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Cost-Estimation in Construction: BIM versus Total BIM

COST-ESTIMATION IN CONSTRUCTION: BIM VERSUS 'TOTAL BIM'

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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).

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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). 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.

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

The second method exported the model as an IFC-file, which was then imported into Solibri (Figure 2).

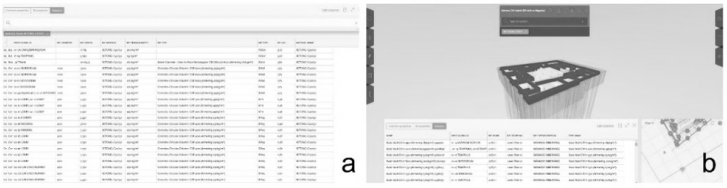

Figure 2: a: Quantity take-off in StreamBIM. *b:* Case where rebar is not stated in a column leading to more manual work.

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.

FINDINGS

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 organisation 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.

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 knowledge of 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.

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 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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