CHALMERS
UNIVERSITY OF TECHNOLOGY

Total BIM in Swedish Installation Contracting

A Comparative Study of Model-based and Traditional Ventilation Contracting

Master's thesis in Design and Construction Project Management

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ABSTRACT

Time waste and budget overruns are common issues in most construction projects. Digital tools like Building Information Modeling (BIM) have been developed to address these problems. While BIM has improved the design process, its adoption on construction sites remains limited, where paper drawings are still dominant. Total BIM is a new concept that is becoming popular in Scandinavia and aims to use BIM models even in the production phase. This approach eliminates the need for paper drawings and has the potential to improve both project efficiency and accuracy. Therefore, this study aims to compare model-based versus traditional working methods in the production phase of a real-world installation project and analyze workers' reactions to the new concept.

To conduct this comparison, the traditional workflows of an installation company were studied, and one of their ongoing ventilation projects, Blå Stjärnan, was selected as the reference project. A 3D model of the project was compiled using StreamBIM, and the company’s installers formed the study group. The comparison focused on three key areas: time spent on quantity takeoff, differences in cost estimation, and the workers’ experience with the installation process. The study also identifies several lessons and challenges related to the implementation of Total BIM.

The results showed that model-based quantity takeoff improved efficiency by 40 times compared to traditional drawing-based methods. Additionally, traditional methods tended to underestimate project costs by 8% due to human errors. Workers on-site reported significant improvements in planning, efficiency, and accuracy when using the 3D model, and noted that communication through the model would have been beneficial if requirements were set. However, despite its potential, the industry remains hesitant to fully adopt Total BIM due to established workflows and the legal binding nature of paper drawings. Increased knowledge within the construction industry and successful real-world implementations could encourage clients to oblige the use of BIM models in production.

Keywords: Building Information Modelling, BIM, Cost Estimation, Digital Installation, Model-based Quantity TakeOff, Total BIM, Ventilation Contracts.

Total BIM i svenska installationsentreprenader
En jämförandestudie av Modellbasserad och Traditionell Ventilationsentreprenad
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SAMMANFATTNING

Tidsslöseri och budgetöverskridanden är vanliga problem i de flesta byggprojekt, där digitala verktyg som Building Information Modeling (BIM) har utvecklats för att hantera dessa utmaningar. Även om BIM har förbättrat designprocessen, har dess användning på byggarbetsplatser varit begränsad, där pappersritningar fortfarande dominerar. Total BIM är ett nytt koncept som börjar bli populärt i Skandinavien och syftar till att använda BIM-modeller även i produktionsfasen. Detta eliminerar behovet av pappersritningar och kan potentiellt förbättra både projektets effektivitet och noggrannhet. Målet med denna studie är att jämföra modellbaserade mot traditionella arbetsmetoder i produktionsfasen av ett verkligt installationsprojekt samt analysera montörernas reaktioner på det nya konceptet.

För att genomföra jämförelsen studerades ett installationsföretags traditionella arbetsmetoder, och ett av deras pågående ventilationsprojekt, Blå Stjärnan, valdes som referensprojekt. En 3D-modell av projektet sammanställdes i StreamBIM, och företagets montörer utgjorde studiegruppen. Jämförelsen fokuserade på tre huvudområden: tid för mängdavtagning, skillnader i kostnadsuppskattning och montörernas upplevelse av installationsprocessen. Studien identifierar också ett antal lärdomar och utmaningar med implementeringen av Total BIM.

Resultaten visade att modellbaserad mängdavtagning ökade effektiviteten med 40 gånger jämfört med traditionella ritningsbaserade metoder. Dessutom tenderade traditionella metoder att underskatta projektkostnaderna med 8 % på grund av mänskliga fel. Montörerna på byggarbetsplatsen rapporterade betydande förbättringar i planering, effektivitet och noggrannhet med användning av 3D-modellen, och de noterade att kommunikationen genom modellen skulle ha varit fördelaktig om det hade funnits krav på det. Trots dess potential är dock branschen fortfarande motvillig att fullt ut implementera Total BIM på grund av invanda arbetssätt och det faktum att pappersritningar är juridiskt bindande. Ökad kunskap inom byggindustrin och fler framgångsrika implementeringar i verkliga projekt kan få beställare att ställa krav på användning av BIM-modeller i produktion.

Nyckelord: Byggnadsinformationsmodellering, BIM, Kostnadsestimering, Digital Installation, Modellbaserad mängdavtagning, Total BIM, Ventilationsentreprenader.

LIST OF ACRONYMS

AEC	Architecture, Engineering and Construction
BIM	Building Information Modelling
BIP	Building Information Properties
CAD	Computer Aided Design
GK	Gunnar Karlsen Sverige AB
IFC	International Foundation Class
IT	Information Technology
LM	Leading Installer
PMI	Project Management Institute
PM	Project Manager
QTO	Quantity Take Off
RQ	Research Question
SBUF	Svenska Byggbranschens Utvecklingsfond
VENT	Ventilation Disciplin
ÄTA	Additional and Changed Order

TABLE OF CONTENTS

1. Introduction

In the construction industry, it is common for projects to experience delays, cost overruns, and quality issues. These problems can be caused by poor drawings, lack of communication, lost information, or misunderstandings within the project. Another important factor is inaccurate cost estimates in the early stages of the project (Famiyeh, 2017). To address these challenges, digital tools have been developed to improve customer outcomes.

Building Information Modeling (BIM) has long been popular in the industry, with most focus on the design stage (Davies and Harty, 2013; Eadie et al., 2013). It is also shown that design processes have been improved with the use of BIM. However, on construction sites, BIM has not garnered significant interest among contractors, and even though 3D models are available, buildings are still often constructed using paper drawings. Project managers feel comfortable with traditional cost estimation methods and often base their decisions on previous experiences, gathering material information from drawing documents when necessary (Wahab & Wang, 2022). Working with 2D drawings on-site can lead to misinterpretations, which in turn increases errors and lead times (Brooks et al., 2023). Traditional methods for cost estimation are not sufficiently accurate and sometimes differ significantly from the actual costs of the project.

In Scandinavia, a new concept called Total BIM has emerged, striving to make the model used even in production (Cousins, 2017). This concept means that BIM serves as the single source of information throughout the entire project, from design to production (Disney et al., 2022). Using a 3D model as the construction document means eliminating paper drawings, which can increase work efficiency, improve the accuracy of calculations, and thereby reduce project costs (Cousins, 2017; Brohn, 2018).

The reason paper drawings are still dominated is that people are adapted to their working methods and hesitate to trust the model (Disney et al., 2024). Additionally, drawings are also legally binding documents in construction projects which make the model a secondary choice. At the same time, there is not enough research on the subject to convince companies to change their mindset, which has hindered the development of Total BIM. Therefore, the aim of this study is to apply Total BIM concept in a real installation project and thereby compare traditional and model-based working methods in terms of work efficiency, calculation accuracy, and their impact on project costs.

1.1 Purpose

The purpose of this study is to compare traditional and model-based working methods by applying the Total BIM concept in a real-world installation project. The comparison will focus specifically on conducting quantity take-offs using both 2D drawings and 3D models and see the impact of each method on cost estimation. The study also aims to apply the Total BIM mindset on the construction site and observe installers' experiences and feedback when using BIM for the assembly process.

1.2 Research Questions

1. *How effective and accurate is the use BIM in cost estimation?*
2. *How are cost estimations impacted by traditional working methods?*
3. *How do the installers perceive the concept of Total BIM?*

1.3 Limitations

The report will address the production phase of a ventilation contracting project in a new hospital facility for animals in Gothenburg. The comparison will be conducted using the same designed model and within the same zone. The cost estimates will only cover the prices for duct materials and labor costs for installation. Other prices for components and equipment will not be included in the calculations. The Total BIM concept will only be followed by the ventilation discipline on the construction site for a period of four weeks.

2. Literature Review

Building Information Modeling (BIM) has emerged as a crucial innovation in the construction industry, revolutionizing how projects are planned, designed, and executed by developing an accurate virtual model of the building (Azhar, 2011). BIM can increase project efficiency, minimize errors and rework, fosters collaboration among stakeholders, and offers valuable data across the project lifecycle. However, despite its potential benefits, the adoption and implementation of BIM in construction projects have been slower than expected (Disney, 2024). This literature review aims to provide an overview of the related subjects for this thesis to better understand their impact on construction projects.

2.1 Costs in Construction Projects

Cost is one of the three central elements of the project management iron triangle. If costs are not managed correctly, the project risks not achieving the required quality standard (PMI, 2017). Additionally, the company as a whole can be affected by the consequences. Therefore, it is crucial for the project manager to understand how costs are estimated, monitored, and effectively determined for a project (PMI, 2017).

In construction projects, it is common for costs to exceed the budget, and it appears that cost estimates are often one of the most challenging aspects. In the study "Rethinking Construction Cost Overruns: Cognition, Learning and Estimation," it was found that cost underestimation is the main reason projects exceed their budget (Dominic et al., 2014). This highlights the importance of accurate cost estimation and using effective methods to minimize the risk of budget overruns. It is also necessary to continuously monitor costs and adjust the budget as needed to ensure that the project stays within the financial outline decided from the beginning (PMI, 2017).

Cost Estimations

Cost estimation in construction is the process of determining a project's approximate cost based on available design information. This involves calculating quantities, pricing labor, materials, and equipment, and adding markups to ensure bids are accurate (Holm & Schaufelberger, 2021). Accurate cost estimates ensure that projects are properly funded and completed on time. However, costs are often underestimated because of traditional estimation methods which heavily rely on historical data and expert judgments, which can be biased (Flyvbjerg et al., 2018). Managers might be overly optimistic and believe their projects will avoid past issues, leading to estimates that are too favorable (Flyvbjerg et al., 2002). Additionally, relying on experience may overlook potential complexities and risks which further contribute to underestimation (Flyvbjerg et al., 2018). These underestimations are not just isolated errors but often reflect systemic problems rooted in flawed estimation practices and cognitive biases that consistently lead to inaccurate projections. Addressing these biases is essential for improving the accuracy of cost estimates, especially in large projects.

Traditional and Model-Based Cost Estimation

Traditionally, cost estimation and bidding have relied on comparisons with similar projects and personal experience due to constraints on time, knowledge, and relevance, despite criticisms of their inherent uncertainty (Akintoye & Fitzgerald, 2000). For more detailed estimates, drawings and specifications are manually reviewed. Quantities are calculated by hand from 2D drawings, and costs are gathered based on current prices and labor rates (Wahab & Wang, 2022). This process is time-consuming and labor-intensive, often delaying project start times and increasing initial costs. Wahab and Wang (2022) found that 2D quantity take-offs are 80% more time-consuming and can deviate by 20% from actual costs when compared to 3D quantity take-offs. The study also suggests that manual calculations increase the risk of human errors, leading to inaccurate estimates. Furthermore, companies do not share information due to competition, which explains why bids can vary significantly (Akintoye & Fitzgerald, 2000). Smaller contractors are more likely to use traditional estimation methods, while larger companies employ more advanced techniques and cost estimation software.

Building Information Modeling (BIM) has helped the construction industry in estimating costs by automating the calculation of material quantities, reducing errors, and improving accuracy (Monteiro & Martins, 2013). By using digital models that contain detailed information about each building component, BIM can quickly perform quantity take-offs, a task that was traditionally time-consuming and error prone. This allows for easy and accurate export of material quantity data from the model (Eastman et al., 2011). Research by Monteiro and Martins (2013) indicates that BIM reduces the chance of human errors and ensures that all design changes are immediately reflected in material calculations. Another study focusing on installation cost estimation using BIM found that the quantity take-offs and estimation process can be up to 10 times faster than traditional methods (Brohn, 2018). Model-based cost estimation not only saves time but also improves budget management by providing a more accurate picture of costs early in the project.

Despite its advantages in cost estimation and streamlined quantity take-offs, BIM is not widely used in the construction industry (Wahab & Wang, 2022). The main reasons for BIM's limited use are the high initial costs and significant changes in workflow, which particularly concern smaller companies (Othman et al., 2021). Investing in training and software licenses can be expensive, and resistance may be faced by employees who are used to traditional methods. However, larger companies use BIM to some extent and mostly for visualization.

2.2 Total BIM

Concept and Remarkable Understandings

Total BIM is a comprehensive method of using BIM as the single source of information throughout the entire construction project, from design to construction and operation (Disney et al., 2023). This innovative approach uses BIM instead of conventional 2D drawings as the legally binding documentation for the contract. All parties can work from a single updated source as all information is digital and accessible via cloud-based systems. This reduces the risk of errors and information loss and increases efficiency and coordination on the construction site (Brooks et al., 2023).

Four central components for Total BIM are identified as production-oriented BIM, cloud-based model management, user-friendly mobile BIM software, and a strong leadership (Disney et al., 2024). For a Total BIM project to be successful, production-oriented BIM should serve as the primary legally binding and contractual documentation. Storing the project's data in the cloud ensures that all parties are always updated, and that information is easily accessible. Construction workers can access and interact with BIM models directly on the construction site using user-friendly mobile applications, facilitating a dynamic and flexible work process.

Advantages of Total BIM

Total BIM offers several advantages, including time and cost savings, improved coordination and communication, and enhanced quality and accuracy in construction (Disney et al., 2023). Adopting to a fully model-based construction approach reduces both project time and overall costs by eliminating the need for parallel processes to create and maintain two-dimensional drawings. According to Disney et al. (2024), using a single, up-to-date source of information that is easily accessible improves coordination between different parties and reduces errors. The case study of Total BIM in Uppsala's "Celsius Project" demonstrates increased productivity and performance due to the elimination of guesswork, mistakes, and changes. Total BIM improves the quality and accuracy of the construction process by ensuring that all parties work with the most current information and by enabling quick and easy communication through cloud-based model management (Disney et al., 2023). These benefits can lead to significant cost savings, particularly during the construction phase of a project.

Challenges with Implementation

Implementing Total BIM can face several challenges, including software and hardware limitations, lack of competencies on-site, interoperability issues, and legal issues (Disney et al., 2023). Previous hardware and software were not optimized for site workers, often requiring them to manually add measurements on printed 3D view. However, recent advances have produced more user-friendly software, reportedly easier for site workers to use (Disney et al., 2024). Additionally, training construction workers to effectively use BIM can be both time-consuming and expensive (Brooks et al., 2023). Disney et al. (2023) also highlight that all involved parties must have access to the necessary technical resources and skills, as the software and hardware requirements can be extensive. Finally, legal and contractual issues present significant challenges, as current regulations and contracts often need modification to support BIM as legally binding documentation.

Another major challenge in implementing BIM technology is the cultural resistance to change (Vass & Gustavsson, 2017). The current and preferred ways of working make transitioning to new technologies like BIM difficult. Many lack the confidence, knowledge, and resources to adopt BIM, and the high costs of training and implementation deter local companies (Ahmed, 2018). Additionally, the lack of awareness about BIM's benefits contributes to the reluctance of construction parties to embrace it. By understanding and overcoming these barriers, organizations can facilitate a smoother transition to successful BIM use within the AEC industry.

3. Methodology

To compare traditional and model-based workflows in installation contracting, this study employed both quantitative and qualitative methods. Combining quantitative and qualitative research methods enhances project outcomes by offering greater depth and breadth of information than using a single approach alone (Almalki, 2016). The quantitative methods involved examining the planning phase of an ongoing project by comparing cost estimates, while the qualitative methods included a real case study of implementing Total BIM on production phase of the same project. By conducting quantity take-offs and cost estimations using both methods, the efficiency and accuracy of the estimates could be compared. Furthermore, implementing Total BIM in a real scenario provided insights into how the involved workers perceive the digital workflow. Figure 3.1 illustrates the reference project "Blå Stjärnan" on which this study is based, along with its surrounding area in Mölndal.

Figure 3.1. An illustration of the reference project "Blå Stjärnan" (Castellum, 2024).

The software used throughout the study was StreamBIM, a newly developed digital tool for construction by Rendra AS. This software was used to create a common digital platform for visualization, planning, measurements and communication for the installation work. It was also used for quantity take-offs from the model for cost estimation and ordering documents.

The reason a real case study was chosen was to illustrate theoretical concepts in practice and to provide concrete examples of BIM's advantages and challenges on site. For the case study on the implementation of Total BIM, participant observation method was chosen to get as close as possible to reality, offering an in-depth understanding of the study group's culture and behaviors (Collingridge et al., 2010). Interviews with project participants, such as site supervisor, and installers, complemented the observation by providing experiences and perceptions of Total BIM on the construction site.

Project Information

The study was conducted on a real, ongoing project in Gothenburg. The project involved the construction of a new hospital for animals called “Blå Stjärnan”, covering an area of 11,200 square meters. Castellum was the client, and Gunnar Karlsen Sverige AB was the ventilation contractor in a design-build contract. The project had previously been estimated by the company, and with a bid of 12,000,000 SEK, the company won the project. The start of the ventilation discipline was scheduled to be in the middle of this thesis work. Due to time limitations, the study focused only on the ventilation contracting in “zone 2” of the project. Figure 3.2 shows the subdivision of zones on floor plans, where the purple area (zone 2) is examined in this study.

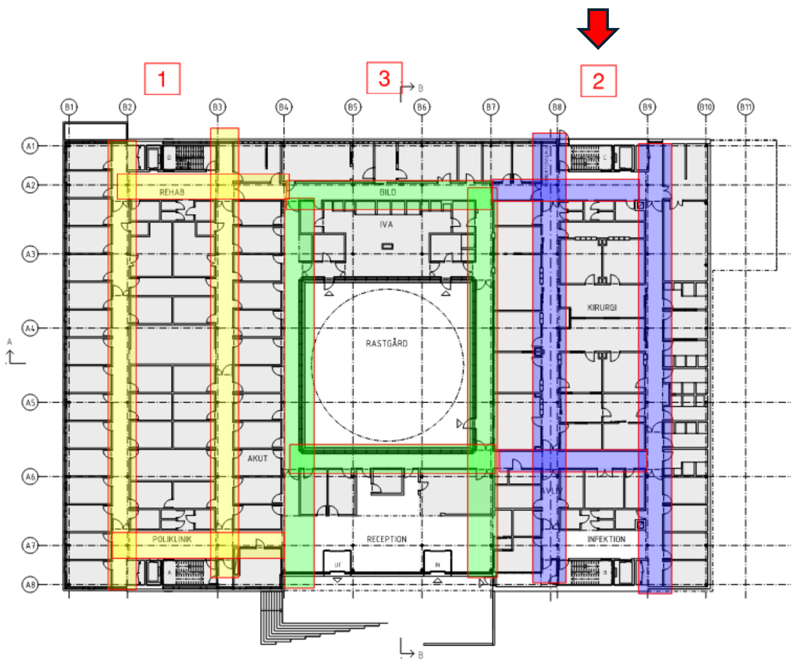

Figure 3.2. Subdivision of floor plan on Blå Stjärnan.

3.1 Quantity Take-off

To compare traditional- and model-based quantity take-offs, both methods were applied to the same zone and time were measured using the same tool. Instructions from an experienced project manager of the company were followed for the traditional take-off, and support from StreamBIM was available for the model-based take-off.

Traditional Quantity Take-off

Traditional quantity take-off was conducted for a predefined zone. The zone was located on the second floor and zone 2 of the actual drawings. With guidance from the project manager and site supervisor at the studied company, the traditional quantity take-off was performed. The construction drawings for ventilation were printed in A3 format, and colored pencils were used to mark the counted areas on the drawings. Time was carefully tracked using a smartphone timer, which was paused whenever the work was interrupted. The aim was to measure only the effective time spent on quantity take-off. Quantities were also written down using paper and pen to closely mirror the traditional work method. Figure 3.3 illustrates how the traditional quantity take-off was conducted using drawings.

Figure 3.3. Traditional Quantity Take-off with Drawings.

Model-Based Quantity Take-off

Model-based quantity take-off was performed using StreamBIM's quantity take-off function. The same predefined zone as used in the traditional quantity take-off was created in StreamBIM. By filtering the VENT Model Layer within the defined zone, quantities were extracted with the desired properties. BIP codes in the model have been used to obtain standard naming for the parameters. An optimal filtering setup could be beneficial for the quantity take-off process. Figure 3.4 shows an example of StreamBIM's quantity take-off function and its filtering on ventilation data with BIP codes.

Figure 3.4. Filtering and Quantity Take-off with StreamBIM.

These quantities were exported to an Excel spreadsheet, where "subtotal" calculations were performed on the total quantities. By further filtering, the desired quantity totals could be found. Figure 3.5 shows an example of exporting ventilation quantities to Excel, followed by filtering and calculating sums within Excel.

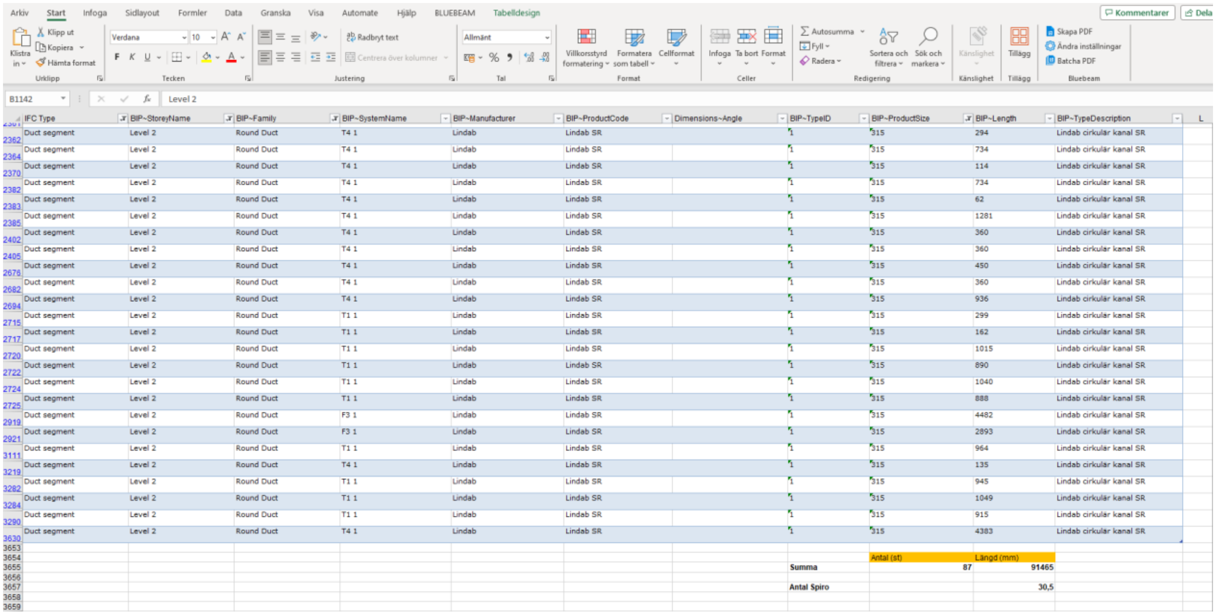

Figure 3.5. Export of data to Excel and "subtotal" Calculation.

3.2 Cost Estimations

When a project begins, several calculations are often required at different stages. Typically, a production estimate is created at the start to assess the expected cost of the project. This estimate is prepared once the design phase is finalized and represents the total cost of building the project. For a ventilation project, a production estimate involves summing up the prices and labor hours for ducts, insulation, components and equipment and other related project expenses.

In Sweden, one of the most used estimating programs in the ventilation industry is Lubekalk (Elecosoft, 2024). Companies use Lubekalk to prepare their bids, develop production estimates, and calculate costs for changes and additional work in projects. In this study, Lubekalk was used to calculate the labor hours and material costs for the studied zone.

The results of both types of quantity take-offs were entered separately into the Lubekalk program to calculate costs and study the differences between them. The total costs were then compared between the traditional and model-based quantity take-off methods. Based on these results, the margin of error in the project's total cost was calculated. Figure 3.6 provides an example of Lubekalk’s calculation result for labor hours in the model-based estimation.

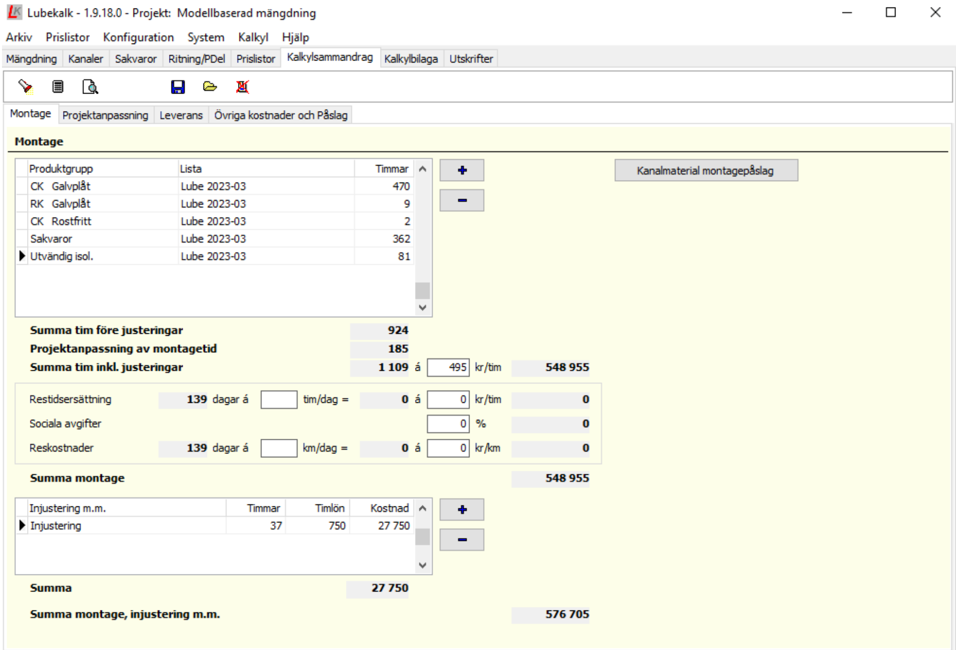

Figure 3.6. Illustration of the Estimating Program Lubekalk.

3.3 Implementation on the Construction Site

To implement Total BIM in practice, a case study was conducted on the same ongoing project within the company. The goal was to complete a part of the project entirely digitally without using drawings. Participants in the project were selected as a study group. The study group consisted of three people: two installers and one site supervisor. The author participated in the installation group as an observer.

Due to delays in the project’s timeline and limited time for this study, a period of four weeks was set. During these weeks, the installation was done completely digitally using StreamBIM, with no traditional drawings involved, and all communication was conducted through the app. The purpose of the case study was to evaluate how Total BIM is perceived by installers and to observe the work efficiency and any improvements in communication among the participants.

Compilation of the 3D Model

To compile a model that can be used on construction site, IFC files from the construction documentation were retrieved from the project's portal and complied using StreamBIM software. Several discussions with the project's managers ensured that the appropriate model files were selected for upload to StreamBIM. These files have been continuously updated with each new revision released by all disciplines. Consultation with StreamBIM's support team also assisted in the zoning according to the drawings, and user-friendly views were created in the model to facilitate navigation. Figure 3.7 shows an example of how the ventilation discipline is represented in StreamBIM for the project.

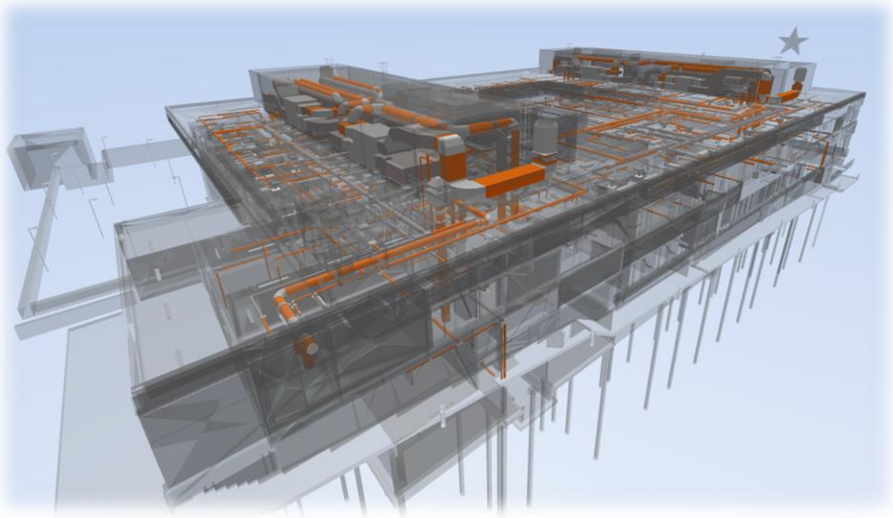

Figure 3.7. Illustration of the Ventilation discipline in StreamBIM.

Design of Communication on StreamBIM

To design the communication chain within the project, several discussions were held with the project management team and the lead installer at the company to understand what was missing in the current system and identify their needs. Following these discussions, and with guidance from the company's project manager and StreamBIM support, a digital communication system was built within the software. Since this new system was intended as a pilot study and the company was not yet familiar with the software, simplifications were made to avoid overcomplicating the communication system. Figure 3.8 illustrates how communication is divided into six categories: 1. Diary, 2. Time-Report, 3. Call Off, 4. Leverance, 5. Self-checks, and 6. Overview. Each category contains a checklist to be signed off daily or weekly. Additionally, each category is linked to a specific ventilation part or zone, which turns green in the model once signed off. In the capture section, various deviation maps are listed to be filled in.

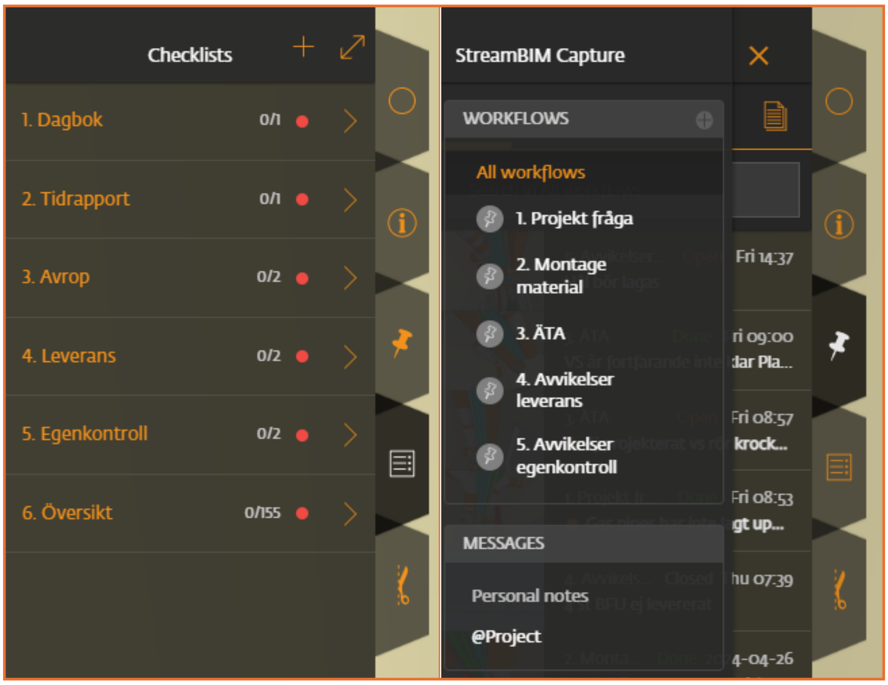

Figure 3.8. The categories of the communication systems for the trial.

Presentation of the Workflow

The new workflow was presented to the installers and project managers during a meeting. The author explained the concept of Total BIM and outlined the expectations for the participants. A representative from StreamBIM provided a presentation on the software and its navigation, while the author explained the usage and the communication system. Since the study group had previously used Dalux to some extent in earlier projects, this familiarity helped in understanding the basic principles of using StreamBIM.

Observations on the Worksite

To get a real picture of how Total BIM works in practice, the participant observation method was used, where the author personally joined the installation group. By joining the group, the author spent more time in close contact with the participants, providing a deeper and different perspective compared to observing from the outside (Collingridge et al., 2010). The observation lasted for four weeks, and during this period, only the model was used for the installation of ventilation ducts. The author assisted the installers in using the software and observed how the new working method developed over time.

Interview with Participants

After the study period, all participants were interviewed to gather their opinions on the model-based work approach. The interviews were semi-structured, where open-ended questions were asked, allowing for natural responses and providing room for discussion. Open-ended questions give the interviewer the opportunity to explore perspectives further, as follow-up questions can develop based on previous answers (Brinkmann, 2014).

The interviews lasted 30 minutes each and were recorded. The respondents were informed about this and gave their consent, allowing for accurate transcription of relevant material. A thematic analysis was then conducted on the respondents' answers to identify patterns and themes related to the comparison between traditional and model-based working methods.

Thematic analysis is a highly flexible and accessible method, adaptable to various research questions, sample sizes, and data collection methods (Clarke & Braun, 2016). It's widely used in qualitative research to explore participants' experiences, perspectives, and behaviors. Table 1 gives an overview of the qualifications of the study group that have been interviewed.

Table 1. Overview of interview participants.

Code	Role	Experience in Role	Company	Type of Interview
M1	Installer	5 years	GK	Semi-structure
M2	Installer	15 years	GK	Semi-structure
LM	Lead Installer	11 years	GK	Semi-structure

4. Results

In this chapter, the results of quantity takeoffs and cost estimations are presented, followed by the findings from observations and interviews with participants during the implementation of Total BIM at the construction site.

4.1 Model-Based vs Traditional Quantity Takeoff

Figure 4.1 illustrates the time spent on quantity take-offs for different ventilation object groups using model-based versus traditional methods in Zone 2. The figure also shows the total time for all object groups and highlights that model-based QTO constantly requires 0.5 hours, regardless of the scope of quantity extracted.

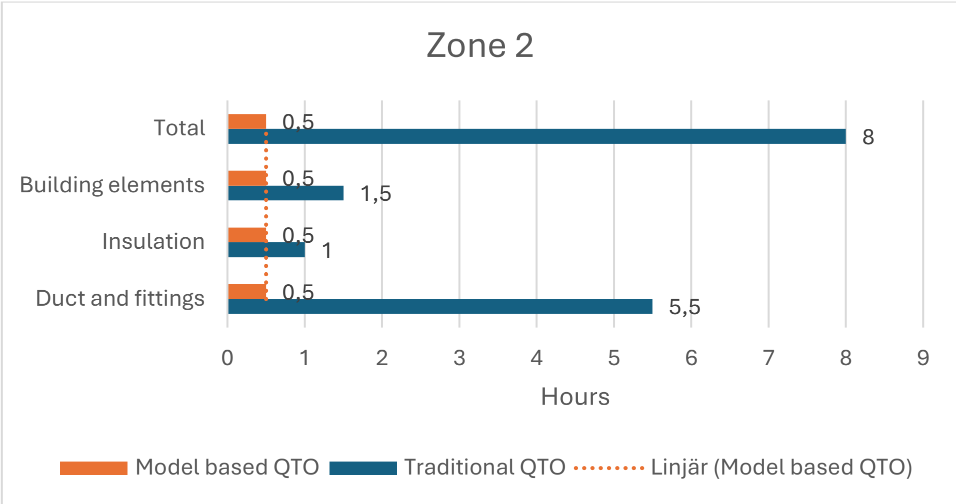

Figure 4.1. Time spent on model-based versus traditional quantity takeoff in zone 2.

The results become more interesting when we compare the estimated time for traditional versus model-based quantity takeoff for the entire project, as shown in Figure 4.2. Since Zone 2 represents approximately one-fifth of the total project, the time required for traditional QTO is estimated to be five times greater for the whole project. Meanwhile, the model-based QTO maintains its constant time of only half an hour.

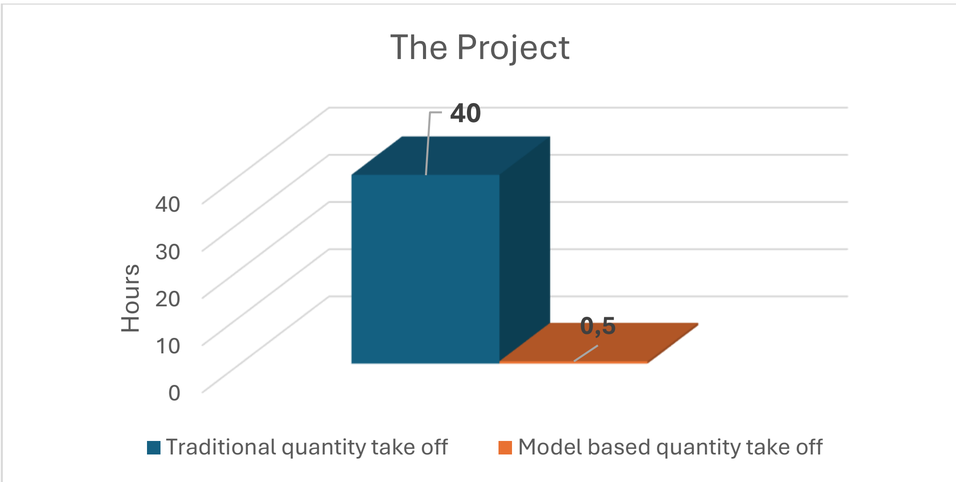

Figure 4.2. Estimated time for traditional versus model-based quantity takeoff for the project.

4.2 Model-Based vs Traditional Cost Estimation

Figure 4.3 presents the results of traditional versus model-based cost estimation for materials and labor in Zone 2. Despite the quantity takeoff being conducted for the same area, the resulting cost estimates differ. In practice, this means that a traditionally estimated bid would be 77 899 SEK lower for Zone 2. This lower cost in the traditional estimate is due to the manual process, which is prone to human error. Furthermore, this human error accounts for 8% of the actual cost, which has been underestimated.

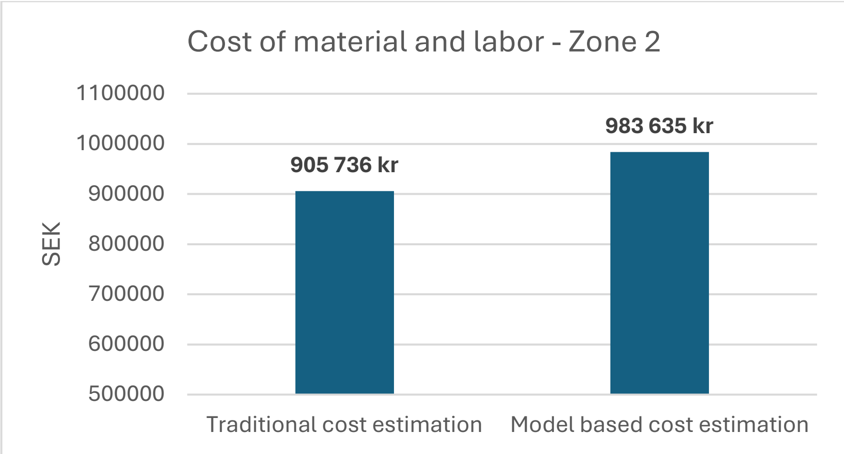

Figure 4.3. Traditional versus model-based cost estimation for materials and labor in Zone 2.

$$983635 - 905736 = \mathbf{77899\ SEK}$$

$$\frac{77899}{983635} = \mathbf{0.079}$$

Figure 4.4 shows the relationship between estimated and underestimated costs for the project. Like the previous results on quantity take-off, the differences become more pronounced when moving from the zone to the entire project. In this case, there is a potential for nearly 300,000 SEK to be mistakeably underestimated. It should be noted that this figure only represents the total cost of materials and labor.

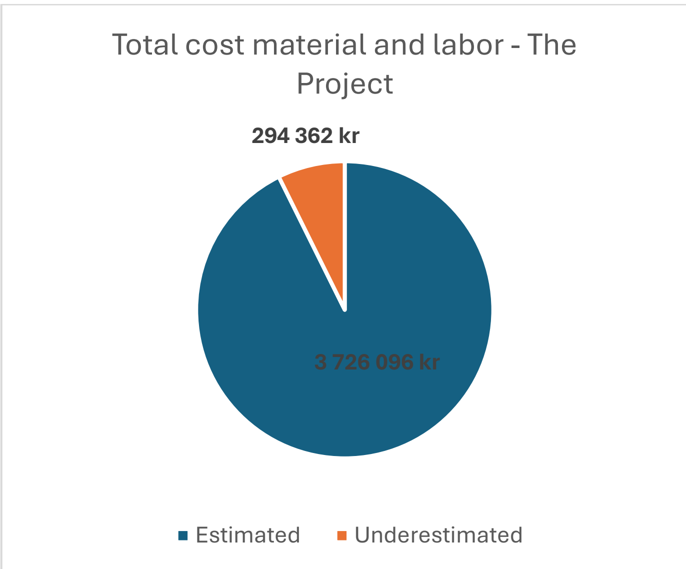

Figure 4.4. The relationship between estimated and underestimated amounts for the project.

4.3 Implementation of Total BIM on Construction Site

The studied project faced delays in its timeline, and the building could not be constructed according to the planned zones. This was due to remaining moisture in the concrete slabs and other deviations caused by contractors. As a result, all installers had to reschedule their work, which sometimes could not be coordinated with other disciplines. When coordination and communication failed, it led to further deviations in the project.

The consequences to this study were that installers had to repeatedly start and stop their work, making it impossible to obtain a clear time estimate for digital installation work, which could have been compared to traditional installation times.

Resistance and Trustworthiness

When the model-based working method was introduced to the study group, it was initially met with resistance. The primary concern was a lack of trust in the model, causing the group to hesitate in fully relying on it. Additionally, the installers found working with 3D models challenging and felt more comfortable with traditional 2D drawings. However, after using the 3D model for four weeks, the author observed that the installers quickly adapted to the new method. As they experienced the accuracy and other advantages of the 3D model in practice, their trust grew. It is also worth noting that younger installers found it easier to learn navigation and measurement in the 3D model, while older installers faced more difficulty with these tasks.

Take-Offs and Ordering

In this project, orders needed to be placed continuously and weekly due to the limited storage space for materials at the construction site. As a result, during the study period, smaller quantity take-offs were made, and orders were placed based on the quantities provided by the model. Figure 4.5 shows an example of isolated quantity takeoffs that were ordered during the study period. The lead installer (LM) found the quantity take-offs from StreamBIM to be "very useful and more accurate," as they reduced human error. LM further explained that "every fitting is unique," and if something is missed in an order, the work must stop until that item arrives. Deliveries from Lindab's factory could be expected within three days, or items buys directly from the store at 3-5 times higher price to avoid production stop.

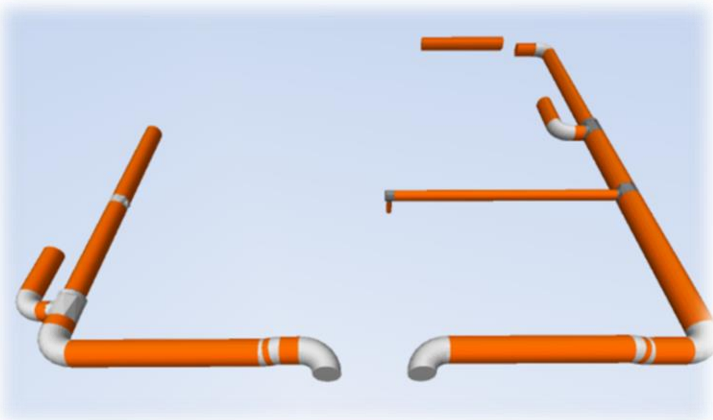

Figure 4.5 Example of isolated quantity take-off from StreamBIM.

However, for smaller orders, LM preferred the traditional method because it was quicker to measure by hand and less complicated. StreamBIM's quantity take-off process required exporting data to Excel and filtering it, which could take up to 30 minutes. As a result, LM felt it was safer and more efficient to handle smaller quantities manually.

It was observed that even when quantities were available, they still had to be manually processed for ordering. Orders were handled through Symbrio, the company's purchasing system. The larger the order, the more data needed to be entered into Symbrio, which required many hours of LM's time. Upon further investigation, it was discovered that article numbers could be imported into Symbrio, but these numbers were missing in the model. To automate this step in Symbrio, designers need to add article numbers to the BIM objects, which can be used by the contractor later on.

Installers' Experience with Model-Based Assembly

In interviews with installers, they were asked about their experience with model-based assembly. M1, who belongs to the younger generation, stated, "It feels like you're working twice as fast." He explained that the model is easily accessible, eliminating the need to "go up and down in the lift" to access drawings and take measurements at the drawing table. He also mentioned that the availability of viewing models from other disciplines made it easy for him to plan the next steps of assembling immediately. Figure 4.6 shows how M1 used to work with traditional drawings versus how he currently works using StreamBIM.

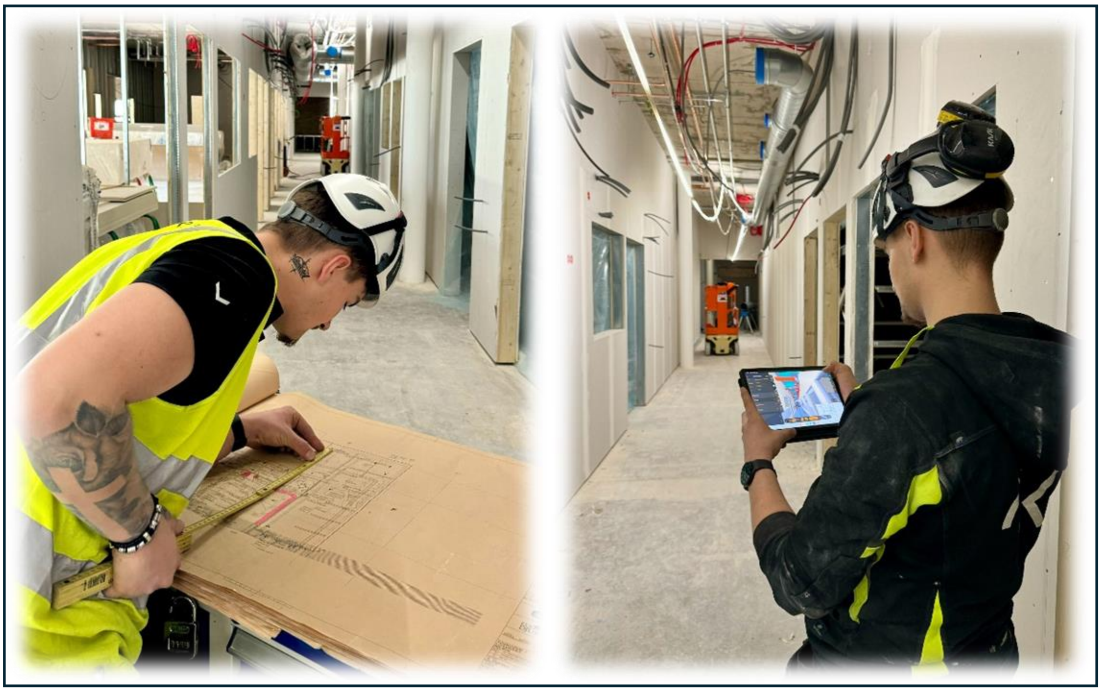

Figure 4.6 Picture of M1 using drawing versus StreamBIM for his work.

When the same question was posed to M2, who belongs to the older generation, he responded, "It feels smooth when it works." He explained that he struggled with navigation and spent time making proper measurements. He added, "I've worked with drawings for 15 years," and since he was not used to 3D model, he found it potentially more efficient to work with traditional drawings. However, like M1, he appreciated the ability to take measurements in the lift and view other disciplines' model drawings.

When LM was asked about his experience, he mentioned that he would "avoid printing all the time." He explained that many changes had been made to the design in this project, and every time a new “change-PM” arrived, it was his responsibility to ensure that all installers had the latest drawings on site. With the model, he no longer needed to worry about printing and delivering drawings on time. He also agreed with M1 and M2 that the ability to see more details improved planning. Additionally, he noted that model-based assembly had improved their workflow by reducing the likelihood of mistakes made by installers.

Quality of Assembly

All installers found the model to be easily accessible, allowing them to take multiple measurements to ensure the correct positioning of the ducts. M2 mentioned that "fewer mistakes are made with 3D" and emphasized the important role of the designer in this process. He noted that sometimes the model didn’t align with reality and that he had faced some clashes within it. On the other hand, LM believed that fewer mistakes occur when conditions can be visualized and adjusted accordingly. He explained that "in 3D, you can see exactly where the clashes are," allowing installers to make adjustments before assembling. Finally, M1 stated that a well-planned model and free of clashes with other disciplines would significantly simplify his work and enhance quality.

From observations it was found that the quality of the assembly also depended on practical aspects, such as the accuracy of duct assembly and the precision of on-site measurements. While the 3D model can assist installers in making the right decisions, the ultimate quality of the assembly is determined by the actual measurements taken on-site.

Obstacles on Construction Site

Observations on site showed that internet connection could be problematic, particularly in the basement and areas with thick concrete slabs, where uploading the model was not always possible. It was also observed that newer and more powerful devices could be beneficial for faster model uploads. M1 reported minimal issues with uploading, while M2 faced more challenges, likely due to using an older device, which negatively impacted the upload process. M1 included that "uploading has gone smoothly on this project" because the site is centrally located in the city.

In his interview, M1 mentioned that sometimes dimensions in the model did not match the reality on-site, such as in the case of a fire damper that was bigger in reality than shown in the model. Later, the project manager explained that this difference was due to the use of products from different suppliers than those specified in the model. It was observed that the model was not updated with these deviations unless someone took the initiative to do so.

In an interview with LM, he noted that construction site culture still mostly relies on 2D drawings, which can be challenging when working with models. This leads to the use of different documents which complicate communication within the project. He also mentioned that often subcontractors involved in the projects come from small companies that may not have received training in using 3D models.

Communication through StreamBIM

It was observed that the communication chain through StreamBIM was neither used thoroughly or for a sufficient time. Therefore, it’s difficult to evaluate the results based on the existing data. The study group primarily relied on familiar communication channels, such as phone calls, messaging and Teams group chat, which made StreamBIM a secondary option. Additionally, documented data like "self-checks" and tracking in the "Overview" section are likely to become more important as the project progresses for longer time. The project also had its own "diary" and "time-report" in the company's system which were prioritized first by the installers.

Features that were found to be useful included “Call off” orders and “Leverance” tracking, which were missing in the existing system. However, during the four-week period, although installers filled out the checklists in these sections, the benefits were minimal due to the short timeframe. In the long run, these features would be beneficial for the project manager, allowing him easy tracking of orders and deliveries throughout the project, as the data would be accessible in StreamBIM. In the "Capture" section, some deviations were noted, which could prove beneficial later when the project manager discusses them in construction meeting. Figure 4.7 illustrates an example of how the checklists and "Capture" section appeared while using the communication chain.

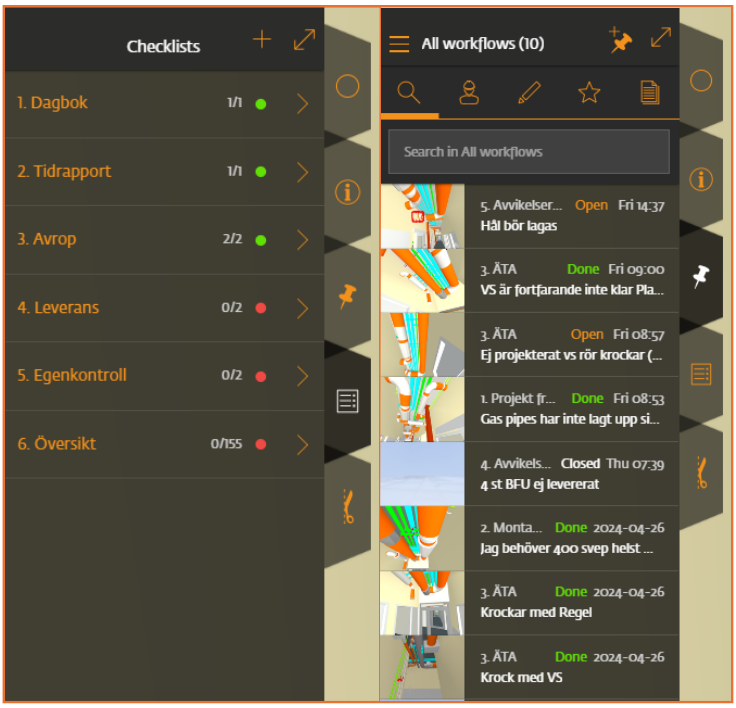

Figure 4.7 Example of checklists and capture used during the study period.

According to M1, "it would work well if you work strictly with it." M1 further explained that it didn’t work well in their case because they were used to communicating in other ways. He added that if there were a requirement to communicate only through the app, the results would have been very different. On the other hand, M2 reported, "when you receive so many emails and notifications a day, you might not read all of them," and noted that information could become outdated by the next day. However, all installers agreed that having all communication in one place would be highly beneficial.

Future Ambitions for Usage

M1, who belongs to the younger generation, had a strong ambition to work with the model and wanted it to become standard in the future. In contrast, M2 did not like the idea of 3D becoming the standard and preferred to have the model as a complementary tool, as it is now. Finally, LM believed that 3D models would become more prevalent in the future but there is still a need for drawings at present.

5. Discussion

5.1 Evaluation of Efficiency and Accuracy

The results show that the larger the project, the more time we can save with the model-based method. This is because the time required for model-based quantity takeoff is constant, approximately 0.5 hours, regardless of the project's size. However, this can be a disadvantage for smaller quantity takeoffs that would traditionally take less than 0.5 hours. For smaller orders on the worksite, manual calculations still perform better, as the model-based process is currently considered more advanced. However, for production calculations and larger orders, BIM is a significant advantage and can save a lot of time. In SBUF's pilot project, it was also demonstrated that calculations via BIM models reduce work by up to 90% compared to manual calculations from drawings (Brohn, 2018).

Interviews with the study group showed that the work steps became more efficient with the use of 3D model. It eliminated non-value-added activities, increased the accuracy of the work, and improved the planning for the next step. However, observations on the construction site showed that work could be efficient with 3D models in areas where no deviations occurred. When reality differed from the model, the study group went back to traditional on-site solutions. One reason discrepancies occurred was the lack of a requirement to use 3D models on the construction site, which meant that other disciplines worked traditionally with drawings. This maintained the drawings' status as the legally binding source of information. Working with drawings on-site can lead to human errors (Brooks et al., 2023). As Disney (2024) wrote in his dissertation, "In projects where traditional drawings are legally binding, BIM tends to not be actively used due to a lack of trust as the data quality is not consistently maintained," a finding that was also observed in this project. Since the model was not legally binding, it was difficult for the installers to trust it. For the study group to experience higher efficiency in their work, there should be a requirement to use the 3D model for all disciplines, which would reduce discrepancies on site.

During the case study at Blå Stjärnan, additional opportunities for time savings with BIM were discovered. Using the information in the model, material orders could be automated, eliminating manual data entry. On the construction site, many hours are spent entering data into the purchasing system for orders. Even if quantities can be served directly from the model, they still need to be manually entered into the purchasing system. Since ventilation ducts have many different dimensions and numerous connecting ducts, this means entering and selecting all dimensions in the purchasing system. The more duct details, the more data to enter. If the material had been designed with article numbers, these could be imported directly into the purchasing system. Such an import would take a few minutes, while today it takes several hours or even days for large orders.

In the ventilation industry, few suppliers have plugins for CAD that can enable the step of designing with specific article number. If a project is designed with such a plugin system, ventilation contractors are limited to these suppliers, which is not desirable among contractors. For contractors to further benefits BIM, more suppliers in the industry should develop plugin systems that can get linked to CAD, and designers should use these systems to include article numbers in the project. For this automation to take place, clear requirements need to be established for both suppliers and designers.

5.2 Impacts on Cost Estimation

The literature review revealed that cost overruns are a common problem affecting many projects (Dominic et al., 2014). A significant reason for this is cost underestimation. The results showed that traditional estimation methods tend to underestimate costs by an average of 8%. A relevant question is why contractors continue to underestimate their costs.

One reason for these ongoing underestimations is the accuracy of the estimates. Traditional methods involve human errors in quantity calculations, which can have significant consequences for the project. In the case project, these mistakes would result in a loss of 294,000 SEK for the project. In a highly competitive industry often profit margins are set low, which is a crucial factor in winning a project. With an assumed profit margin of 5% on a project sum of 12,000,000 SEK, this means a total profit of 600,000 SEK. The loss on traditional estimation of duct material and labor would halve this profit. Duct material and labor is only one-third of the project sum. If we also consider the risks of inaccuracies in the rest of the project, this will result in the project becoming unprofitable.

According to the project manager at GK, time limitations during bid submissions are a common problem. He also explains that there is not enough information about the project in the early stages to make an accurate estimate. Therefore, traditional methods are often chosen over model-based methods. The lack of information may be due to clients not wanting to provide too much information when requesting a quotation for a design-build contract. This strategy creates opportunities for clients to get a lower price, but also to identify any mistakes within the project.

From the contractor's perspective, the competition during bid submissions is very high. Contractors often choose to submit a lower bid and then try to recover the profit through changes and additional work (ÄTA). Changes and additional work are very common during the project's run, and builders usually choose the same contractor for these jobs. Thus, contractors have a greater opportunity to overestimate costs when ÄTA occurs. In practice, this means that contractors chase more ÄTA to secure their profits, while the builder tries to reduce project costs by exploiting contractors' inaccurate estimates. However, to ensure the quality of the building, all stakeholders must work towards the same goal. By moving to a model-based estimation and bidding process encourages stakeholders to work together for a common goal.

5.3 Lessons and Challenges with Total BIM

Implementing Total BIM on construction sites offers many advantages, but several challenges need to be overcome to achieve an effective implementation. A common technical challenge in construction projects is the inability of different software and tools to communicate and exchange information with each other (Disney et al., 2023). For example, the case study showed that even quantities could be exported from the model to Excel, it was not possible to import the data into cost estimation program. This created a time-consuming process to transfer information manually. The lack of standardized data could also lead to data loss and misunderstandings which affects the project negatively. Since many stakeholders use different software, it is essential that software can read each other easily.

Implementing Total BIM requires some investments from the start, but in the long term it saves the budget. For example, in the Celsius project, the design cost increased from 11 to 13 percent but the project in total came underbudget (Disney et al., 2024). An efficient use of BIM requires employees to have skills and knowledge, which many construction workers lack today. This means that an investment in training is needed for employees to use BIM and extract information from the model. However, software has become user-friendly and adapted for construction sites lately, therefore extensive courses are no longer necessary. But upgrade of IT infrastructure and the purchase of software can still be costly, especially for smaller companies.

Resistance to change is a significant organizational challenge (Vass & Gustavsson, 2017). Many in the construction industry, especially those with long experience, may be unwilling to change their work habits or learn new systems, which can slow down the implementation of Total BIM and hinder the full potential of the technology. In the study group, older installers had more difficulty navigating and showed more resistance compared to younger installers. Resistance could also come from the culture on construction site. When the majority on the site work with drawings, installers may feel their discipline is insulted when they must work with a model. Additionally, communication between disciplines becomes more challenging when they work from different documents. However, the resistance can overcome by informing project stakeholders about the potential and value of BIM, providing sufficient training, and raising awareness of its benefits (Ahmed, 2018).

Communication through StreamBIM was considered a secondary choice because there were no specific requirements for its use. Disney et al. (2024) also highlight that setting clear requirements is important for Total BIM to function optimally. Also, the four-week time constraint made it difficult to draw any conclusions about the results. However, some aspects were observed to be useful, even though the communication chain was a secondary option. Communicating via StreamBIM was effective in that it eliminated the need to search for information, understand it, and switch between different folders. Traditionally, one would need to write down daily logs on paper, manually mark self-checks on drawings, and take photos of any additional work (ÄTA) to later transfer and save them on the computer in the appropriate folders. This information could easily be lost, misunderstood, and the process was time-consuming. The platform enabled visualization of communication, allowing users to see the exact location, relationships with other disciplines, and ensuring that all information was stored in a central place. The mobile application also made it easier to report deviations and daily notes, regardless of the user's location. Despite these advantages, StreamBIM was still considered a secondary choice because the study group was comfortable with traditional communication channels, requirements were set for manually marked self-checks on drawings, and the project had its own communication system in place.

In model-based orders, a clear reduction in waste material was observed compared to traditional orders in other zones. The model's quantity takeoffs allowed for ordering materials in exact amounts, which resulted in no extra materials being present on the construction site which forced the installers to optimize the lengths of the ducts. This also improved material logistics and reduced the number of returns compared to the zones with traditional work. The disadvantage of ordering based on the model's quantities is that it does not account for waste material, which sometimes leads to a shortage of a few meters of duct when material is wasted during the work. In the case study, no extra material needed to be ordered because leftover material from earlier zone could compensate for the waste material. However, ordering based on the model's quantities would work optimally if a certain amount of waste material gets included in the orders.

The implementation of Total BIM can occur quickly once the model is tested practically. In the beginning, several installers were skeptical about the model's functionality in real situations, where they thought it would complicate their work but after working with the model-based method for just four weeks, they noticed that their workday became much easier than before. The model facilitated their work and improved accuracy at the same time. A new working method does not necessarily mean something negative. In this project we could see improvements in efficiency, accuracy and planning. By informing industry colleagues about the benefits of BIM, while being aware of its challenges and daring to try the method in pilot projects, the development of Total BIM can progress very quickly.

6. Conclusions

This research aimed to compare traditional versus model-based installation contracting by applying the Total BIM concept in a real word ventilation project. Based on the quantitative and qualitative results of this thesis, it can be concluded that Total BIM offers significant improvements in efficiency and accuracy within Swedish ventilation contracts, especially in larger projects. BIM has been shown to save significant time in the planning stage by reducing calculation time from manual quantity take-offs, thereby achieving more accurate cost estimates. However, calculating small amount av quantities tends to be easier by hand while human mistakes can still be an issue. The use of BIM models in production has also eliminated non-value-adding activities, increased work accuracy, and improved installers planning which led to fewer errors and deviations on the construction site.

This thesis has shown that the benefits of using BIM on construction site are many. BIM can streamline material orders, reduce material waste, and improve communication through user friendly platforms like StreamBIM. It enables site workers to be continuously updated and help them to make the right decision. However, there are also challenges with the integration of Total BIM. Technical barriers between different software, initial investments in training and IT infrastructure, as well as resistance to change from experienced workers and established work habits, are some of these. However, resistance can be overcome through education and increased awareness of BIM's benefits. When BIM is used correctly, installers experience a clear improvement in the simplicity and accuracy of the workday. Even skeptical installers can become positively inclined after working with BIM in practice. Moreover, to fully utilize the potential of BIM, it is necessary for BIM to be the legally binding document where all disciplines on the construction site using 3D models and for any deviations to be quickly addressed through updates in the model.

Overall, the study shows that despite certain challenges and initial costs, Total BIM has the potential to revolutionize installation contracts in Sweden by increasing efficiency, improving accuracy and quality in construction projects. A broader and more integrated use of BIM, along with necessary educational and technical investments, can lead to faster and more profitable construction projects.

6.1 Future Research Suggestions

In the future, there is potential to save even more time in the ventilation industry by automating both calculation and purchasing processes. To eliminate time-consuming and manual tasks, calculation programs should be able to import data from IFC files. Additionally, more suppliers should develop plugin systems with article numbers included so that designers can use them to create and inform the models, which can then be automatically imported into the purchasing system during the production phase. Therefore, it is useful to further research how information from BIM models can be easily imported into calculation programs and how models can be designed with suppliers' component information for seamless import into the purchasing system.

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