Cost Estimation in Construction

BIM vs Total BIM

Master's thesis in Design and Construction Project Management

DANIEL PÅSSE

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
DIVISION OF CONSTRUCTION MANAGEMENT

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Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Department of Architecture and Civil Engineering
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ABSTRACT

It is known that cost overruns are an issue in the construction industry, and in an industry with such small margins of profit there is always a desire to cut costs. To facilitate and improve the efficiency and quality of cost-estimation processes, the implementation of Building Information Modelling (BIM) has been promoted in the construction industry. Recently, the concept of 'Total BIM' has emerged in Scandinavia, where the BIM becomes the legally binding construction document. This approach excludes traditional 2D-drawings and puts more requirements on the actual BIM, which should then promote more use within cost-estimation. This thesis highlights, explores issues, challenges, and potential within the cost-estimation process. 10 interviews were conducted with participants from recent projects involving the use of BIM and traditional construction documents in parallel. Secondly, an in-depth investigation of a Total BIM project was performed with respect to model quality, quantity take-offs, and cost estimations. Findings show that even in projects where BIM is present, traditional 2D-based methods were still used for cost-estimation. Common reasons include lack of trust for the BIM, the BIMs unclear legal status and quality, and that the existence of traditional 2D-drawings makes it possible to still use "tried and tested" methods. By using Total BIM, the time taken to perform cost estimations may be reduced up to 90% over traditional methods, but issues regarding training, data and information management and education must be addressed. Greater investment is also necessary in early project stages.

Key words: Total BIM, Cost estimation, BIM, Digital Construction

Kostnadskalkyler i byggbranschen

BIM vs Total BIM

Examensarbete inom mastersprogrammet organisering och ledning i bygg- och fastighetssektorn

DANIEL PÅSSE

Institutionen för arkitektur och samhällsbyggnadsteknik
Avdelningen för Construction Management
Chalmers tekniska högskola

SAMMANFATTNING

Det är känt att kostnadsöverskridanden är en stor fråga i byggbranschen och i en bransch med så små vinstmarginaler finns alltid en önskan att skära ner på kostnaderna. För att underlätta och förbättra effektiviteten och kvaliteten i kalkylprocessen har implementeringen av Building Information Modelling (BIM) främjats i byggbranschen. Nyligen har begreppet ‘Total BIM’ dykt upp i Skandinavien, där BIM blir det juridiskt bindande byggdokumentet. Detta tillvägagångssätt utesluter traditionella 2D-ritningar och ställer fler krav på själva BIM, vilket då borde främja mer användning inom kostnadsuppskattning. Detta arbete belyser, utforskar problem, utmaningar och potential inom kalkylprocessen. 10 intervjuer genomfördes med deltagare från nyligen genomförda projekt som involverade användning av BIM och traditionella bygghandlingar parallellt. Det genomfördes även en fördjupad undersökning av ett Total BIM-projekt med avseende på modellkvalitet, mängdning och kostnadskalkyler. Resultaten visar att även i projekt där BIM finns användes fortfarande traditionella 2D-baserade metoder för kostnadsuppskattning. Vanliga orsaker är brist på förtroende för BIM, BIM:s oklara juridiska status och kvalitet samt att förekomsten av traditionella 2D-ritningar gör det möjligt att fortfarande använda "beprövade" metoder. Genom att använda Total BIM kan tiden det tar att utföra kostnadskalkyler minskas med upp till 90 % jämfört med traditionella metoder, men frågor om data- och informationshantering och utbildning måste lösas. Större investeringar är också nödvändiga i tidiga stadier i projekt.

Nyckelord: Total BIM, Cost estimation, BIM, Digital construction

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Preface

This study was carried out during the fall semester 2021 and spring semester 2022 as the thesis work of the master's program "Design and construction project management" at Chalmers university of technology. The findings in the study highlight issues surrounding cost estimation and BIM in the Swedish construction industry today. The conclusions found in this research can help companies highlight obstacles to improve their implementation of Total BIM. Furthermore, the research process and findings has also provided me with an experience and knowledge in the cost estimation process, BIM and Total BIM, and has helped motivate the me to further improve the construction industry in his professional career.

The thesis is a result of a year of hard work and could not have been possible without the support from the helpful people along the way. I would like to make a special thanks my supervisor at Chalmers university of technology, Mattias Roupé, and my fiancé, Sara Hammarskjöld, for always supporting me throughout the year.

I would also like to thank all the participant in the interview study. Without their professional insight and extensive knowledge, the study would not be possible. Finally, I would like to thank my student opponent, Jingjing Zheng, for her valuable feedback on this thesis report.

Gothenburg May 2022

Daniel Påsse

1 Background

It is well known that cost overruns are an issue in the construction industry, and in an industry with such small margins of profit there is always a desire to cut costs (Flyvbjerg, 2002). However, the cost estimation process is very complex and has a lot of factors to consider, and in order to make the desired cost cuts this process must improve if the quality of the project is to remain the same.
Building Information Modelling (BIM) is on the rise and there is an increase of digital solutions for construction projects due to its reported benefits (Barlish and Sullivan 2012; Smith 2016; Tingvall 2020). The sector is already better at using BIM and other digital tools, especially during the design phase. Although there is a lot of work left to be done regarding BIM, many actors are ready to take the next step and start using BIM in a broader sense.
However, currently it is common that BIM and 2D paper drawings are used together in projects and in that case, two parallel design processes occur where designers focus on delivering 2D drawings as the legally binding construction document (Disney et al. 2021; Sundqvist et al. 2020; Johansson et al. 2019). When this happens, BIM usually ceases to be updated and becomes merely a reference model for visualisation purposes on the construction site. In Scandinavia some firms have begun to explore a broader use of BIM and the concept of 'Total BIM' has emerged (Cousins 2017). In this context, Total BIM connected to cost could be an interesting approach to explore. An approach where the BIM becomes the legally binding construction document, and where traditional 2D-drawings are excluded (Disney et al. 2021). This approach puts a higher requirement on the actual BIM, which should then promote more use of the BIM in other areas, such as cost-estimation. The Total BIM concept has gained attention after the recent success of the Celsius project, that was delivered under time and under budget and scored highly in worker surveys in Uppsala, Sweden. Instead of creating 2D drawings from a 3D model, the model should be used in the production phase as well as the design phase. The model could also act as a digital representation of the project, also called Digital Twin.

The cost estimation process is very complex and has a lot of factors to consider. All actors in the industry have their own approach and data for estimating costs and this adds to the difficulty of the process (PMBOK, 2017). Cost-estimation plays a big part in the project's lifetime, and an inadequate cost-estimation can have disastrous consequences (Ottosson, 2009). Even though there are a lot of reasons behind a cost overrun, the human factor and the lack of information are among the most common reasons for underestimation (Klakegg and Lichtenberg, 2015).

1.1 Aim

This thesis investigates the current issues in the cost estimation process as well as the issues with using BIM in construction projects and aims to find what's lacking in regards to these areas. This thesis aims to find how BIM could be used to improve cost estimation through an interview study and case analysis. The results from these studies aim to demonstrate issues that need attention in order to implement BIM in the cost-estimation process and further implement Total BIM in the construction process.

1.2 Problem formulation

As found in previous research, cost overruns are a problem in the construction sector (Flyvbjerg, 2002). Furthermore, the research shows that Total BIM can be beneficial for the time and economy in construction projects (Disney et al. 2021). This led to an interesting question on how Total BIM could help improve cost estimation to get better estimations and therefore counter cost overruns. However, the research approach to this thesis aims to first understand current issues in the cost estimation process as well as the BIM process in order to highlight areas that need attention. Furthermore, the results from the investigation are validated in a case study and analysed to find if and how Total BIM could improve the cost estimation process.

The goal for the study is to find issues in the cost estimation process and the BIM process in the construction industry today. Furthermore, the goal is to validate the findings in a case analysis and finally analyse the results to find if and how Total BIM can improve cost estimation in construction projects and help counter cost overruns.

Due to the limited information available surrounding BIM in the cost-estimation process, the approach to the subject had to be divided into two parts: BIM and cost-estimation. This limited information strengthens the problem formulation and clearly show the knowledge gap in this area. The research approach had to be adapted to this which led to the division of two areas. This was helpful during the interview study due to the interviewees work areas and work descriptions. The interviewees working with BIM does not work with cost estimation, and the interviewees working with cost-estimation does not work with BIM.

1.3 Research questions

Research questions that were aimed to answered for the thesis were:

- What are the current issues in cost estimation and how are they connected to cost overruns?
- What are the current issues with BIM and what is needed for a Total BIM approach to construction projects?
- Can Total BIM in cost estimation help reduce costs and counter cost overruns, and if so, how?

1.4 Delimitations

This study is limited to the Swedish construction industry. Furthermore, this paper focuses on cost estimation and BIM and their potential relation. The thesis also investigates the concept of Total BIM connected to cost estimation. However, while there are many reasons behind cost overruns (Klakegg and Lichtenberg, 2015) and many benefits to BIM (Barlish and Sullivan 2012; Smith 2016; Tingvall 2020), due to time constraints this study mainly focus on cost estimation BIM connected to this. However, findings from this study may be applied to other areas, but this is not included in this thesis.

2 Related Work

An extended literature search was made to find what has been done in the field and what the research is saying about the subject. Furthermore, the literature search also contributed to the literature study questions and aim.

2.1 Cost estimation

Cost estimating is a key part in a project's lifetime according to Ottosson (2009). He further states that the developer makes decisions about the project based on their knowledge about the estimated cost. This cost is based on a calculated estimate of the earnings and return of investment. That is why, in order to start a project, there is a need for a cost estimation. The initial cost estimation is done during the pilot study and has a high level of uncertainty. Ottosson states that the levels of uncertainty can range from under 25% to over 50% on big projects and under 10% to over 15% on smaller projects.
Ottosson further explains that when the cost estimation is later compared with final cost of projects, they did not meet the economic criteria. Several reasons that could affect the costs in a project were found. These reasons were: unclear demands on score and quality, forgotten posts during calculation, needs/ wishes have surfaced without being added to the budget, project have been delayed, the market forces have been put out of play, a lot of change and added works due to poor planning/design/procurement, the level of uncertainty have been misjudged, index evolvement, and currency changes.

Furthermore, the process of estimating the cost is presented in the Project Management Body of Knowledge (PMBOK, 2017) and it is presented as a part of the cost management.
Cost estimation is "the process of developing an approximation of the cost". In order to estimate costs according to the PMBOK you need a set of inputs. These inputs are the project management plan which contains the cost management plan, the quality management plan, and the scope baseline. These plans together create the framework of the plan. Other inputs needed are the relevant project documents, such as project schedule, lessons learned register, resource requirement and a risk register. There are also some environmental factors that affect the cost management, and they are counted as inputs. The environmental factors are factors such as the market conditions, exchange rates and inflation. Lastly, the organisations also typically have their own processes and policies such as cost estimation policies and templates.

Additionally, the PMBOK then states that using these inputs a cost estimate can be calculated using a set of tools and techniques. A few of them are mentioned in the PMBOK. Among the tools and techniques are expert judgement, using expertise with experience from similar projects, or experts within cost estimating methods, or experts with knowledge about the industry and discipline. The PMBOK also mentions a few different ways of estimating costs, such as: Analogous estimating which uses data from previous projects to estimate costs, parametric estimating that uses statistics to estimate costs (examples are square metres), bottom-up estimating is a way of estimating by estimating all activities in great detail and then adding them all for a total sum, and lastly three-point estimating were three different scenarios is calculated (most likely, optimistic and pessimistic) and are then used to calculate a more accurate cost estimate.

Klakegg and Lichtenberg (2015) states that cost overruns are a big problem for the sector and that the reasons behind the cost overruns are often political and strategic. One cause they found was that by underestimating the costs and overestimating the gains from the project the likelihood for funding and approval is increased. The cost estimation and risk assessments are often inadequate as well according to the paper. Furthermore, the human factor plays a big part in cost overruns according to Klakegg and Lichtenberg. They found that many experts are biased in their evaluations. Although there are scientific methods for cost estimation the experts tend to make subjective evaluations.

2.2 BIM

Building Information Modelling (BIM) can be defined as: "set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in a digital format throughout the building's life cycle" (Succar 2009). There are many benefits with BIM, time and cost savings can be made as well as material waste reduced and the collaboration between disciplines is increased (Tingvall, 2020). According to Tingvall, savings on bigger projects can with the use of BIM reach savings of 8-12% of the total project cost. In addition, Tingvall states that the BIM model also acts as a tool in visualisation, quantity take-offs, production control and simulation.

Furthermore, BIM is starting to gain traction in the construction industry today (Smith, 2016) and companies are starting to grasp the potential of BIM. However, the full potential of BIM has yet not been reached. The models typically lack all the data necessary to fully reap the benefits a model has the potential to provide. Smith continues to explain that many issues that lead to the lacking data is that many actors in projects in the sectors are reluctant to share their full version of the model with each other. There are many reasons for this but the main one is that the designer cannot control what will be done with the model and that is a potential liability. The key to successfully work with BIM, according to Smith, is data management. Smith explains this by arguing that the designer must know what data needs to be added, in what form and how the model can be changed. It is important to have a quantity surveyor that can explain to the designer what they want. Ideally the surveyor has access to the model.

However, Smith emphasises the importance of comprehensive and accurate data in order to fully reach the potentials of BIM. A comprehensive model requires much time and a knowledgeable BIM team. In many projects the model fails to deliver due to poor data. The reasons for the poor and inadequate data are many, but the main one being costs. Many clients do not see the value in paying for a comprehensive model or lack the knowledge to know if the model is comprehensive enough. Smith explains that they found BIM modellers that had to make quick and inadequate models just to satisfy the clients and then the rest of the project team had to work with poor models.

A study made in the USA by Barlish and Sullivan (2012) tried to measure the benefits of BIM in order to argue for a bigger investment in BIM in projects. They found that the long-term savings with a flexible design outweigh the initial costs and risk of rework. Barlish and Sullivan also state that the full potential of BIM has not yet been reached due to a lacking business case for owners.

Furthermore, adding dimensions to BIM increases the use from a sticky visible aid to the ability to generate take-offs and courts in the model (Kehily and Underwood, 2017). Kehily and Underwood explain that adding time and cost to a 3D model gives a 4D time model and a 5D cost model. These dimensions are what make a BIM more than a visualisation tool, and a tool for data management.

Redmond et al. (2012) did research on cloud-based BIM where everyone in the project had real time information from the model. Instead of the traditional export-import relation that is the industry standard today, the idea of a cloud-based tool is to give everyone the same data. This would eradicate the issue of every discipline in a project having their own model and creating multiple copies of the data. The research found that there is a need for a solution where BIM is able to share and synchronise information across different applications and platforms. However, Redmond et al. found that the openness this would require is an issue due to companies not being so keen in sharing information between themselves and access to all data is the key for cloud-BIM.

In Sweden a classification system called BSAB 96 is used (Svensk Byggtjänst, 2016). This system is based on ISO 12006-2 and is used as a way of standardising building parts. However, this system is outdated and Svensk Byggtjänst is now working on a new system called CoClass. This new system is better adapted to the digital process of BIM and can therefore contain more information than the previous system. CoClass is supposed to be used throughout the whole building process, from the initial start and investigation to the production phase and to the management of the finished building. The aim is to use the system as a tool to present load bearing functions, relations, location, cost, logistics and affiliation in the organisations. Svensk Byggtjänst explains that the system is very important for the maintenance of the finished building. To have access to the information of all parts during remodelling and reworks is one of the key factors behind the development of the system. Furthermore, Svensk Byggtjänst states that the system, CoClass, enables better communication between different actors and phases in building projects. By using the same name for parts, rooms, and locations the risks of miscommunications decrease as well as the integration between different softwares and disciplines increase. They also state that costs from both the production and management phase can be linked to objects and thus making it easier to test the cost efficiency of different technical solutions.

In a report by BIM Alliance (2016) they found that there is a need for proper standards for processes and definitions of terms in order to avoid misconception and increase clarity in contracts. In the report the authors also found that the various actors' needs and gains from BIM has to be made clearer so that BIM can be optimised for the various phases and actors. Furthermore, the report from BIM alliance also adds to the importance of data management. What information is important at what time and for whom.

The various standard agreements that exist in Sweden (AB 04, ABT 06 and ABK 09) should also be updated according to BIM alliance (2016). The handling of the model in the different phases in projects as well as the hand over process should be better regulated. The report emphasises the importance of clear and comprehensive contracts that state how the model will be handled and who has the responsibility to deliver the

model and what it should contain. However, standards such as level of detail (LOD) exist outside of Sweden (Tingvall, 2020). LOD states how much data the model contains, and the author states that LOD can be used as a standard measurement on how BIM should be used in projects and what the model should contain and when. LOD is today used internationally but is lacking in Sweden.

2.3 Cost estimation with BIM

In a report made by Carl-Erik Brohn (2018) it is shown that the amount of time needed for a cost estimation differs greatly depending on the technology used. The numbers he states are approximately 160 hours of traditional work with manual calculations, approximately 100 hours of work when using Bluebeam (digital drawings), and 15 hours when using an IFC model. Furthermore, the author also states that the model should be the primary source of information.

3 Research Method

To investigate and research the cost estimation process and Total BIM, a literature review followed by interviews with different stakeholders in the Swedish construction industry was performed. The findings from literature and interviews were tested and validated in a case study of a Total BIM project in Gothenburg, Sweden.

Figure 1. Illustration of methodology

3.1 Research approach and design

The research approach of the thesis adopted a qualitative approach based on semi-structured interviews with key persons from the construction sector that are active in either BIM or cost-estimation. This approach creates an opportunity to understand and explore the issues of the topic through the knowledge and experiences of the interviewees (Bryman and Bell, 2012). This thesis uses a deductive approach to the theoretical framework. As explained by Dubois and Gadde (2002), the theoretical framework should be used as a guideline to the empirical data collection.

The empirical data was also tested and validated in a case study to provide a better in-depth insight of the empirical findings (Dubois and Gadde, 2002). The findings from the interview study and the case analysis were evaluated using an abductive approach, using the literature found as a guideline. This research approach, according to Dubois and Gadde (2002), facilitates an iterative and flexible process where the empirical data analysis and collection is conducted alongside the theoretical framework's development.

3.2 Related works

The initial part of the study was to investigate the current state, find issues and the research gap connected to the cost estimation process and the Total BIM process. The two research areas are firstly separated to enable a deeper understanding of each. Then they are combined and developed to see how they can improve the cost estimation process using Total BIM. Due to the limited information, and clear knowledge gap, of BIM in cost-estimation, the literature research for related works was divided to create a framework for the empirical data collection.

3.3 Interview study

The interviews were semi-structured, meaning that there were some questions prepared but there was room for discussion (Bryman, 2012). Having room for discussion creates a better way for the interviewees to share their thoughts and observations without limitations.

In total ten interviews were conducted with twelve different participants. Among these interviewees there were two clients, two contractors, five consultants, one software developer, and two estimators. The interviews were conducted as semi-structured and the interview questions were divided into two parts, namely cost estimation and BIM, following the related works and the knowledge of the interviewees. As stated above this was helpful study due to the interviewees work areas and work descriptions. The interviewees working with BIM does not work with cost estimation, and the interviewees working with cost-estimation does not work with BIM, making the connection of the areas difficult and very relevant. Among the interviewees there were some key actors in BIM in the Swedish construction industry. One of the interviewees was in charge of the digital implementation of the successful Total BIM project Celsius. Another interviewee is responsible for the digital implementation and strategy for the project Total BIM project Kaj 16, e.g., case study in this thesis.

3.4 Data analysis

The findings from the empirical data collection from the interview study was later analysed systematically using a thematic analysis to detect themes and patterns (Alhojailan, 2012). This analysis is a method that allows the researcher to understand the potential of issues more widely and determine the relationships between concepts using the collected data. Something that Bryman and Bell (2012) emphasise when analysing data is to ensure the quality of the study. This was made by validating the findings in a case study to test the trustworthiness of the data found in the interviews.

3.5 Case study

The findings from the interview study were later tested and validated in an ongoing Total BIM case project in Gothenburg, Sweden. The case was a project called Kaj 16, which is meant to be a Total BIM project, see Figure 2.

The project is in its design phase and is still being revised prior to the building permit process. The model is to be used to calculate and estimate the quantities and cost of the project. This study is limited to the concrete elements of the basement instead of the entire project due to time constraints and the authors prior knowledge of concrete in the construction process. However, the findings should not be affected by the scope of the research and the highlighted issues should remain relevant throughout the project.

The study tested using two different methods for performing a cost estimation. The first method used BIM viewer and collaboration software, StreamBIM's own export and data structure to calculate quantities (figure 4 & 5). The second method exported the model as an IFC-file, which was then imported into Solibri. The reason for using two different approaches to the case study is to further the understanding of the findings from the empirical data.

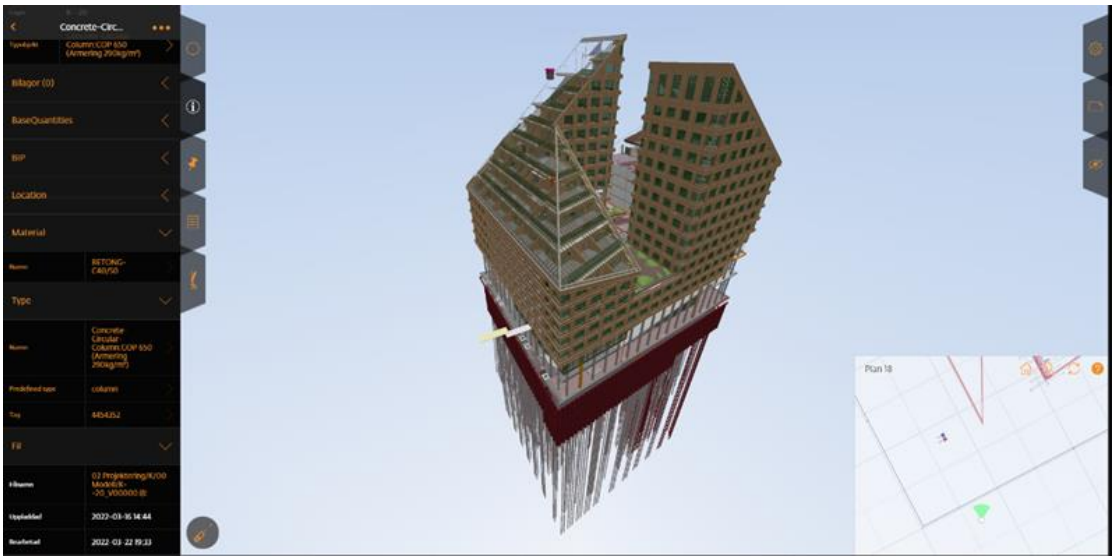

Figure 2. Screen-shot from Case project, Kaj 16 in StreamBIM.

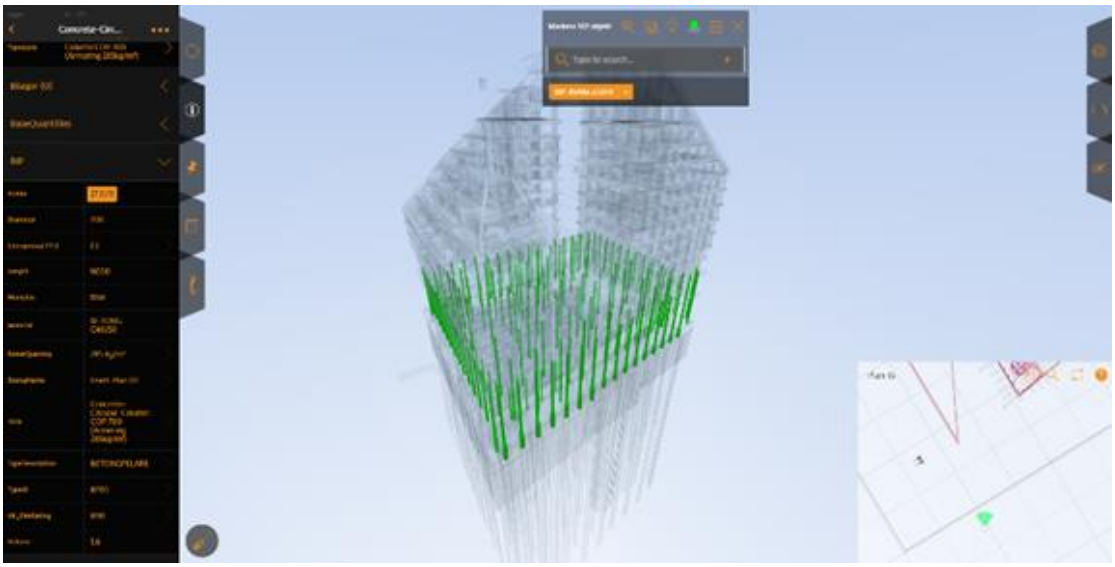

Figure 3. Use of classification system as a filter

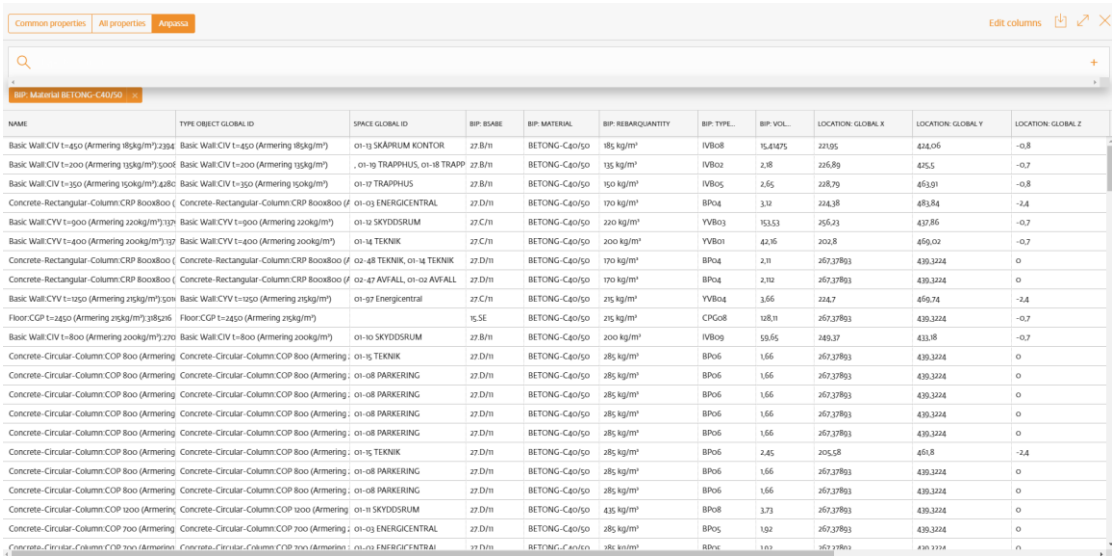

Figure 4. Quantity take-off in Stream-BIM

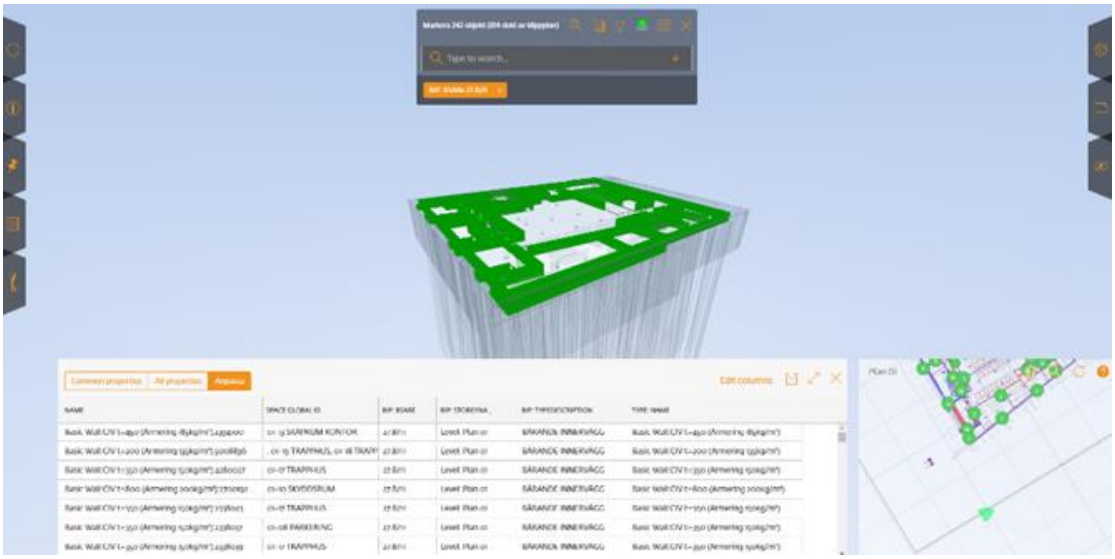

Figure 5. Case where rebar is not stated in a column leading to more manual work

3.6 Schedule

Since the thesis is 60hp and was carried out during two semesters, it was divided into two parts (fall and spring). During the fall the goal was to explore and investigate and have a comprehensive report about the process and technology containing a detailed explanation of the process and tool and how it is used today, how the tools should and could be used, and what the users from all disciplines (design, production, client) want from the technology. The second half of the thesis has focused more on validating the results in a case study and then analysing these results to reach a conclusion. The most interesting findings was summarized and discussed in an ARCOM conference paper, see appended paper in appendix.

3.7 Validation

Translations and transcriptions of the interviews and literature were made by the author. The interview study findings are the opinions of twelve actors in the construction industry and cannot speak for the whole sector. However, the positions

and experience of the interviewees add to the validation of the findings. Furthermore, the case study strengthens the validation of findings further through testing of an ongoing Total BIM project. Therefore, the findings in this study have a strong validation for the Swedish construction industry. However, the findings are analysed by a single author and should therefore be considered as interpreted.

3.8 Ethical aspects

The ethical aspect of this thesis is related to how the interview study was executed and how the data was validated in the case analysis. When studying processes or issues connected to humans, the ethical aspects must always be considered. This study aimed to be as objective as possible to the results and interviewees, the results from the interview study are anonymous mainly for this reason. Furthermore, considering the ethical aspects in a case study, issues found could be related to human error and it is therefore important to note that separating human error and issues found in the process is a must. Considering ethical aspects in this study shows that human factors can affect the results as well as the results can affect the human factor.

4 Results: Interview study

Here, the results of the interview study are presented. The interviews were held online and recorded and were later transcribed by the author. The interviewees were representatives from the Swedish construction industry and the interviews were held in Swedish.

4.1 Cost estimation

All interviewees agree that cost overruns are a problem, but that the reasons are many and complex. However, most agree that this is a serious issue that affects everyone in the industry and that the idea that projects often exceed cost estimates most people have of the construction industry is accurate. The interviewees do not, however, agree that the cost overruns are intentional. Some think that there could be political and tactical benefits to underestimating cost, but not more than half of the interviewees believe that there is any intention behind cost overruns.

Furthermore, there does not seem to be any standard cost estimation process and even within the same company it differs greatly between projects. Some companies have their own key figures for cost estimation and some companies do not have any 'in house calculators' at all, and instead hire external experts to estimate costs. Although, most state that the cost estimation only acts as a tool in the decision process and that the decision is made by a manager that could alter the number however they like. This was also mentioned in regards to the question about cost overruns as one of the reasons that projects exceed the estimated costs. The interviewees stated that the most common reason for the alterations made were to increase the competitiveness of the company. To win a project, the company can lower their procurement bid or in some cases increase it if profit from the project outweighs the desire to win it according to the interviewees. The only discipline that did not state this in the interview study was the consultants because they are not part of any procurement phase and are paid by the hour in most cases. However, the interviewees still emphasise the importance of an accurate cost estimation. Especially if managers are to alter the costs prior to a bidding. The consequences of inaccurate cost estimation would be twofold if they were to alter an incorrect cost estimation.

Most interviewees state that the initial cost estimation usually follows the project and is updated at hand but the follow up is lacking. However, there are not many people in projects who actively work with the budget to keep it up to date during the production phase.

Furthermore, there is some disagreement to costs connected to cost estimation work. The clients have a successive approach and only approve some money at the time. But the consultants and contractors want to have more money in order to make a better design and estimation work. This, according to the findings, adds to the problems of cost estimation.

4.2 BIM

When discussing BIM, the interviewees all agree that BIM is standard in all their new building projects. However, the level of BIM usage and the quality differs greatly. It is also apparent that in order to succeed with the implementation of BIM in any project or organisation you need a key person who is driven and invested in the subject.

Another important aspect in the implementation are the contracts. They play a big part in the level of quality and usage of BIM. The contracts are closely linked to the project delivery method. Some interviewees state that the Design-Build method never works with BIM, while some states that this is the only method that works. Generally, the clients do not want Design-Build contracts if they want to control the level of BIM and for the builders it is the other way around.

A reason for the lack of BIM according to some of the interviewees is that it is difficult to use the model as a legal document in the contracts. However, the interviewees do not see any legal issues with BIM as a methodology and state that the legal issues are only myths made by "nay-sayers". One interviewee working for a big client explained that they hired a team of legal workers to investigate the potential legal issues with BIM and that they found none.
This connects to a bigger issue regarding BIM implementation and that is scepticism without reason. Most interviewees have noticed this in their work. Many actors are sceptical of the technology, but when it becomes apparent that they lack knowledge of the subject their view usually changes.

Furthermore, findings show that data management is not about importing all data but choosing the right one. It is clear in the interview study that the issues with data management in BIM is not the lack of data, but the overflow of unnecessary data and no way or bad way of sorting the data. The interviewees state that bad unstructured data is almost as bad as no data. The transfer of data between parties also often leads to loss of data and misunderstanding. All interviewees agree that having the model in the cloud is beneficial, but some are worried with the security and risks that comes with a cloud-based model. However, all interviewees see the benefits and want a more accessible model.

On the subject of classification there are big disagreements. Some say it's the solution to implementing BIM and some say it's not necessary on a national level, you can use different systems on different projects.

However, when asked about issues with BIM, many interviewees mentioned are communication, technological maturity, and knowledge, where knowledge was the most limiting. Many clients believe that BIM is only a 3D viewer and that makes it difficult to work with, which also leads to trust issues. There are cases, they state, when the clients order a BIM model without knowing what it is. Several interviewees stated that there is a lack of trust in the model and that they had to check the BIM data many times, often there is inconsistent information.

However, there is no hesitation among the interviewees that BIM is the future of the construction industry. Most agree that BIM should be used earlier in the building

process and that the construction method should have a more collaborative approach than the “baton” approach that we have today, meaning that many disciplines act as “information islands”.

5 Results: Case study

The results from the interview study were tested, evaluated, and validated in an ongoing Total BIM project in Gothenburg, Sweden, Kaj 16. The model was used to calculate and estimate the amounts and cost of the project. Using the findings from the literature and interview study as a framework when estimating the costs for the project. Due to limited time and the authors prior knowledge of concrete construction, the project was filtered to the concrete elements of the basement for the project.

The project is called Kaj 16 and is part of an initiative from the client Vasakronan. The client is Sweden's biggest client in construction development and are known for their innovation projects.
After a very successful project carried out by said client in Uppsala, they wanted to implement this Total BIM concept on more projects. The project in Uppsala was called Celsius and Byggstyrning was the hired general contractor and was delivered under budget and ahead of time. According to Byggstyrning and Vasakronan the key to their success was foremost due to the use of the model as a legal document as well as the "only source of truth".

During the experiment in the case study, two different methods for cost estimation were tested. The first used StreamBIM to export data and the second imported an IFC file into Solibri. Both methods lead to an excel sheet with quantities which meant that the numbers also had to manually be updated with prices and some additional information such as the amount of rebar in some structures. The BIM was very comprehensive with much information about the building components and their quantities. However, StreamBIM's functionality is lacking in some aspects. For example, it is still quicker to export the IFC file to Solibri for a better quantity take-off due to the abilities to structure data. Although the tool is focused on production the ability to quickly calculate cost and quantities is missing.

The experiment in the case study showed the importance of data management. It was important to have the desired data in the model with a good structure and sorting out undesired data. In this experiment in the case study, a quantity take-off for concrete was performed but the model lacked detail as no reinforcement was included, so it had to be manually calculated. Information also had to be sorted into different property-sets to ease the data management for the user, see Figure 4 & 5. Findings from the case analysis suggests that maintaining a good data structure throughout the project is essential. Otherwise, information chains and information sustainability may be jeopardised when transferring data between users, leading to a loss of quality. Therefore, well-structured data is essential to achieve an accurate cost estimation process.

One of the most challenging aspects and a learning experience from the case study was the process to discover and learn the different software functionalities to perform an accurate cost estimation. Software like Solibri is tailored towards expert users and not user-friendly enough, which highlights drawbacks and limitations towards end users' lack of knowledge using software. It is likely that an expert in the software may be able to perform a more accurate estimation than a novice user, but on construction sites the user target group is a "novice user". However, with the current situation when using BIM for cost estimation in projects it would be beneficial to have support

or an expert user present. Furthermore, the case study showed the differences between different software and how the software can affect the quality of the cost estimation. However, the case study shows a clear benefit of a BIM approach to cost estimation compared to a traditional 2D-drawing approach. Having data structured in the BIM massively decreases quantity take-off time and increases the take-off accuracy. Finally, the case study test showed that exporting data may lead to version control issues. Working in a cloud-based model ensures that information is accurate and up to date. This, in turn, leads to all actors working with that same information, and one source of truth.

6 Analysis

In an industry with small profit margins, it might be expected that there is an emphasis on accurate cost estimation and budgets, but this is often not the case. Although the findings show that cost overruns are a significant problem in projects, the willingness to improve them seems to be lacking. Some interviewees thought that the issue is not with the methods and processes of cost estimation but with the tender and procurement process. Furthermore, cost estimation in many cases is just a guide for the managers and decision makers to use for the bidding process. The client that was interviewed thought that a thorough cost estimation was not worth the work because it is usually not detailed enough. This could be an issue in the cost estimation process because the party that is funding the project does not work in the same profit margin.

A need for a more standard BIM process is apparent, especially in regards to BIM implementation in the cost estimation process. If the industry were to try to implement a more model based approach in the cost estimation process today, there would be issues with adapting it to all the different methods that currently exist. The results show that there are many different methods and approaches to cost estimation and while this level of flexibility may be beneficial for the current methods, it would only increase the complexity of a more automated method using BIM. Whilst flexible methods may benefit some actors, they represent significant challenges moving towards a more standardised, automated BIM approach. As the result from the case study experiment showed, software like Solibri is tailored towards expert users and not user-friendly enough for non-daily users as on construction sites. In the Celsius project they recognized this as a problem during the bidding process and therefore gave the bidding sub-contractors an excel-sheet with all the quantities of their responsible building components. This quantity take-off excel-sheet was updated weekly throughout construction as change orders were updated through the design team (Disney et al. 2021). The biggest trade off for efficiency is flexibility.

Identifying issues with BIM today are necessary to understand how to improve and implement BIM in the future of cost estimation. There are opportunities to save both time and money as occurred in the Total BIM project, Celsius. While BIM implementation has developed significantly over the last decade, its benefits are not fully realised (Disney et al. 2021). BIM is still mostly used in the design stage of projects, where parallel processes occur to produce 2D drawings from BIM. The model ceases to be updated and trust is lost in the model. To be able to use BIM for accurate cost estimation it is important that BIM represents what is actually going to be built, with accurate quantities. Then users can begin to trust the model and perform accurate work.

Today there is a significant lack of knowledge regarding BIM in the construction process. From the interviews we heard that BIM is still thought of as merely a tool for representing a 3D model and the case study highlighted the need for expert software users. An interviewee stated that information from the model may as well be in 1D (a list in excel), because the current focus is on data and not the 3D viewer. The interviewee means that the real benefit of BIM is not the viewer but the data management. This creates issues later in the project because some actors do not have the knowledge to know what the information is used for. Furthermore, knowledge

regarding the available BIM tools needs to improve and users must fully understand how to use them. To implement the Total BIM concept construction companies need to invest in educating workers. User-friendliness of software, ease of access and information structures may also help adoption. It is also apparent from the interviews that for change to occur and a wider use of BIM, an organisation's leaders must be fully committed. The difference between the tools could also lead to many potential issues. However, the issues are linked to the user experience and compared to estimating costs without a model the issues are minor. Comparing manual quantity take-offs and the model the time difference is massive. The key difference between a model and paper drawings is that you have access to all the information instantly in the model. But a requirement to this is the level of detail and quality of the model. A bad model is useless and can in the worst-case lead to more work. A bad model can also very easily lead to trust issues, an issue that was discussed in the interview study as a big problem in implementing BIM. Trust issues can also relate to the user friendliness in the software. If there is a risk of missing information due to software handling, the trust in the BIM decreases.

A lack of trust in the model and BIM has been found to be an obstacle in the move towards Total BIM. As stated by the interviewees, in the worst case it may lead to extra work. Traditionally 2D drawings are the legally binding construction documents, which means that to have an accurate BIM extra work is required, or BIM is used merely as a reference model and not used to its full potential. When there are few or no requirements set on the BIM it is difficult to trust and information must be double-checked. This makes it difficult to work with and there is no incentive to do so. In a Total BIM project, BIM has a higher legal status than 2D drawings and completely replaces them. At this point BIM becomes a single source of information and an accurate representation of the object to be built, as it is legally required. The case study findings also support this, since attempting to use BIM for cost estimation when the model cannot be trusted is pointless. However, as Brohn (2018) described, there is a huge potential to save time by using BIM in cost estimation compared with traditional methods. If BIM is used in this context higher demands and requirements must be placed on developing an accurate representation. Incorrect or missing data could have serious consequences, so trust needs to be established in the model. The importance of BIM as the primary source of information and the legally binding document is therefore essential. This still may be a novel concept but has been proven by the Celsius case and the interviewee findings where no legal barriers could be found.

Despite scepticism, legal issues connected to Total BIM have been shown to be minimal and not hinder the process of implementing Total BIM or using BIM in cost estimation. However, it should be noted that this may not be possible in other countries due to local regulations, but the Total BIM approach in Celsius does highlight the need for it to be considered. In Sweden regulations have been established around traditional 2D documents and they are lacking regarding BIM. While there are not currently any issues there still needs to be a certain level of BIM maturity before using it as legally binding. Users need training to adapt to new work methods. It can be discussed whether BIM, 2D drawings or technical documents should be ranked highest in projects, but another benefit shown in the Celsius project was using StreamBIM as a central communication platform. In StreamBIMs case, issue management, question-handling and more occurred through the platform. To

support this, all object information, technical documents, and construction information were linked to BIM, and easily accessible. Establishing the model as the single source of all construction information and a single construction process. This single process if executed well may streamline the unnecessary work that goes into producing and maintaining 2D drawings. As found in other parts of this study, an accurate BIM has potential to be used for accurate cost estimation, providing users have the necessary support.

As stated above, BIM is focused on data management and to structure data there needs to be a classification system, which users can easily understand. When analysing the results, it shows that although some users may not see the need for a standard classification system, it may help implement a more structured process and method when working with BIM. It could also help actors to quickly understand and comprehend project data if it is structured consistently between projects. Data management is a key part of working with Total BIM successfully and implementing BIM in cost-estimation. The importance of data management found in the interview study is also found in the case analysis. The case study showed that for cost estimation to work with BIM, data must be well structured. Findings suggest that it is highly important to be able to structure and filter data in BIM to easily find the desired information. While data may be accessible even without a good structure, it should be structured in a way where users can easily filter to information that is relevant to them. In a Total BIM project this is essential since BIM is the single source of information and construction workers must be able to easily access the information they need.

Connecting cost-estimation and BIM in this thesis shows that the process today is not as efficient as it could be, but it remains challenging due to the level of complexity in construction projects. It also shows that both the cost estimation process and BIM lack standards which may be necessary to achieve accuracy and consistency. However, if BIM was used to a greater extent in the cost estimation process, there needs to be a more structured approach than found in most projects today. By going 'all-in' on BIM and using a structured Total BIM approach, where BIM is legally binding, other benefits may also be achieved. Designers work more collaboratively as they work on the model at the same time, focusing on high-quality design where all object information is present, and consider how construction occurs on-site. Producing 2D drawings is no longer necessary and site workers can construct directly from the model by using mobile devices to extract the construction information they need themselves.

Finally, using BIM in cost-estimation could not only improve the project's quality and efficiency, but it could also create a more sustainable project. As shown in the findings from the interview study, BIM can be used in many areas if implemented correctly. Total BIM could help make construction projects more sustainable, both economically by implementing BIM in the cost-estimation process, and environmentally due to Total BIM ability to structure data, reduce cost and time, and making the project more available to everyone in the project by removing the “baton-effect”. Connecting the findings to the UN sustainable development goals (UN, 2022), implementing Total BIM could work towards achieving three of these goals: goal 9, 11 and 12. Goal 9, industry, innovation, and infrastructure, aims to foster innovation and the findings in this thesis contribute towards this goal by increasing digital

construction and innovation in the construction industry. Goal 11, sustainable cities and communities, aims to make cities sustainable which the findings in this thesis contributes by showing how Total BIM in cost estimation can reduce costs and therefore free resources for better and more sustainable solutions. Finally, the third goal, goal 12, responsible consumption and production, aim to make production sustainable. This study adds towards this goal through reducing waste and CO2 in the construction process by showing the benefits of Total BIM and thorough planning.

7 Conclusion

As highlighted in this thesis, BIM is very time efficient to use when it comes to quantity take-off and cost estimation. However, as BIM in most cases is not used as a legally binding construction document, design teams focus more on delivering correct 2D drawings instead of BIM. This causes quality and trust issues when it comes to using BIM on construction sites and for cost estimation. The interviewees mentioned the lack of trust in BIM and that they had to double check data with drawings and descriptions if it was used. Using BIM in the cost estimation process requires that all disciplines trust it. If trust issues arise towards BIM, it will quickly become redundant. This could have greater consequences further down the project's lifetime. However, in Scandinavia the Total BIM approach has started to gain interest as it focuses to implement BIM in its "totality", as a single source of information and communication platform and the legally binding construction document.

If we are to implement Total BIM the way it is meant, then the construction process needs to change. The decisions that usually are postponed as much as possible have to be taken earlier. This is because the biggest reason the cost estimation has an uncertainty is the lack of information in the early process. By taking more decisions earlier the cost estimation can be made more accurate. Making these decisions would also help all other disciplines and improve the project overall. The backside to this approach is that it is more rigid, and it requires a large amount of work in the early stages as well as a clearly defined project by the clients. The biggest trade-off to efficiency is flexibility.

Connecting the results from the cost estimation and the BIM results shows that the cost estimation process today is not as efficient as it could be, but that it is difficult due to the level of complexity. It also shows that both the cost estimation process and the BIM process lack standards which may be necessary to achieve the flexibility necessary. However, if the model were to be used to a greater extent in the cost estimation process it needs to be more structured. Data management is key in a successful Total BIM project.

In conclusion, Total BIM has a lot of future potential in a more cost-efficient way of working. However, to successfully implement Total BIM in the cost estimation process, there are some areas that need attending. If BIM is going to be used to a greater extent in the cost estimation process, it needs to be more structured. The information, data and management structures are key to being successful. Another finding is that the lack of knowledge surrounding BIM as a big reason for the lack of implementation. For instance, findings also show a lack of understanding and maturity in the industry regarding Total BIM, as the belief and statements of legal obstacles and scepticism without real-knowledge or reason occurs. In this case the industry must be educated and acquire more understanding and knowledge. Total BIM can be a driving-force for using BIM on the construction site and increase the efficiency and quality in the cost estimation process. Furthermore, comparing Total BIM to the traditional cost estimation approach it is apparent that the process is not only more efficient but more accurate as well. However, to reach its full potential, the industry has some issues to tackle e.g., putting more knowledge, money, and time into the design process to get a higher-quality BIM design. The findings in this study,

contribute, add knowledge and understanding to current issues and how these can be approached to implement Total BIM in the cost estimation process.

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9 Appendix A - Appended paper

COST ESTIMATION IN CONSTRUCTION: BIM VS TOTAL BIM

Implementing Building Information Modelling (BIM) has been promoted to address cost overrun issues in the construction industry by improving the efficiency and quality of cost-estimation processes. Recently, the 'Total BIM' concept has emerged in Scandinavia, where the BIM is the legally binding construction document, 2D-drawings are excluded, and stricter BIM requirements are implemented. This paper highlights, explores issues, challenges, and opportunities within the cost-estimation process. Ten interviews were conducted with participants from traditional projects, involving the parallel use of BIM and traditional construction documents. An in-depth investigation of a Total BIM project was also performed. Findings show that even in projects where BIM is present, traditional 2D-based methods were still used for cost-estimation due to a BIM's unclear legal status and lack of trust in BIM. Total BIM may reduce cost estimation time by up to 90%, but issues regarding training, data and information management and education must be addressed.

Keywords: BIM, Cost estimation, Digital construction, Total BIM.

INTRODUCTION

It is well known that cost overruns are an issue in the construction industry, and in an industry with such small profit margins there is always a desire to cut costs (Flyvbjerg 2002). To improve efficiency and quality in cost-estimation processes, implementing Building Information Modelling (BIM) has been promoted. In recent years, BIM adoption in the design phase has rapidly increased due to several reported benefits (Barlish and Sullivan 2012; Smith 2016; Tingvall 2020). However, it is still common that BIM and 2D paper drawings are used together in projects where two parallel design processes occur, and designers focus on delivering 2D drawings as the legally binding construction document (Disney et al. 2021; Sundqvist et al. 2020; Johansson et al. 2019). When this happens, BIM usually ceases to be updated and becomes merely a reference model for visualisation purposes on the construction site. In Scandinavia some firms have begun exploring a broader use of BIM and the concept of 'Total BIM' has emerged (Cousins 2017). In a Total BIM project, BIM is the legally and contractually binding construction document for both designers and site workers. On the construction site, sub-contractors extract all information directly from BIM on mobile devices (Disney et al. 2021). This includes creating production-oriented views on-site where filtering, dimensioning, sections are all performed by the construction workers themselves to carry out their work. BIM is the single source of information and a central platform for communication, utilizing modern hardware and BIM viewer software. Where question-handling, checklists, change orders and other construction processes are integrated in the software and connected to BIM. This approach completely excludes traditional 2D paper drawings and puts more requirements on the actual BIM, which may promote more use during cost-estimation and construction (Disney et al. 2021). The Total BIM concept has gained attention after the recent success of the Celsius project, that was delivered under time and under budget and scored highly in worker surveys in Uppsala, Sweden.

The cost estimation process in construction is complex and has many factors to consider. There is no standard approach or data for estimating costs, which adds to the difficulty of the cost-estimation process (PMBOK 2017). Cost-estimation is significant in a project's lifetime, and inadequate cost-estimation can have disastrous consequences (Ottosson 2009). Human factors and lack of information are among the most common reasons behind under estimation (Klakegg and Lichtenberg 2015).

Recent projects carried out in Sweden with an aim of implementing the Total BIM concept show the benefits and how it can improve the cost estimation process during bidding and construction (Disney et al. 2021). However, many actors are still hesitant to use this approach and are unsure of the benefits. This paper aims to add to the understanding of current issues in the cost estimation process and using BIM in this context. These two areas, cost estimation and BIM use in cost estimation, are first analysed individually to understand how Total BIM can be used in the cost estimation process for a construction project.

RELATED WORK

In a report made by Brohn (2018) it is shown that the amount of time needed for a cost estimation differs greatly depending on the technology used. He writes that it takes approximately 160 hours of work with traditional manual calculations, 100 hours of work when using Bluebeam (digital drawings), and 15 hours when using a BIM model. Furthermore, the author also states that the model should be the primary source of information. Investigating the use of BIM for cost estimation is important, to unlock the reported potential benefits.

Cost estimation

Klakegg and Lichtenberg (2015) state that cost overruns are a significant problem for the construction sector, cost estimation is complex and considers many factors. According to Ottosson (2009), cost estimation is a key part in a project's lifetime. Despite its importance, initial cost estimation due to its complexity can often range from 25% under budget to 50% over budget on large projects, from the initial estimate to final actual cost. The process of cost estimating can vary due to the amount of approaches available (PMBOK 2017; Sayed et al. 2020). However, they all have their own benefits and drawbacks, meaning that cost estimation is not only complex due to the number of factors, but also due to the number of methods available (PMBOK 2017). In research it has been argued that using BIM enables many benefits, such as time, cost savings and increased collaboration between disciplines (Tingvall 2020). On large projects savings of 8-12% of the total cost can be realized with the use on BIM (Tingvall 2020). Furthermore, BIM is starting to gain traction in the construction industry today and companies are starting to grasp the potential of BIM (Smith 2016).

Data management and standards

According to Smith (2016) the key to successfully working with BIM is data management. Many clients do not see the value in paying for a high-quality BIM and lack the knowledge to know if the BIM is detailed enough, leading to poor and inadequate data. A study made in the USA by Barlish and Sullivan (2012) tried to measure the benefits of BIM to argue for greater investment in projects. They found that long-term savings with a flexible design outweigh the initial extra costs and risk of rework, further adding that implementing BIM in the construction process leads to cost savings.
In a report by BIM Alliance (2016) they found that there needs to be standards for processes and definitions of terms to avoid misconceptions and increase clarity in contracts. In the report the authors also found that the requirements and gains from BIM must be made clearer so that BIM can be optimized for the various project phases and actors. However, the process of implementing BIM standards remains challenging because today most contracts and regulators do not require detailed BIM use (Vukovic et al. 2015). Therefore, whilst BIM use has become more common in projects its full potential has not been realised.

METHOD

To investigate the cost estimation process and Total BIM, a literature review followed by interviews with different stakeholders in the Swedish construction industry was performed. The initial part of the study investigated the current state, found issues and the research gap connected to cost estimation and Total BIM processes. The two research areas are firstly separated to gain a deeper understanding of each. Then they are combined and developed to see how Total BIM can improve the cost estimation process.

Interview study

Ten interviews were conducted, eight of these were one-on-one, the other two occurred with interviewees in pairs. In total twelve professionals were interviewed, and all interviews were performed online on Microsoft Teams. The interviewees held different positions, including two clients, two contractors, five consultants, one software developer, and two estimators. The interviews were semi-structured, and the questions were divided into two parts, cost estimation and BIM. One of the interviewees was responsible for digital implementation in the successful Total BIM project, Celsius. Another interviewee was responsible for the digital implementation and strategy for the project Total BIM project Kaj 16, which is used for the case study in this paper.

Case analysis

The interview study findings were later tested and validated in an ongoing Total BIM case project in Gothenburg, Sweden. The case was an ongoing project called Kaj 16, which aims at being a Total BIM project (Figure 1).

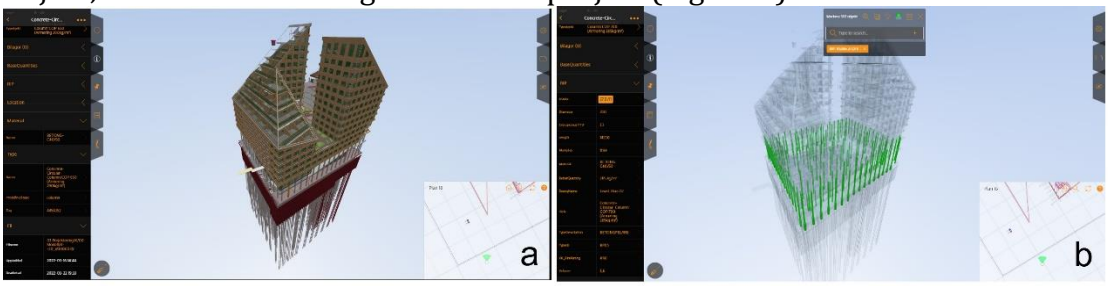

Figure 1. a: StreamBIM screenshot of Case project, Kaj 16. b: Filtering of the BIM use classification system.

The project is currently in the design phase and is still being revised prior to the building permit process. BIM is to be used to calculate and estimate quantities and costs in the project. This study is limited to the concrete elements of the basement instead of the entire project due to time constraints. However, the findings should not be affected by the scope of the research and the highlighted issues should remain relevant throughout project.
The study tested using two different methods for performing a cost estimation. The first method used BIM viewer and collaboration software, StreamBIM's own export and data structure to calculate quantities. The second method exported the model as an IFC-file, which was then imported into Solibri (Figure 2).

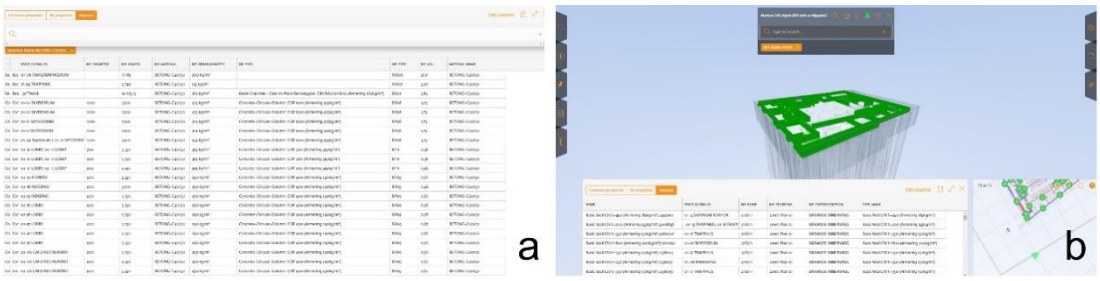

Figure 2. a: Quantity take-off in StreamBIM. *b:* Case where rebar is not stated in a column leading to more manual work.

Data analysis

To analyse the findings from the study, a thematic analysis was adopted. This approach allowed for a data analysis where data can be searched and sorted according to themes and patterns (Alhojailan, 2012). This method of analysis enabled a flexible examination of the findings and generates insight through categorising the empirical data into themes.
As stated above, the empirical data found in the interview study was validated in a case analysis to improve the trustworthiness of the study and gain a deeper understanding of the findings. The data analysis was therefore twofold, an initial analysis after the interview study and later when the findings had been validated in the case study, i.e., Kaj 16.

RESULTS: INTERVIEW STUDY

All interviewees said that cost overruns are a problem in construction projects but there are many complex reasons for them. Most also said that it is a serious issue that affects everyone in the industry. Furthermore, there did not seem to be any standard cost estimation process, even within the same company and it could differ greatly between projects. Interviewees stated that cost estimation only acts as a tool in the decision-making process and managers may alter the numbers depending on their goals. The most common reason given for making the alterations was to increase the competitiveness of the company, which is why projects often exceeded estimated costs. As stated by one interviewee, *"we have many employees, and they must have work. […] So, for a project that we really want, we can submit a low bid and even accept it at a loss. And for some project that we don't really want, we can bid anyway but really high. It is difficult to identify cost overruns because it depends on how we approach the project."*
However, the interviewees still emphasised the importance of accurate cost estimation. The consequences of inaccurate cost estimation would be twofold if managers were to alter an incorrect cost estimation. The interview results also showed that lack of information in early stages of a project is a common reason for cost overruns, along with a too short design phase.
When discussing BIM, the interviewees all agreed that it is standard in their new building projects. However, the level of usage and quality differs greatly, sometimes rendering BIM useless. It was also apparent that to succeed with implementing BIM in an organization or project there needs to be key leaders who are driven and invested in the approach. According to some of the interviewees a reason for BIM being limited in projects is that it is difficult to use the model as a legal document in contracts. However, other interviewees contradict this statement by showing examples of successful projects that have used the model as the legally binding document. These interviewees do not see any legal issues with BIM and state that the legal issues are only myths made by 'naysayers'. One interviewee working for a large client explained that they hired a legal team to investigate potential legal issues with BIM and that they could not find any. They said, *"we've discussed with a number of legal practitioners about working digitally and they stated there are no issues. They also said our current standard agreements work fine with BIM. One legal practitioner even said that it is better because it increases the traceability of the documentation."* This connects to a wider issue regarding BIM adoption which is scepticism without reason. Most interviewees noticed this in their work. Many actors were sceptical about the technology, but when it becomes apparent that they lack knowledge, their view usually changes.
It is clear from the interview study that the issue with data management in BIM is not the lack of data, but the overflow of unnecessary unstructured data. Data that is unsorted becomes unclear what it should be used for. The interviewees state that poor unstructured data is almost as bad as no data. Adding that transferring data between parties often leads to loss of data and misunderstandings.
When asked about the issues with BIM, many interviewees mentioned communication, technological maturity, and knowledge, where knowledge was the most limiting. Many clients believe that BIM is only a 3D-viewer and that makes it difficult to work with, which also leads to trust issues. Several

interviewees stated that there is a lack of trust in the model and that they had to check BIM data many times, as there is often inconsistent information. One estimator stated that, *"currently the issue is that you still have to double-check BIM data with the drawings, which leads to more work. […] As an example, I calculated a garage with a slab roof which was part of a building further on. In the drawings, they added information about the slab not being included, but not in BIM, leading to many millions [Swedish crowns] too much."*
There is no hesitation amongst the interviewees that BIM is the future of the construction industry. Most thought that BIM should be used earlier in the building process and that the construction process should have a more collaborative approach than we have today.

RESULTS: CASE STUDY

As mentioned, some statements and findings were validated in an ongoing Total BIM case project Kaj 16. During the experiment in the case study, two different methods for cost estimation were tested. The first used StreamBIM to export data and the second imported an IFC file into Solibri. Both methods led to an Excel sheet with quantities which meant that they had to be manually updated. BIM was extensive with detailed object information. However, StreamBIM's functionality is lacking in some respects. It is still quicker to export the IFC file to Solibri for a better quantity take-off due to the abilities to structure data.
The experiment in the case study showed the importance of data management. It was important to have the desired data in the model with a good structure and sorting out undesired data. In this case study experiment, a quantity take-off for concrete was performed but the BIM lacked detail as no reinforcement was included, so it had to be manually calculated. Information also had to be sorted into different property-sets to ease the data management for the user (Figure 2). Maintaining a good data structure throughout the project is essential. Otherwise, information chains and information sustainability may be jeopardized when transferring data between users, leading to a loss of quality. Therefore, well-structured data is essential to achieve an accurate cost estimation process.
One of the most challenging aspects and a learning experience from the case study was the process of discovering and learning the different software functionalities to perform an accurate cost estimation. Software like Solibri is tailored towards expert users and not sufficiently user-friendly, which highlights drawbacks and limitations towards end users lack of knowledge using software. It is likely that an expert in the software may be able to perform a more accurate estimation than a novice user, but on construction sites the target group is a "novice user". Currently projects may benefit from having additional support or expert users present on-site, to help with training and problem solving.
Furthermore, the case study showed the differences between software and how the software can affect the quality of the cost estimation. However, the case study showed a clear benefit of using the BIM approach to cost estimation compared with a traditional 2D-drawing approach. Having data structured in BIM massively decreases quantity take-off time and increases take-off accuracy. Finally, the case study test showed that exporting data may lead to version control issues. Working in a cloud-based model ensures that information is accurate and up to date. This, in turn, leads to all actors working with that same information, and one source of truth.

ANALYSIS

In an industry with small profit margins, it might be expected that there is an emphasis on accurate cost estimation and budgets, but this is often not the case. Although the findings show that cost overruns are a significant problem in projects, the willingness to improve them seems to be lacking. Some interviewees thought that the issue is not with methods and processes of cost estimation but with tendering and procurement. Furthermore, cost estimation in many cases is just a guide for managers and decision makers to use for the bidding process. The client that was interviewed thought that a thorough cost estimation was not worth the effort because it is usually not detailed enough anyway. This could be an issue in the cost estimation process because the clients that are funding projects do not work with the same profit margins as contractors.

It is apparent that there needs to be more standardised BIM processes, especially regarding implementation in the cost estimation process. If the construction industry tried to implement a BIM based approach to cost estimation today, there would be issues adapting it to all the different methods that currently exist. Whilst flexible methods may benefit some actors, they represent significant challenges moving towards a more standardised, automated BIM approach. As the findings from the case study experiment showed, software like Solibri is tailored towards expert users and not user-friendly enough for non-daily users such as those on construction sites. In the Celsius project they recognized this as a problem during the bidding process and therefore provided sub-contractors bidding on the project an Excel-sheet with all the relevant quantity data. This quantity take-off Excel-sheet was updated weekly throughout construction as change orders were updated by the design team (Disney et al. 2021).

Identifying issues with BIM today are necessary to understand how to improve and implement BIM in the future of cost estimation. There are opportunities to save both time and money as occurred in the Total BIM project, Celsius. While BIM implementation has developed significantly over the last decade, its benefits are not fully realised (Disney et al. 2021). BIM is still mostly used in the design stage of projects, where parallel processes occur to produce 2D drawings from BIM. The model ceases to be updated and trust is lost in the model. To be able to use BIM for accurate cost estimation it is important that BIM represents what is actually going to be built, with accurate quantities. Then users can begin to trust the model and perform accurate work.

Today there is a significant lack of knowledge regarding BIM in the construction process. From the interviews we heard that BIM is still thought of as merely a tool for representing a model in 3D and the case study highlighted the need for expert software users. An interviewee stated that information from the model may as well be in 1D (a list in Excel), because the current focus is on data and not the 3D viewer. The interviewee meant that the real benefit of BIM is not the viewer but data management. This creates issues later in the project because some actors do not have the knowledge to know what the information is used for. Furthermore, knowledge regarding the available BIM tools needs to improve and users must fully understand how to use them. To implement the Total BIM concept companies need to invest in educating workers. User-friendliness of software, ease of access and information structures may also help adoption. It is also apparent from the interviews that for change to occur and a wider use of

BIM, company leaders must be fully committed. Differences between the tools could also lead to potential issues. However, the issues are linked to the user's experience and compared to estimating costs without BIM the issues are minor. By using BIM significant time savings can be realised. A key difference between using BIM and 2D paper drawings is that users have access to all the information instantly. To achieve this, it is required that BIM is developed to an appropriate level of detail and quality. Low-quality BIM is useless for cost estimation and can in the worst-case lead to more work. It can also very easily lead to trust issues, which were discussed during the interview study as an important issue limiting further implementation of BIM. Trust issues can also relate to the user-friendliness of software. If there is a risk of missing information due to user software skills, trust in BIM decreases.

Traditionally 2D drawings are the legally binding construction documents, which means that to develop production-oriented BIM, extra work is required. Otherwise, BIM is used merely as a reference model and not used to its full potential. When there are few or no requirements set on BIM it is difficult to trust and information must be double-checked. This makes it difficult to work with and there is no incentive to do so. In a Total BIM project, BIM has a higher legal status than 2D drawings and completely replaces them. At this point BIM becomes the single source of information and an accurate representation of the object to be built, as it is legally required to do so. The case study findings also support this, since attempting to use BIM for cost estimation when BIM cannot be trusted is pointless. However, as Brohn (2018) described, there is a huge potential to save time by using BIM in cost estimation compared with traditional methods. If BIM is used in this context higher demands and requirements must be placed on developing an accurate representation. Incorrect or missing data could have serious consequences, so trust needs to be established. The importance of BIM as the primary source of information and the legally binding document is therefore essential. This still may be a novel concept but has been proven by the Celsius case and the interviewee findings where no legal barriers could be found.

Despite scepticism, legal issues connected to Total BIM have been shown to be minimal (in Sweden) and not hinder the process of implementing Total BIM or using BIM in cost estimation. However, it should be noted that this may not be possible in other countries due to local regulations, but the Total BIM approach in Celsius does highlight the need for it to be considered. In Sweden regulations have been established around traditional 2D documents and they are lacking regarding BIM. While there are not currently any issues there still needs to be a certain level of BIM maturity before using it as legally binding. Users need training to adapt to new work methods. It can be discussed whether BIM, 2D drawings or technical documents should be ranked highest in projects, but another benefit shown in the Celsius project was using StreamBIM as a central communication platform. In StreamBIM all case, issue management, question-handling and more occurred through the platform. To support this, all object information, technical documents and construction information were linked to BIM, and easily accessible. Establishing the model as the single source of all construction information and a single construction process. This single process if executed well may streamline the unnecessary work that goes into producing and maintaining 2D drawings. As found in other parts of this study, an accurate

BIM has potential to be used for accurate cost estimation, providing users have the necessary support.
As stated above, data management is essential in BIM and to structure data there needs to be a classification system, which users can easily understand. When analysing the results, it shows that although some users may not see the need for a standard classification system, it may help to implement more structured processes and methods when working with BIM. It could also help actors to quicker understand and comprehend project data if it is structured consistently between projects. Data management is a key part of working with Total BIM successfully and implementing BIM in cost-estimation. The importance of data management found in the interview study is also found in the case analysis. The case study showed that for cost estimation to work with BIM, data must be well structured. Findings suggest that it is highly important to be able to structure and filter data in BIM to easily find the desired information. While data may be accessible even without a good structure, it should be structured in a way where users can easily filter to information that is relevant to them. In a Total BIM project this is essential since BIM is the single source of information and construction workers must be able to easily access the information they need. This paper shows that connecting cost-estimation and BIM in today's process is not as efficient as it could be, it remains challenging due to the level of complexity in construction projects. It also shows that both the cost estimation process and BIM lack standards which may be necessary to achieve accuracy and consistency. However, if BIM was used to a greater extent in the cost estimation process, there needs to be a more structured approach than found in most projects today. By going 'all-in' on BIM and using a structured Total BIM approach, where BIM is legally binding, other benefits may also be achieved. Designers work more collaboratively as they work on the model at the same time, focusing on high-quality design where all object information is present, and consider how construction occurs on-site. Producing 2D drawings is no longer necessary and site workers can construct directly from BIM by using mobile devices to extract the construction information they need themselves.

CONCLUSION

As highlighted in this paper, BIM is very time efficient when it comes to quantity take-off and cost estimation. However, as BIM in most cases is not used as a legally binding construction document, design teams focus more on delivering accurate 2D drawings instead of BIM. This causes quality and trust issues when it comes to using BIM on construction site and for cost estimation. The interviewees mentioned the lack of trust in BIM and that they had to double check data with drawings and descriptions if it was used. Using BIM in the cost estimation process requires that all disciplines trust it. If trust issues arise towards BIM, it will quickly become redundant. This could have greater consequences further down the project's lifetime. However, in Scandinavia the Total BIM approach has started to gain interest as it focuses on implementing BIM in its 'totality', as a single source of information, a communication platform, and the legally binding construction document.

In conclusion, Total BIM has future potential in achieving a more cost-efficient way of working. However, to successfully implement Total BIM in the cost estimation process, there are some areas that need attending. If BIM is going to be used to a greater extent in the cost estimation process, it needs to be more structured. The information, data and management structures are key to being successful. Another finding is the lack of knowledge surrounding BIM is a big reason for the lack of implementation. For instance, findings also show a lack of understanding and maturity in the industry regarding Total BIM, as the belief and statements of legal obstacles and scepticism without real-knowledge or reason occurs. In this case the industry must be educated and acquire more understanding and knowledge. Total BIM can be a diving-force for using BIM on the construction site and increase the efficiency and quality in the cost estimation process. Furthermore, comparing Total BIM to the traditional cost estimation approach it is apparent that the process is not only more efficient but more accurate as well. However, to reach its full potential, the industry has some issues to tackle, there must be a willingness to invest more knowledge, resources, and time into the design process to obtain a higher-quality BIM. The findings in this study, contribute, add knowledge and understanding to current issues and how these can be approached by implementing Total BIM in the cost estimation process.

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10 Appendix B - Interview questions

Questions / Guide

Formalia frågor

- Är det okej att jag spelar in intervjun?
- Önskar du eller ditt företag vara anonym i rapporten?
    - Om nej: Vad heter du och var jobbar du?
- Kan du berätta lite snabbt om företaget?
- Vad är din roll idag?
- Vad har du för bakgrund och erfarenhet?
- Är det något mer du önskar berätta om dig själv?

Om arbetet

För att ge en inblick i arbetet tänkte jag presentera en kort bakgrund.

Master Thesis:

Arbetet är ett examensarbete på masterprogrammet Design and Construction Project Management (DCPM) på Chalmers. Jag går dvs femte och sista året på civilingenjörsutbildningen samhällsbyggnadsteknik med inriktning på projektledning inom bygg och projektering. Arbetet omfattar 60 hp vilket innebär ett år av 100% (HT21 + VT22). Med tanke på storleken av arbetet är det tvådelat där första delen som jag arbetar med nu fokuserar på att kartlägga industrin idag och vad det finns för önskemål/potential/hinder kring BIM i kalkylprocessen. Och andra del som påbörjas efter årsskiftet kommer undersöka hur vi kan ta oss dit vi vill och vilka “DOs and DON'Ts” det finns.

Bakgrund:

BIM börjar blir väldigt populärt i nya byggprojekt och inte minst i projektering, men det finns fortfarande mycket kvar att göra. Många aktörer är idag redo att gå vidare till nästa steg och då kommer vi till vad BIM kan användas till i bredare bemärkelse.

Original-idén till detta arbetet var att undersöka hur BIM kan användas i produktion för att kontrollera kostnader under byggfasen för att undersöka problemet med projekt som går över budget. Men nu när jag börjat undersöka saken närmare så börjar problemen med kostnadskontroll och budget redan i de tidigaste skeden. Så nu undersöker jag samband mellan BIM och kalkyl och om det finns potential där.

Även om fokus ligger på kalkyl så är dock projektets hela livscykel intressant för jag har märk att allt oftast hänger ihop. Och det är intressant att se hur BIM kan användas över hela projektets livslängd.

Arbetet undersöker Total BIM, ett koncept som går ut på att använda BIM i hela projektet och där man hanterar all data. Man brukar prata om olika dimensioner i BIM där 3D är modellen, 4D är även tid och 5D så är kostnader medräknat. Total BIM handlar om att inte bara göra ritningar för produktion utan använda modellen i såväl produktion som projektering, samt även i förvaltningen (en så kallad Digital Tvilling).

Mål:

Målet med studien är att förstå och utvärdera processen kring Total BIM och undersöka BIM i de olika faserna i byggprojekt. Detta ska förhoppningsvis leda till en typ av guide kring hur man kan effektivt jobba med BIM som verktyg och process i byggprojekt.

Kalkylprocessen

- Ser du kost-överskridande projekt som ett problem i branschen?
- Kan det finnas taktiska och politiska fördelar med att undervärdera projekt vid start?
- Hur funkar kalkylprocessen i er organisation?
    - Gärna hela processen från start till slut. Varför?
    - Vilka metoder används för att ta fram kalkyler?
- Var får ni den data som används vid kalkyler?
- Brukar projekten följa kalkylen? Varför/Varför inte?
- Hur upplever du kostnader vid projektering fram till beslutfattandet? dvs kostnader mellan idé-fas till go/no-go beslut?

BIM

- Hur jobbar ni med BIM idag?
    - Är BIM standard i era projekt?
    - Skiljer det sig från projekt? I så fall, varför?
- Hur stor betydelse för BIM har kontraktet?
    - Spelar upphandlingen stor roll?
    - Spelar entreprenadformen stor roll?
    - Spelar anbudet stor roll?
    - Något annat som spelar större roll eller som du tänker på?
- Hur hanteras data/information i projekt?
    - Vem ser till att det finns tillräckligt och korrekt data?
    - Får projektören rätt data vid rätt tillfälle?
    - Är datahantering/informationshantering ett problem? Varför/Varför inte?
    - Upplever du att många projekt har en bristfällig BIM model? Varför/Varför inte?
- Cloud BIM är ett koncept där modellen är molnbaserad, dvs den ligger uppladdad på internet så den alltid går att nå. Vad är dina tankar om det konceptet?
    - Går det ha en modell som alla kommer åt hela tiden?
    - Kan det vara farligt ur juridiska synpunkter med secretes osv?
- Klassificeringssystem är system som med hjälp av standarder ger alla byggdelar och utrymmen i modellen en speciell kod. Tror du det hjälper att förtydliga?

    - Använder ni sådana system?
    - Tror du det hade hjälp med bättre klassificeringssystem i modellen?
    - Vad tror du om att koppla till prislistor och få priser direkt i modellen?
    - BSAB och CoClass är Svensk byggtjänst system. känner du till det? Något ni använder? Åsikter om systemet?
- Vad tror du det finns för problem med BIM?
    - Finns det några problem med BIM? isf vilka?
    - Kan det bli för mycket BIM?
    - Vad finns det för hinder med att implementera och använda BIM enligt dig?
- Hur skriver vi avtal för BIM? (AB 04, ABT 06 och ABK 09)
- Saknar vi standarder för BIM tycker du? isf vilka?
    - Behöver vi standarder terminologi och processer kring BIM?
    - LOD (Level of Detail) är en amerikansk standard som används internationellt som går ut på att specificera hur mycket BIM som ska användas i projekt? vill vi ha något sånt i Sverige? Eller är det mer allt eller inget?
    - Hur ska eventuella standarder fungera?
- Finns det juridiska hinder i Sverige att använda BIM? Bromsar de utvecklingen? isf hur?
    - Litteraturen lyfter äganderätt till modellen som ett problem? Tror du det? Vill ingen vara ansvarig för en modell?
    - BIM i bygglovsprocessen och liknande. Tror du det är ett hinder för utvecklingen att många juridiska handlingar ändå måste finnas i pappersform?
- Vad tror du BIM i tidigt skede? Dvs redan i förstudien. Går det? varför/varför inte?
- Tror du BIM är framtiden? Varför/Varför inte?
    - Hur ska vi dit?
- Ser du andra fördelar med BIM? Litteraturen nämner LEED, LCA och logistik som exempel som kan effektiviseras mha BIM?
    - Finns det vinster med att automatisera byggprocessen? är det ens möjligt och/eller värt det?

Övrigt

- Något du vill tillägga?
- Kan jag återkomma om jag får fler frågor?

Stort tack för din tid.

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