definitely more benefits with BIM"

---

[125] Contractor (Interview, 2012)
[126] Contractor (Interview, 2012)
[127] Contractor (Interview, 2012)
[128] Designer (Interview, 2012)
[129] Designer (Interview, 2012)
[130] Owner (Interview, 2012)
[131] Owner (Interview, 2012)
[132] Owner (Interview, 2012)

The opinion on BIM depending on the procurement varies though, and a model manager[133] at the STA means that the DBB (Design-Bid-Build) approach is the best. When a contractor is hired using DB (Design-Build), then the contractor also makes the design documents, and there will be difficulties to succeed with BIM. On the other hand, in a DBB procurement the STA contracts a designer to produce the design documents and that is more suitable for BIM[134]. But the chance of succeeding with BIM in a project is also depending on the knowledge and skill level of the contractor, the designer as well as the demands we have as an owner.

The procurement in project Mälarbanan

According to the design phase manager[135] the procurement is DBB, even if it is done in a form of increased collaboration. He is also talking about the DB procurement and there is not a problem in either one of the contract methods to handle the information flow digitally. He predicts a smooth handling of the documents during the project; instead of receiving several file folders a USB memory can hold the same information.

The model manager[136] argues that it is important in a project like Mälarbanan to adapt a common picture of BIM between the designer and the contractor to make things clearer. By doing so it is easier to produce the correct information and get a more effective handling of the process.

A common economic incentive to share among the parties in a project, works as motivation to increase the efficiency. An example of this is the procurement in project Mälarbanan where there are bonuses of 50 million SEK if certain goals are accomplished in time. The project manager explains how this works[137]:

"The parties in Mälarbanan chose to enter a form of collaboration with a standard price that we believe in, that the contractor believes in, and the owner believes in. Then our goal is to try and end up below that price"

[133] Owner (Interview, 2012)
[134] Owner (Interview, 2012)
[135] Owner (Interview, 2012)
[136] Owner (Interview, 2012)
[137] Designer (Interview, 2012)

5 ANALYSIS AND DISCUSSION

This chapter is based on the theory in Chapter 3, the result from the interviews in Chapter 4, and the author's own opinions.

5.1 Different views on BIM

An understanding of how BIM is perceived in the railway industry today is necessary to know where we stand and how we can develop from there. The interviews showed that there is not a common picture of BIM among the players in the AEC industry. The level of knowledge varied among the respondents, regardless of if they come from the owner, designer or contractor organization. The view of BIM is usually revolving around a 3D model but with more intelligence. If we imagine a project team where some of the participants only have a vague idea about what BIM really is it can cause friction in the collaboration. It seems as if the designers and contractors are ahead of the owner (the STA) in terms of BIM use, and have developed a broader insight into how it can be used in projects.

When asked about the picture of BIM many of the answers revolved around the benefits from using BIM such as visualization, machine-guidance and so forth. The organizations look at how BIM can impact their part of a project; how they can benefit from it. This is natural, but it also indicates that there is no deeper understanding of the full extent of BIM. The parties involved in a project need to look not only to their own part, but also have an understanding and a dialogue with the other parties involved.

Some of the respondents answered that they have used certain BIM features in earlier projects. The contractor had been using machine-guidance for up to 10-15 years and was very familiar with that aspect. However it was not clear if the digital terrain model used in the beginning was generated automatically from a BIM model. Another example is from the designer where quantities have been extracted from 3D models since the late 90's, but that is also an isolated benefit from using BIM. Not until the last couple of years there has been serious talk about BIM in the industry, some of the respondents had never before heard the word until they started working with project Mälarbanan, or the internal BIM project at Vectura. With these examples it is clear that although some aspects of BIM have been used before, it is not until now that the bigger picture is seen.

If we look at BIM in a wider perspective, considering the BIM lenses in Chapter 3.3.2 we can establish that both Vectura and the contractor belongs to the process field, as users of the technology for their work. Also the STA as an owner belongs to this field, but they also have another, more important role as a regulatory body within the policy field. Today's situation can be compared to a stalemate where not much is happening in the policy field. Despite this fact the designers and contractors are well on their way in terms of BIM implementation and use.

5.1.1 From Vectura's point of view

BIM is described as a tool and a process. The process is the creation of information to develop an intelligent 3D model; a process that starts as soon as the design phase is initiated and lasts until the product is finished, using BIM tools such as RailTrack running on Microstation. The view on BIM from Vectura can be seen in Figure 15.

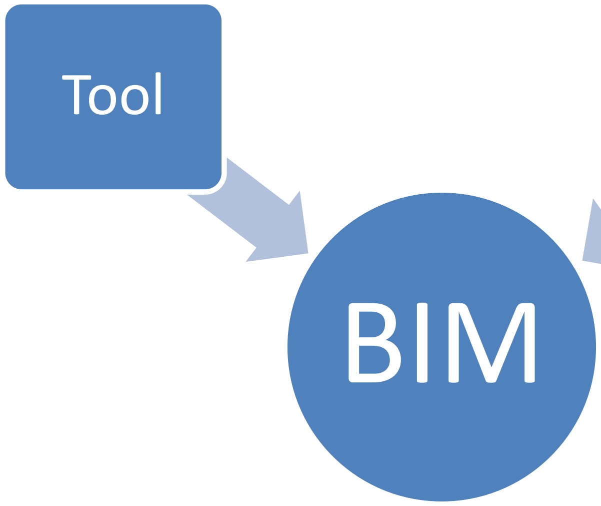


Figure 15: The resulting picture of BIM can be seen as both a tool and a process.

Vectura has historically been separated in different organizations, one working with railway design and one with road design. This means that there are also two different approaches to BIM and how it should be implemented in practice. For example, the road and railway divisions at Vectura use different technical solutions, i.e. different BIM tools for the design. Basically the two divisions think in the same way but there are details that differ. Long code-strings are used by the road division to label the different layers in their design files, while the rail division uses more logic names for the layers. This could cause problems when developing one general company BIM policy at Vectura, since people with a background in the road division prefers to work with their tools and work methods, and the other way around.

5.2 Implementing BIM within the railway sector

The internal BIM project

Although there have been an internal project at Vectura about the implementation of BIM within the railway division, not much has happened since that project was completed. Now six months have passed which means that the validity of the results is decreasing in a changeable environment. Although most people are talking about BIM in enthusiastic words, more needs to be done from top-level management to further encourage it. Currently there is no plan for a continuation of the project and no BIM adoption plan has been developed. Mälarbanan as a pilot project functions as a BIM workshop for Vectura where they can try new BIM technology and work processes.

The result from Mälarbanan will help to guide the continued BIM adoption of both software and staff training.

No completed BIM projects yet

There are several outspoken BIM pilot projects within the infrastructure sector of the AEC industry, such as Bypass Stockholm. However, most of these projects have not yet reached the construction phase, meaning that the experience from those projects only include the design phase where intelligent 3D design and visualization are the most notable benefits. Since the BIM use is in the early years within infrastructure it seems that there are no projects yet that have gone through all the project phases; design, construction and operation. The lack of experience from real projects makes it hard to show the effects from using BIM on the economy of a project. Even with completed projects at hand it might be difficult to quantify the profit from using BIM in a project. For that all BIM-related costs must be isolated, analyzed and compared against the amount of money saved from using BIM.

Comparison to the BIM implementation steps

Considering the steps for implementing BIM described in Chapter 3.5.5 and applying them on Vectura, we can ascertain that more can be done. Some of the steps are fulfilled while others need to be attended to. For example, there is neither an existing BIM adoption plan covering all aspects of the company’s business, nor a team of managers responsible for implementing the plan and monitoring the performance. Even though there have been some previous, smaller projects which has made use of certain aspects of BIM such as model-based collaboration, Mälarbanan is the large BIM project where useful experience will be gained for Vectura. The initial results can then ideally be used to educate and guide the staff in the continued BIM adoption. It is difficult to quantify the economic benefit from using BIM, but if that somehow could be monitored in project Mälarbanan it could be used as further argumentation.

There were also opinions expressed in the interviews that a new work method for CAD designers working with BIM need to be developed, or adapt the current method. Contractual documents and relations to business partners need to be overlooked and adapted to the new business processes. This is something that Vectura needs to do in agreement with other industry players such as the STA and contractors. Clearer demands and more standardization in the industry will have positive effects on the use of BIM.

5.3 Status of BIM in the railway division

BIM within railway design is still in in its early days, but the experiences from project Mälarbanan will hopefully change this and drive the implementation of BIM forward. It is an area subject for a rapid development and technology and practices changes quickly. The ambition with BIM in Mälarbanan is set high, but the project is still at an early stage and has a lot to prove yet.

The different stages of BIM maturity described in Chapter 1.1.1 will be used when discussing the status of BIM in the railway division. The first stage is pre-BIM which is much depending on 2D documentation, or 3D modeling lacking intelligence. This can be compared to the situation at Vectura before the new BIM tools were launched. That is, some technical areas work with 3D modeling while others continue to work in a 2D environment. The generated 3D models lack intelligence since there are no attributes linked to them at this stage.

With the introduction of the new BIM tools, it means that the requirements of BIM stage 1 is fulfilled – working with object-based 3D design by using the RailTrack, PROL and Promis-e applications. The difference between BIM stage 1 and BIM stage 2 is that the previous one still depends on collaborative practices comparable to a pre-BIM stage, whereas the latter includes a more extended collaboration between different disciplines and even between different project phases. An example of this is the interaction between designer-contractor which is significant for BIM stage 2; model-based collaboration. This suggests that Vectura belongs to stage 2 according to Figure 16 below.

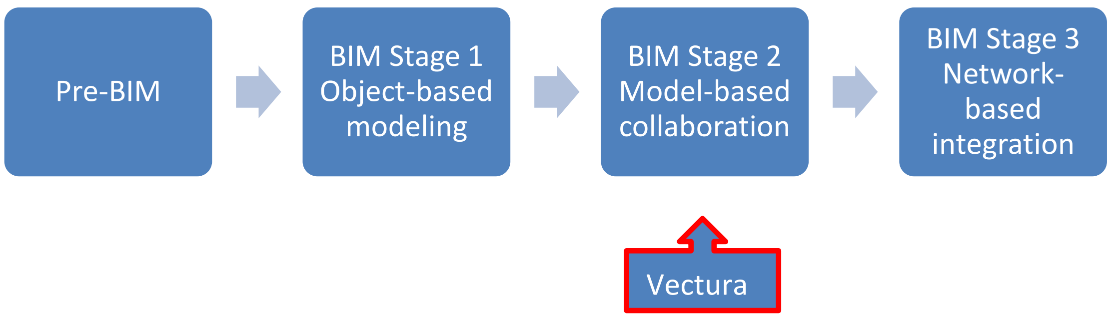


Figure 16: An indication of Vectura's position in terms of BIM maturity, BIM stage 2.

To reach the third stage a more integrated approach is needed with a deeper collaboration between the parties, and also more focus on the whole life-cycle of the facility. Some features already exists that will drive the development further towards network based integration such as the ProjectWise solution from which all the parties can work from and exchange information. The ultimate goal of BIM is to achieve an integrated project delivery, and that stage is far from the reality today. But as the parties get more experience from working under more collaborative forms, the IPD approach is not an unreachable goal in the future.

In conclusion, it seems as if the civil sector in the AEC industry is catching up with the more developed building sector in terms of BIM maturity. The development is fast and driven by the designers and contractors.

If we consider BIM as both a tool and a process, it is the latter that needs most development. One of the most difficult aspects of a technology-driven change is not the technology itself but the associated work methods. New collaborative work methods need to be developed, suitable for the new technology.

5.4 Benefits during design, construction and operation

Although there are many benefits from using BIM, the whole lifecycle of a structure needs to be considered to get the most of them. The process of railway planning and design as was described in Chapter 3.1 is very long and can take many years to go from idea to design and construction. After the construction of the railway is completed it is handed over to facility management which will operate and maintain the railway for a long period of time. Bearing this in mind the process from Chapter 3.1 can be simplified to consist of three major parts: design, construction and operation. In Figure 17 on the next page the identified benefits are listed where they can be applied during the project.

Benefits like improved communication, visualization, quality and collaboration are naturally not associated to a specific project phase.

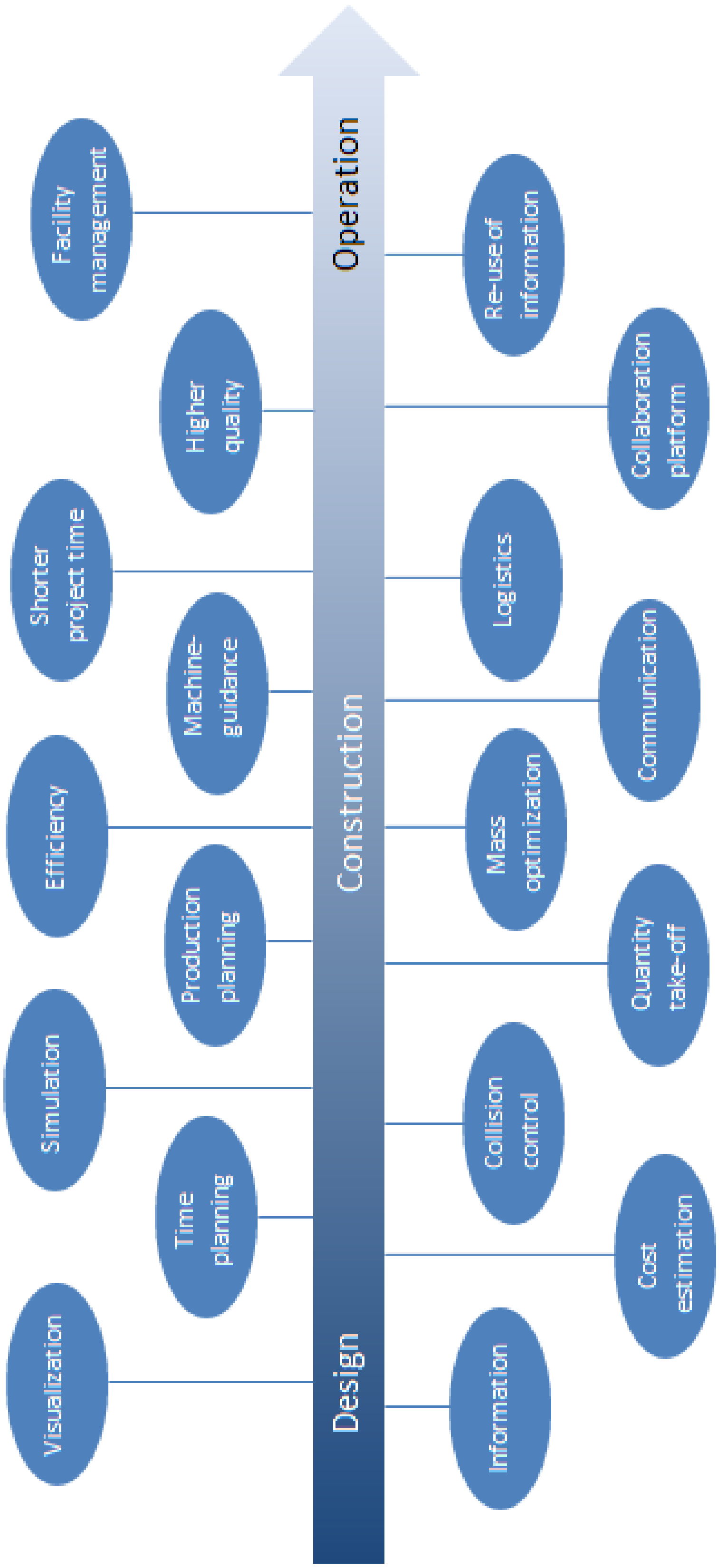


Figure 17: Some of the identified benefits from using BIM throughout a project.

5.4.1 Changes in the design curve

The design process will change when BIM is used in a project. As the result showed, the CAD designers will have to work more hours in the beginning of the project. Design changes made early in a project are not as costly as changes made in the latter design stages. With a BIM design process the changes to the design will not be as costly, since they will be identified and resolved earlier. This is illustrated in Figure 18 below.

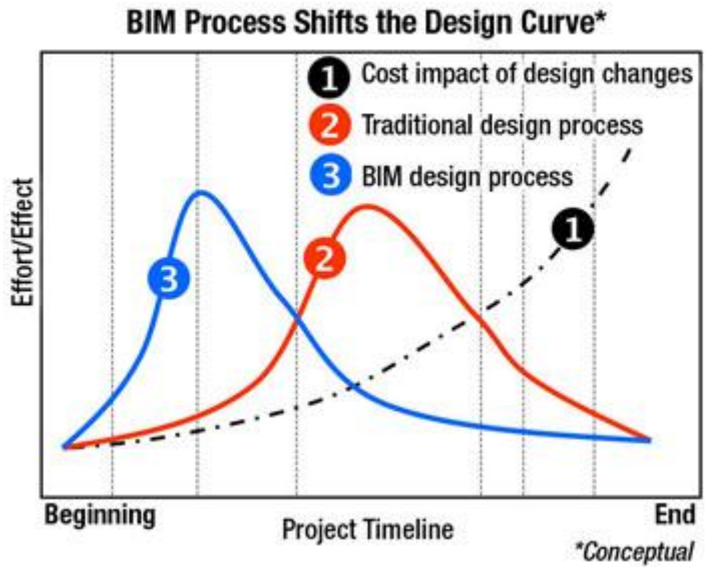


Figure 18: The design curve changes with the implementation of BIM (Post, 2007)

In a pilot project like Mälarbanan there is also the need to train staff to use the new tools, which demands even more effort. A comparison to a traditional design process shows that the peak effort occurs later in the project phase. The BIM start-up costs are a big concern mainly for smaller firms, but that should not be a problem for Vectura. Software licenses are already purchased for the necessary BIM tools. However, the design process needs to be changed to better fit the new BIM tools. Vectura has developed a work process which the CAD designers have used previously. This might need to be adapted to a BIM design process. For example, it is important that the design process is synchronized according to the design review steps and the status of the files in ProjectWise.

5.4.2 How can Vectura benefit from BIM?

Vectura has the responsibility for developing the design documentation used for construction. This is one part of the whole lifecycle, which means that the benefits for Vectura are normally limited to the design phase, although in a project like Mälarbanan Vectura is more actively participating in the construction phase, as a result of the collaboration with the contractor. There are many benefits for Vectura from using BIM, although some require a more integrated and higher level of BIM and more development to be realized.

A natural starting point is to use the BIM tools to produce an object-based 3D design of the railway facility. That all the technical areas can work in 3D will enhance early multi-discipline collaboration and understanding among the CAD designers. Using Bentley Navigator a 3D model for visualization and simulation can be generated and used for project meetings. This will clarify design review meetings and make more effective, compared to using the old 2D practice. Clashes can be tagged with the create mark-up function, and more accurate quantities can be extracted from the model. Consistent 2D drawings for construction can be extracted at any stage of the design. Design errors and CAWs will be detected before the construction phase which means they will be cheaper to resolve. The overall quality of the design will improve with better understanding from the persons involved in the project team. BIM will allow for re-use of information within a project, and possibly between projects as well. Another advantage is that BIM can provide better feedback and follow-ups after the project is completed, to learn from the experience. This is not prioritized today since there is no time, but it is desired by the CAD designers.

In combination with the contract method "Extended collaboration" there will be a natural interaction between designer and contractor. This means that they can come up with solutions together, and the contractor has a chance to impact the design with ideas and constructability know-how. It will lead to a more effective and production-oriented design. Powerful 4D-models can be used for project planning, where objects in the model can be linked to a time frame and visualized accordingly.

As the BIM use spreads within infrastructure projects it is important to keep up with the changes. There will be more demands about using BIM in new projects. Therefore it will be a significant advantage to have knowledge and experience from BIM in upcoming procurements, providing an important strategic capability for the company. It is a competitive advantage to be first with BIM, and even though other design companies are also implementing it, Vectura can learn a lot from using it in project Mälarbanan. At an early stage in the implementation it is important to have an iterative approach to the process and continuously improve it. Working with the latest cutting-edge technology will also attract skilled employees and improve the status of Vectura as an innovative company in the industry.

More information and functionality can be built into the model in the future. 4D-models are already here, 5D-models with cost analysis will most likely be developed soon and then other capabilities can be built into the model if desired.

Building Information Modeling works well with lean construction. Those two factors combined with an IPD project delivery will further increase the productivity and minimize the waste generated. This way a more environmentally sustainable design and construction process is possible.

5.5 Hinders and challenges

Chapter 3.5 gave an insight to some of the challenges with BIM implementation. It is true that the designer as the key adopter does not benefit most from the use of BIM. However, new business practices such as the procurement in Mälarbanan gives economic incentives to all the parties involved: they get to share the profit if they can build a cheaper railway facility. This suggests that Vectura as a key adopter does get rewarded for the extra effort needed to implement BIM. Furthermore there is the subject of collaboration challenges, which is a result of different practices among the participants in a project, i.e. if the contractor uses traditional paper-based drawings and the designer uses digital models. This could be a problem but as the contractor not yet is procured it is too early to know if this will be a problem or not.

5.5.1 Legal status of the model

There is however other more concerning barriers to BIM, both theory and empirics point out that the current contract models do not encourage the use of BIM. The legal status of the model needs to be at least equal to that of a printed drawing. For example in Mälarbanan, it is clearly stated in the contract document that a paper document is valued above a digital document. This paragraph has different meanings depending on its context. In a project like Mälarbanan where a collaborative framework is being used it is not as much of a problem as it would have been in a traditional approach. The transition from paper-based to model-based collaboration is made more difficult by one small contract paragraph. Contracts used in BIM projects should encourage the use of digital deliveries and not the other way around.

OpenBIM has developed a document for digital deliveries which can be used as an attachment to a regular contract. In the contract the file format is stated, as well as information of where the digital data should be delivered, for example to a project server. NCC has been using this contract for digital deliveries in other projects and they are satisfied with it.

5.5.2 Technical challenges - interoperability

One obvious obstacle to overcome when implementing BIM is linked to interoperability. The ideal situation would be if all the parties work in just one BIM model, using the same software. In reality this is not the case however. Not every party uses the same software and it is not possible to use a single software for every possible task there is. It would result in an overly complex program. Vectura uses the Microstation environment for railway design, but in a project certain disciplines use other, for example AutoCAD is used for bridge design. This results in two different formats, DGN from Microstation and DWG from AutoCAD. It is possible to import and export files between the different programs, generally Microstation is better at importing DWG files than vice versa. But when exporting files from one program to another does not guarantee that all the information is included and that the model looks the same in the other program. Known interoperability problems are related to line widths and colors, which might not appear the same after import from different software. However, according to the interview responses the interoperability works rather well with only a few problems linked to different file formats.

Then there is also the interoperability problem with different file formats and how they might change in the future and not be usable any longer. In a long project like Mälarbanan, with many years until completion, it is important that the file formats used today also will be useful in the future. The software needs to be backwards compatible so that also old file formats can be used without having to convert them. A good example of this is that the latest version of Microstation can open files created during the 1980's.

The 3D object library will cover as much as possible of the railway facility. A smaller object library from another project was provided which then was expanded with more objects. There were some initial problems with the level of detail in the objects, as well as how they should be connected to other objects. This problem is now solved by using hook-points for insertion, and detailed object information placed in a database. Future projects will use this object library so the development work is well invested for the future. Then it needs to be continuously updated throughout the project.

5.5.3 Different skill levels and vague owner demands

There are differences in how far the different players in the AEC industry have come in the BIM implementation. The STA, as the largest owner within infrastructure, is still learning how to implement and use BIM in projects. They can be perceived as being passive and waiting for the market to drive the development forward. This relation should be the opposite and the STA as an owner should lead the development, but the empirics indicate that both contractors and designers are ahead.

To support the implementation of BIM for the contractors and designers the Swedish Transport Administration needs to develop a set of regulations and requirements for the use of BIM in projects today. As the situation is today, there are no regulations at all when it comes to BIM. According to the consultants at Vectura, and also NCC, there are no demands on the use of BIM in infrastructure projects. This is one of the major reasons why the implementation takes so long. It can be compared to a catch 22 situation where the STA are biding their time, not wanting to formulate a set of regulations until the matter is properly investigated. Meanwhile the designers deliver information traditionally according to the current practice, since there are no demands saying otherwise in the enquiry documentation.

An example that highlights the need to change the current practice to better facilitate the use of BIM-related models and processes is from Mälarbanan where the STA did not demand the digital model that was developed by another designer before Vectura was procured. Instead of delivering the model, a PDF drawing was handed out to Vectura which meant that they had to develop the same model again, costing many hours re-do. This is destruction of information and is an example of how BIM calls for a change in the current practice. The owner needs to be clear about the demands from the beginning and know what to ask for.

5.5.4 What happens after the construction phase?

If we consider BIM in project Mälarbanan, only the design and production phase are included in the current plans. Focus is on using the new BIM tools to work in a common intelligent 3D environment, improve the project meetings, plan the construction phase effectively and develop solutions in collaboration with the contractor. It is beyond doubt that BIM will make the design and construction process more effective, but still the fact remains that the facility management phase is not included in the plans today. A concern is that much of the intelligence in the BIM will be destroyed in the interface when the railway is handed over to facility management (between construction-operation). The model files that describe the whole railway facility might not be used for operation once construction is completed. Figure 19 below shows the different project phases and information flow.

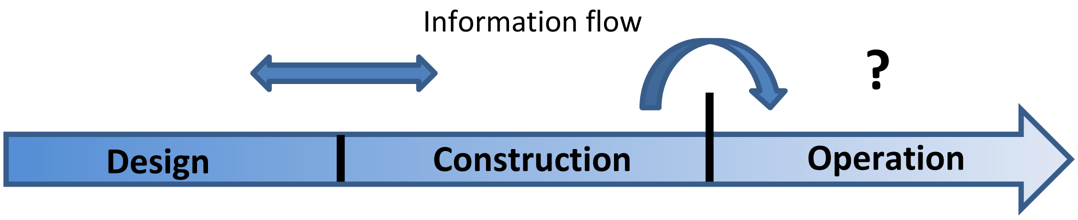


Figure 19: Shows the different project phases and the information flow in the interface between them.

Between the design and construction phase this is not a problem since they work together to come up with solutions. This is illustrated by the two-way arrow in Figure 19 above, symbolizing the exchange of information.

However, if we look at what happens after the construction phase, it is more unclear. The function within the STA responsible for the operation of the infrastructure is currently looking into the matter to see how they can make use BIM for operation and maintenance. Technical questions remain about which digital formats to use for facility management and to make sure that the interoperability is ensured so that the formats used today will be useful also in the future. If the BIM model could be used for facility management it would mean that the whole lifecycle of the facility will be taken into account and the benefits from BIM will increase when using it from design through construction to operation. As we saw in Chapter 3.4.4 the handover of facility information will be easier and it can be used to improve and integrate facility operation and management systems.

At the moment the level of integration of BIM seems to be high in the design process, lower in the construction phase and very low or absent in the operation phase. This is something that needs to be changed in order to maximize the use of BIM. In project Mälarbanan the parties involved does not include the one responsible for the operation and maintenance of the railway. If that function of the STA was actively participating in the project from the start a higher level of BIM could be realized, and a more effective handover after construction would be possible.

5.6 BIM depending on the procurement

The procurement is an important factor when discussing BIM, and has a great impact on the result in the end. Most respondents agree that a contract method that allows for an early collaboration between the different parties involved in a project is more suitable. The chance of succeeding with a BIM project is also very much dependent on the knowledge and skill level of the owner, designer and contractor organizations, as well as the will to work collaboratively.

In a DBB procurement the owner, designer and contractor are separated which means that the different project phases design, construction and operation are fragmented. Between the different phases there is a handover of information (design documents for example) which can cause problems. The contractor might not be able to use the model created by the designer, and therefore has to develop his own model to use for machine-guidance for example. With a DBB procurement there is an obvious risk that information and intelligence will be destroyed in these handover phases since the parties involved are separate entities. An example of this was the case in Mälarbanan when the first 3D model was developed, only to be delivered to the STA as a PDF, leaving out all the intelligence. In a more fragmented design and construction process these problems are more common, and therefore the DBB approach is not a suitable procurement for a BIM project.

The DB procurement is better since there is not the same degree of separation between the contractor and designer. It means that information can be delivered more seamlessly between the two. But there is still not the same collaborative framework as the IPD approach which suggests that the BIM use will not be as effective. The owner and the designer/contractor entity are still separated which means that for example legal issues can arise concerning model files, versions and information ownership.

5.6.1 Mälarbanan – a step towards IPD

BIM without collaboration between the parties in a project is possible but not recommended. It can be done, but that is not an efficient way to go about it. Many of the benefits from using BIM are destroyed then. Instead BIM should work as a platform for collaboration. According to Bilal Succar the ultimate goal with BIM is to achieve IPD – Integrated Project Delivery. If we look at the procurement in Mälarbanan, it is collaboration between the owner, designer and contractor. The contract method encourages this with a common economic incentive and additional bonuses for the parties involved to share. Even though it is not clearly an IPD project it has some of the characteristics of one. This has several benefits, and the most important is of course gained from a high level of collaboration already at an early stage.

The extended collaboration procurement also means that legal issues are less of a problem in Mälarbanan, since they are working together towards a common goal – to build a cheaper but still qualitative railway facility. The experience concerning legal issues in other projects that have been procured traditionally is that it is a much bigger problem in those projects. Normally formal design documents are produced and then approved by the owner, but in this case the designer only need to produce what is needed by the contractor to start the construction. Problems that do occur during the project are solved together in Mälarbanan, and the risk as well as the potential bonus money is distributed among the parties. However, there are still things that can improve in the contractual documents concerning the legal status of the model. As the contract stated a paper document is valued higher than a digital document, and this can cause problems when the exchange of information is digital and centered around model rather than paper-based. The contractual language should instead encourage the use of models as deliverables, since it is a BIM project.

5.7 Suggested changes

In all the interviews the respondents were enthusiastic about using BIM with all its benefits, but there is still a long way to go before it will be integrated throughout the whole lifecycle. As we saw in Mälarbanan, BIM is only used for two thirds of the three phases, since operation and maintenance is still not there yet. In the future this should be considered already when starting a project, so that facility management can be integrated in the BIM model.

Since BIM within the railway sector today is still in an early and developing phase an iterative approach is recommended. We need to learn from previous experiences and use them to develop the technology, as well as new processes and roles. Large owners such as the STA need to develop new contract terms to avoid the legal issues that come with the use of BIM and model collaboration. Today the STA can be perceived as being too passive and only watch the development instead of leading it. The demands about using it should also be sharper, what should the model include, what are the deliverables, which file formats should be used and so on. BIM standardization efforts could also be done at a governmental level, to further encourage and make BIM use easier in practice.

The interfaces between the different design stages and between the project parties also need to be clarified. This can be helped from an iterative approach where feedback is given on the material delivered, but there needs to be time assigned for that in the projects. The design process which previously was carried out first, and then handed over to the contractor will now be more integrated and production-oriented.

BIM is still a work in progress, and as it develops and becomes more widespread the impact will be more apparent. It will contribute to a closer collaboration; make the construction process faster, cheaper and with fewer errors.

6 CONCLUSIONS

The research questions from chapter 1.3 are used as a framework for the conclusion chapter together with the result from theory, empirics and the analysis.

The view of BIM

There is not a common view on BIM, and the knowledge varies greatly both between the companies in the AEC industry, as well as within the companies. These different skill levels can cause collaboration problems in a project. The performed interviews show that few parties have a uniform picture of BIM; instead they tend to see mainly to their part. The overall picture of BIM is very positive though, and many of the parties in the industry are currently implementing it in their business.

Building Information Modeling is a term that has been used the last couple of years and there is limited experience from it. Some capabilities of BIM have been used for several years, such as machine-guidance and extracting quantities from a 3D model. However, a deeper understanding of BIM in a lifecycle perspective is necessary to receive all the positive effects throughout a project, and also after the handover of the completed facility.

BIM is described as both a tool and a process. The tool is the BIM software used for designing the facility, and the process is the creation of input information to the model.

What is the status of BIM use in the railway sector at Vectura?

The use of Building Information Modeling within the railway sector is in its early days, the ambition in Mälarbanan is set high. Object-based modeling is used for the design, and the collaboration is based on models rather than pre-BIM paper based practices. Considering the BIM maturity stages and the use of BIM in Mälarbanan, it suggests that Vectura is at BIM stage 2: model-based collaboration.

The level of integration of BIM seems to be high in the design process, lower in the construction phase and even lower in the operation phase. This needs to be changed in order to maximize the benefits of BIM.

The civil construction sector is catching up with the building sector where BIM has been used longer and is more widespread. The development is fast and it is driven by the design companies and the contractors. There are still large differences when it comes to BIM maturity though, depending on the project and the participants.

What are the benefits and challenges of implementing BIM in a large railway project like Mälarbanan?

There are many benefits from implementing BIM in a railway project, throughout the different project phases. The whole lifecycle needs to be considered to get the most of BIM.

Extended collaboration from an early stage in the project is both demanded and enhanced by the use of BIM, across companies as well as within them. There will be synergistic effects when using a suitable contract method with BIM.

Building Information Modeling can be used to visualize, improve project meetings, better understanding and communication, higher quality of the design, extract accurate quantities earlier, detect clashes, lower the number of design errors and CAWs, increase interaction and understanding between technical areas, re-use information throughout the project, improve the feedback and follow-up of the deliverables, increase integration between designer and contractor leading to a more production-oriented design, use 4D models for project planning, attract new employees. BIM experience and skills will be important in upcoming procurements as a strategic capability.

The legal status of the model is a barrier when implementing BIM. The contractual situation today states that paper drawings are valued over a digital drawing, which is a problem when model-based working and communicating is practiced. Another barrier is that there are vague demands about BIM in civil construction projects from the largest owner, the STA. A clear definition of BIM needs to be established, as well as clearer demands on the content of the model. Technical challenges with the new BIM tools remain, and also the interoperability between different applications.

What type of procurement is most suitable for a BIM project?

Considering the three different contract methods studied (Design-Bid-Build, Design-Build and Integrated Project Delivery) it is clear that the IPD approach is the most suitable for BIM projects. IPD and BIM will give synergistic effects since they both demand and provide an early collaboration within the project team.

The DBB approach is very common today, but it remains a fragmented process where the owner, designer and contractor are separated. BIM will be much more efficient in a collaborative environment. There is a large risk that information and intelligence will be destroyed in the interfaces between the different phases.

The DB approach is better since there is a high level of interaction between designer and the contractor, often it is one single entity.

The most suitable procurement is integrated project delivery (IPD), and the Extended Collaboration contract method used in Mälarbanan is a step towards reaching there. It works well with the collaborative framework provided by BIM, and there will be positive synergistic effects from using BIM with a collaborative contract method.

6.1 Future research

When writing this master thesis I learned a lot about BIM in civil construction projects but there were also some questions that were raised or remained unanswered afterwards. They are listed below and could provide ideas for future studies.

- **Further case studies:** It could be interesting to make a case study on a project that has reached further than the design stage. How can BIM be used in the production phase, and how much money or time can be saved throughout a project?

- **BIM for facility management:** What needs to be done before the BIM model can be used to operate and maintain a railway facility for example. What should the model contain to be used for this purpose?

- **Legal status of the model:** Today paper documentation is still used as a contract document, and is valued above a digital model. How can the contractual documentation be changed to better suit BIM projects?

7 REFERENCES

Ashcroft, Howard (2009): *Building information modeling: A framework for collaboration.* (Electronic) PDF-format. Available: http://www.myscl.org/publications_7_1_3.pdf

Bentley (2012a): *Microstation.* (Electronic) Available: http://www.bentley.com/en-US/Products/microstation+product+line/ [2012-05-03]

Bentley (2012b): *Engineering Information Management and Project Collaboration Software.* (Electronic) Available: http://www.bentley.com/en-US/Products/projectwise+project+team+collaboration/ [2012-05-03]

Bentley (2012c): *3D Rail Infrastructure Design and Maintenance Software.* (Electronic) Available: http://www.bentley.com/en-US/Products/Bentley+Rail+Track/ [2012-05-03]

Bentley (2012d): *Power Rail Overhead Line.* (Electronic) Available: http://www.bentley.com/en-US/Products/Power+Rail+Overhead+Line/Product-Overview.htm [2012-05-03]

Bentley (2012e): *Promis-e.* (Electronic) PDF-format. Available: ftp://ftp2.bentley.com/dist/collateral/docs/promise/promise_datasheet.pdf [2012-05-03]

BuildingSMART (2012): *Model – Industry Foundation Classes (IFC).* (Electronic) Available: http://buildingsmart.com/standards/ifc [2012-04-06]

Drogemuller, Robin (2009): *Can BIM be Civil?* (Electronic) PDF-format. Available: http://eprints.qut.edu.au/27991/ [2012-02-03]

GSA (2007): *BIM Guide Overview*. (Electronic) PDF-format. Available: http://www.gsa.gov/graphics/pbs/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf [2012-02-25]

Infomap (2012): *GPS Machine Guidance FAQ.* (Electronic). Available: http://www.infomapsurveys.co.uk/gps/faq.htm [2012-04-29]

Jongeling, R (2008): *BIM istället för 2D-CAD I byggprojekt.* (Electronic) PDF-format. Available: http://epubl.ltu.se/1402-1528/2008/04/LTU-FR-0804-SE.pdf [2012-03-16]

NCC (2012): *About NCC Construction Sweden.* (Electronic) Available: http://www.ncc.se/en/About-NCC/NCC-Sweden/NCC-Construction-Sweden/ [2012-04-25]

OpenBIM (2012): *Om OpenBIM.* (Electronic). Available: http://www.openbim.se/ [2012-04-05]

Palmer, J & Pressley, S (2009): *Civil Information Modeling and Building Information Modeling.* (Electronic) PDF-format. Available: http://onlinepubs.trb.org/onlinepubs/circulars/ec145.pdf [2012-05-03]

Patel, R & Davidsson, B (2003): *Forskningsmetodikens grunder: Att planera, genomöra och rapportera en undersökning*. Studentlitteratur: Lund.

Post, M. Nadine (2007): *Structural Engineering Transition to 3D Digital Design Is Toughest for Small Firms.* (Electronic) Available: http://enr.construction.com/news/buildings/archives/070523.asp

SCB (2012): *Tillväxt och produktivitet* (Electronic). Available: http://www.scb.se/Pages/List____254962.aspx [2012-02-13]

Steel, J., Drogemuller, R., Toth, B: (2010): *Model interoperability in building information modelling*. P. 99-109.

Succar, B (2009): *Building information modelling framework: A research and delivery foundation for industry stakeholders.* (Electronic) PDF-format. Available: http://www.sciencedirect.com/science/article/pii/S0926580508001568 [2012-04-04]

Trafikverket (2012a): *Så blir väg och järnväg till.* (Electronic) Available: http://www.trafikverket.se/Privat/Vagar-och-jarnvagar/Sa-blir-vag-och-jarnvag-till/ [2012-03-03]

Trafikverket (2012b): *How we procure.* (Electronic) Available: http://www.trafikverket.se/Om-Trafikverket/Andra-sprak/English-Engelska/Procurement/How-we-procure/ [2012-03-04]

Trafikverket (2011c): *Projekt Mälarbanan Uppdragskontrakt*. Stockholm: Trafikverket Stora Projekt

Vectura (2011): *Införande av BIM i järnvägsdivisionen.* Stockholm: Vectura Division Järnväg.

Interviews:

Project manager, Vectura [2012-03-21]

Design coordinator, Vectura [2012-03-14]

Design coordinator, Vectura [2012-03-16]

Technical manager, Vectura [2012-03-22]

Model coordinator, Vectura [2012-03-23]

Senior CAD designer, Vectura [2012-03-22]

CAD designer signaling, Vectura [2012-03-22]

CAD designer track, Vectura [2012-03-12]

Design phase manager, the STA [2012-03-15]

Data coordinator, the STA [2012-04-03]

Technical manager, the STA [2012-04-11]

Project engineer, NCC [2012-04-26]