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Structuring Building Information for Cost Control

A Case Study of BIM in the Housing Production

Master's thesis in Design and Construction Project Management

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CHALMERS UNIVERSITY OF TECHNOLOGY

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MASTER'S THESIS ACEX30

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ABSTRACT

Construction projects have for a long time been characterized by sub-optimization and fragmented information exchange, resulting in inefficient production control and cost overruns. Cost control represents an important part of taking appropriate actions to keep the budget on track. Research within the context of cost control and Building Information Modeling (BIM) has discussed how it can facilitate early phases of construction projects. However, limited attention has been on BIM benefits and its requirements for cost control in the construction phase. The aims of this thesis were to identify how BIM can facilitate cost control and to determine the requirements that need to be established for information and model in the housing production. Semi-structured interviews were conducted with 13 support functions and 11 site management respondents at a contractor company in Sweden. Results show that BIM can be used as a decision-making platform to facilitate information take-off for cost control, as in filtration, comparison, and visualization of multidimensional information. Furthermore, for supporting cost control in the housing production, BIM guides are required to inform all concerned stakeholders about the requirements on information and model, such as a common structure and level of development. Altogether, BIM can contribute to proactive cost control, making the cost control activities easier and more efficient. Finally, the findings can promote contractors' strategic work to develop new and innovative cost control methods in the construction phase.

Keywords: Building Information Modeling, BIM, Cost Control, Construction Phase, Housing Production, Information Structure, Visualization, Information Take-Off, Level of Development, LOD

Strukturering av byggnadsinformation för ekonomistyrning

En fallstudie om BIM i den svenska bostadsproduktionen

Examensarbete inom masterprogrammet Design and Construction Project Management

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SAMMANFATTNING

Byggbranschen är en viktig sektor som utgör en stor andel av Sveriges totala ekonomi. Samtidigt är det vanligt att byggprojekt är ineffektiva och går över budget. Det kan vara till följd av det fragmenterade fackspråket som försvårar informationsutbytet mellan branschens olika intressenter och skapar suboptimeringar inom de olika kompetensområdena. Ekonomistyrning är en viktig del av produktionsstyrningen för att vidta lämpliga åtgärder för att hålla projektets budget. Forskning inom Byggnadsinformationsmodellering (BIM) har identifierat hur ekonomistyrningen kan underlättas i tidiga faser av byggprojekt. Det har dock varit begränsad uppmärksamhet på nyttor med BIM och dess medföljande krav på ekonomistyrningen i produktionen. Syftet med examensarbete var att identifiera hur BIM kan underlätta ekonomistyrningen och att fastställa vilka krav som behöver ställas på information och modell i bostadsproduktionen. Semistrukturerade intervjuer genomfördes med 13 supportfunktioner till produktionen och elva platsledningsrespondenter på ett byggföretag i Sverige. Resultaten identifierar att BIM kan användas som en beslutsplattform för att underlätta informationsinhämtning för ekonomistyrning genom filtrering, jämförelse och visualisering av multidimensionell information. För att stödja ekonomistyrningen i bostadsproduktionen krävs BIM-guider för att informera alla berörda intressenter om kraven på information och modell, såsom en gemensam struktur och level of development. Sammantaget kan BIM bidra till proaktiv ekonomistyrning, vilket gör dess aktiviteter enklare och mer effektiva att utföra. Slutligen, resultatet kan främja byggföretags strategiska arbete med att utveckla nya och innovativa ekonomistyrningsmetoder i produktionen.

Nyckelord: Byggnadsinformationsmodell, BIM, Ekonomistyrning, Produktionsfas, Bostadsproduktion, Informationsstruktur, Visualisering, Informationsinhämtning, Level of Development, LOD

Contents

1	INTRODUCTION	1
1.1	Purpose and Research Questions	2
1.2	Scope and Delimitations	2
1.3	Structural Outline	3
2	METHODOLOGY	5
2.1	Research Design and Strategy	5
2.2	Data Collection	5
2.2.1	Interviews	5
2.3	Analysis of Data	7
2.4	Quality Assurance	7
2.5	Ethics and Sustainability	8
3	THEORETICAL BACKGROUND	9
3.1	Cost Control	9
3.2	Building Information Modeling	9
3.3	Benefits with BIM for Cost Control	10
3.3.1	Cost Control Activities	10
3.3.2	Quantity Take-Off	11
3.3.3	Visualization	11
3.4	Challenges with BIM for Cost Control	12
3.5	Requirements on Information and Model	12
3.5.1	Information Exchange and Modeling Requirements	13
3.5.2	Object Classification Systems	13
3.5.3	Building Stages and Model Elements	14
3.5.4	BIM Functions and Uses	14
3.5.5	Level of Development	14
4	CASE COMPANY DESCRIPTION	17
4.1	The Organization's Structure and Information Exchange	17
4.2	Requirements Specification for Model and Information	18
4.3	Cost Control	18
4.3.1	Cost Control Activities	19
5	RESULT	23
5.1	Challenges with Cost Control	23
5.2	Visions with Cost Control	17

5.3	The Respondents' Definition of BIM	18
5.4	Challenges with BIM	25
5.5	Benefits with BIM for Cost Control	26
5.5.1	Control of Common Costs	26
5.5.2	Accurate Purchases	26
5.5.3	Streamlined Contract Variation Management	27
5.5.4	Efficient Forecasting	27
5.6	Requirements on Information and Model to Facilitate Cost Control	28
5.6.1	Information Structure for Filtration and Linking	28
5.6.2	Common Code Language	28
5.6.3	Grouping of Geographical Position	29
5.6.4	Level of Detail in the Model	30
6	DISCUSSION AND ANALYSIS	31
6.1	Current Challenges and Visions with Cost Control	31
6.1.1	Deficient Information Exchange	31
6.1.2	Defective Division of Production Costing	31
6.1.3	Support Functions' Unawareness	32
6.1.4	Involvement of the Supervisors	32
6.1.5	Compare Financial Data	32
6.2	Requirements on Information and Model for Cost Control	33
6.2.1	Explicate the Required Information Use	33
6.2.2	BIM Guides – Requirements Specification	33
6.2.3	Structure and Level of Development	34
6.3	Benefits with BIM for Cost Control	35
6.3.1	Control of Common Costs	35
6.3.2	Accurate Purchases	36
6.3.3	Streamlined Contract Variation Management	36
6.3.4	Efficient Forecasting	37
6.4	General Benefits with BIM	37
6.5	Limitations and Future Research Recommendations	38
7	RECOMMENDATIONS TO THE CASE COMPANY	41
8	CONCLUSION	43
9	REFERENCES	45

List of Tables

Table 1. Distribution of the site management interviews.....	6
Table 2. List of all interviews.....	7

List of Figures

Figure 1. The case company's organizational structure.....	17
Figure 2. Flow chart over information exchange related to cost control	18

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Isabelle Melin & Josefin Persson

1 Introduction

The construction industry is fragmented with stakeholders that have different technical focus and technical language (Dainty et al, 2006). Consequently, the communication can be noisy and to obtain a structured overview of the multidimensional information in the building process can be nearly impossible (Bryde et al., 2013; Tallgren, 2021). In addition, divergent skills of numerous competence areas may optimize their own outcomes, causing sub-optimization of other areas in the construction projects (Dainty et al, 2006; Ljung & Malik, 2022).

Inefficient work procedures, schedule, and cost overruns are the results of the fragmented information exchange in the construction industry (Tallgren, 2021). Thereto, it also causes inaccuracy of the quantity take-off and the cash flow analysis, which have a negative impact on the project's cost performance (Vigneault et al., 2020). Cost performance is a central part of business and a commonly used indicator of the project's success. Hence, with cost overruns still being a problem in project management, it means that the project deviates from the expected direction and does not achieve the project objectives (Vigneault et al., 2020).

Cost control, crucial for minimizing cost overruns and ensuring predicted profitability (Malkanthi et al., 2017), is a cost management step typically done during a project's construction phase, with several project performance indicators being observed (Vigneault et al., 2020). Since cost control entails taking necessary corrective actions to keep the budget on target (Potts, 2008), it can be seen as a fundamental managerial activity (Lester, 2017). Hence, it is a course of action for efficiently managing various competences' information while also decreasing the complexity and uncertainty caused by the fragmentation in the industry (Dvir et al., 2003).

Several articles emphasise the application of Building Information Modeling (BIM) to facilitate information sharing and collaboration among participants in construction projects (Lester, 2017; Brohn, 2021; Smith, 2016; Tallgren, 2021). BIM is *“a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle”* (Succar, 2009, p. 357). When the authors refer to BIM in this thesis, multidimensional information management is in mind. Multidimensional information is for example cost, time, geographical position, and materials, which with the aid of BIM can be connected to each other to give a structured overview of building information (Lester, 2017).

BIM imposes specific requirements on the information provided by all stakeholders in the project, for instance to have a predetermined structure for the information (Monteiro & Poças Martins, 2013). Smith (2016) discusses how BIM can improve speed, quality, and accuracy in cost estimations for cost management professionals. Thus, it frees up time that can be spent on providing *“knowledge and expertise intensive advice to the project team”* (Smith, 2016, p. 194). Similar benefits with BIM in the construction phase, such as improved quality and efficiency in addition to visualization and automated quantity take-off, are identified by Sunquist et al. (2020). However, the true capacity of BIM in the construction phase is still unrealized (Ghaffarianhoseini et al., 2017; Sunquist et al., 2020).

All in all, there is a need to develop BIM requirements that can facilitate the construction progress and accomplish BIM's fullest potential in the construction phase

(Ghaffarianhoseini et al., 2017). Although Smith (2016) discusses how BIM can facilitate cost management, it is still referred to the earlier stages of construction projects and not specifically to cost control. However, Vignault et al. (2020) explain that BIM may help cost control become more effective and useful. But still, previous research identifying benefits and requirements on BIM connected to cost control in the construction phase is limited.

1.1 Purpose and Research Questions

The aims of this thesis are to identify the benefits of using BIM for cost control, as well as to determine requirements that need to be imposed on BIM to support cost control in the construction phase for a Swedish contractor.

The objectives of this study are to identify the uses of BIM that facilitates cost control in the construction phase, to conclude the current challenges and visions with cost control in the housing production, and to determine requirements requested on information and model for supporting cost control in the housing production. The expected outcome of the thesis is to gain an understanding of how BIM can be utilized by a contractor to minimize sub-optimizations in construction projects and to efficiently and proactively manage cost control throughout the construction phase.

This research will contribute to the body of knowledge on BIM applications in the housing production for contractors' cost control. This will help to fill the current research gap in this area and provide value to organizations operating in similar circumstances. Accordingly, the following research questions (RQ) are sought to be answered:

RQ1: How can BIM facilitate the cost control in the construction phase?

RQ2: What are the current challenges and visions with cost control in the housing production?

RQ3: What requirements are requested on information and model for supporting cost control in the housing production?

1.2 Scope and Delimitations

The thesis empirical data encompasses cost control and the usage of BIM at a contractor within the housing production in Sweden. The empirical study will concentrate on the construction phase, and mainly on the frame completion and fixtures stage, since the site management has a great impact on the project's costs and responsibility of the cost control at that stage. Accordingly, the respondents in this study are the site managements that are directly working with cost control in the construction phase, as well as the support functions at the case company, which are operating earlier in the construction process and generate the information needed to cost control on site. The empirical findings cannot be generalized to other industries or countries, due to the specific industry and location, but they are expected to provide an insight into companies with similar contexts. The theoretical data, on the other hand, is based on worldwide sources to avoid being constrained by a shortage of data.

To further limit the thesis scope, it is restricted to merely identifying requirements on content and structure for information and model. Thus, it is not within the scope of the research to consider other kinds of BIM requirements, as in terms of software, file

classification standards, implementation procedures, and so on. In terms of cost control, most activities in the construction phase were covered in this thesis, such as purchase, contract variations, and forecast. However, a delimitation that has been made is to not examine choice of production method, because it is more of a requirement for experience than for information. Furthermore, even if the focus is on proactive cost control, reactive follow-up is addressed since it is required for managing cost control.

1.3 Structural Outline

The thesis consists of eight chapters and is structured as follows:

In chapter one, the setting of the thesis was introduced. The research aims, objectives and questions have been established, as well as the significance of such research. The scope and delimitations of the thesis have also been addressed.

In chapter two, the methodology used to conduct the research is outlined. It encompasses the process of collecting and evaluating the empirical and theoretical data. Also, considerations of ethics and sustainability are discussed.

In chapter three, the available literature is presented to comprehend cost control and BIM, and to identify vital information and model requirements, as well as the advantages and challenges of using BIM for cost control during the construction phase.

In chapter four, the case company is described concerning its organizational structure and information exchange, as well as their existing requirements on information and model, and how cost control is currently executed.

In chapter five, the results from the semi-structured interviews with support functions and site managements at the case company are presented.

In chapter six, the theoretical and empirical findings of the thesis are analysed and discussed in terms of their significance. In addition, the research's strengths, limitations, and suggestions for further research is discussed.

In chapter seven, recommendations for the examined case company are presented.

In chapter eight, the research questions are answered, and the key findings are presented.

2 Methodology

The methodology employed for the master's thesis is presented in this chapter. It covers the research design and strategy, how data collection and analysis were performed, and the assurance of its quality. Also, ethical and sustainable considerations are presented.

2.1 Research Design and Strategy

This master thesis has of a qualitative research approach and was conducted through a case study. Qualitative research focuses on making sense of and interpreting the nature of the inquiry (Denzin & Lincoln, 2000); while a case study comprises a thorough and in-depth examination of a specific instance (Bell et al., 2019). Thus, it was feasible to comprehend how the specific case organization function, with its interactional relationships and activities. To find answers to the exploratory research questions in scientific articles and books, the search engine Chalmers Library and the data base Scopus were used. Other types of data were collected by internal documents and empirical material in terms of taped interviews. By applying an abductive research strategy, the collection of theoretical and empirical data could be mutually influenced (Dubois & Gadde, 2002). All in all, with an interpretivist research philosophy, key insights and understandings were gained throughout the research process (Bell et al., 2019).

2.2 Data Collection

The data has been collected in three steps, first with an initial literature search to define the scope of the study and to investigate what previous studies have discussed and to gain a broad understanding of the current state within the subject of 'cost control and BIM in the construction phase' (Bell et al., 2019). The search was limited to literature in Swedish and English. The keywords used in the literature search were "cost control", "cost control activities", "building information modelling/BIM", "5D BIM", "information management", "BIM requirements", "BIM benefits and challenges", "housing", and "construction". Articles identified as relevant to the study were selected and added to a bibliography. The articles in the bibliography were content analysed by a first analysis of the abstract and the conclusion. If the article was still relevant after the review, the entire article was read. Thus, articles were filtered out of scope and the relevant articles were summarized (Bell et al., 2019). Qualitative interviews were the second step in the data collection process, which is elaborated in the next subsection. The third step in the process of collecting data was the main literature search, where keywords influenced by the initial literature search and the interviews were used. Those were "LOD", "BIM guides", "forecast", "contract variations", "common costs", "quantity take-off", "classification systems", "visualization", and "contractors". Furthermore, participatory and informal observations were done to develop an understanding of the case organization and gradually prepare for the interview study (Patel & Davidson, 2019); this was done once a week during internships on two of the three reference projects of the study. Altogether, the two authors contributed equally to the work of this thesis.

2.2.1 Interviews

The case company studied is the contractor company Skanska and its two housing districts in Gothenburg. The empirical data was collected in a two-phase process and

the interviewees were selected in collaboration with one of the district managers and the supervisor, a design manager, at Skanska. The first phase contained semi-structured interviews with 13 people in support functions to the construction phase and lasted for approximately 30 to 60 minutes. Interviewed support functions were two district managers, four purchasers, an estimator manager, a design manager, a digital strategist, an operational manager, a planning specialist, and two business project managers. The semi-structured interviews were conducted to create an understanding of how the fragmented construction industry might affect the communication and information exchange between different actors in the project. Also, to gain an understanding of the support functions' role within cost control at early stages in the project; to form a body of knowledge for the second and main phase of interviews at the case company.

The second phase involved 11 semi-structured interviews with three site managements, which in total entailed three project managers, four site managers, three supervisors, and one project engineer, see Table 1. The interviews lasted for 60 to 90 minutes in order to obtain an insight in how they work with cost control and how they can utilize BIM in the daily cost control. The three projects were selected based on that they work much with production control; Project A and B put a lot of effort on planning, and Project C is a pilot project within 5D BIM. The projects would provide a diversity in working methods and experiences in cost control, to present a complete picture of how cost control currently is performed and what is desired of BIM. Unfortunately, the study has a shortage of project engineer respondents, since the one at Project A was on parental leave, and the project engineer at Project C had only recently started working in that role. The study also lacks a supervisor from Project A due to that it was difficult to get an appointment, therefore it was decided to interview two supervisors from Project C instead.

Table 1. Site management respondents in the three reference projects in the housing districts A and B.

	<i>District A</i>	<i>District B</i>	
<i>Projects</i>	Project A	Project B	Project C
<i>Interviewees</i>	Project Manager A	Project Manager B	Project Manager C
	Site Manager A	Site Manager B	Site Manager C
		Assistant Site Manager B	Supervisor C1
		Project Engineer B	Supervisor C2
		Supervisor B	

As the body of knowledge expanded through interviews and literature searches, and thanks to the abductive research strategy, the interview questions could be more accurately formulated during the study. Semi-structured interviews were chosen since the respondent freely could express their thoughts on the subject while being guided to stay on topic. Also, semi-structured interviews provide reliable and comparable data (Bell et al., 2019), which allowed the interviews to be analysed and compared with each other to give answers to the research questions.

Number of interviews in the first phase was decided in the manner that they would cover the various support functions for construction. In the second phase, number of interviews was not set from the beginning of the study; instead, it was considered to be adequate of respondents when 11 number had been interviewed, as the answers were repeated and did not provide with new information. The interviews were held both physically on site and digitally through Teams, see Table 2.

Table 2. Format and dates of the interviews with the support functions and the site managements.

<i>No. of interviews</i>	<i>Position</i>	<i>Type of role</i>	<i>Format</i>	<i>Date</i>
1	District Manager A	Support function	Digital	8 February 2022
2	District Manager B	Support function	Digital	9 February 2022
3	Digital strategist	Support function	Digital	9 February 2022
4	Purchaser A	Support function	Digital	10 February 2022
5	Purchaser B	Support function	Digital	22 February 2022
6	Design Manager	Support function	Digital	22 February 2022
7	Business Project Manager A	Support function	Digital	23 February 2022
8	Purchaser C	Support function	Digital	23 February 2022
9	Business Project Manager B	Support function	Digital	23 February 2022
10	Purchaser D	Support function	Digital	24 February 2022
11	Estimator Manager	Support function	Digital	24 February 2022
12	Operational Manager	Support function	Digital	24 February 2022
13	Planning Specialist	Support function	Digital	25 February 2022
14	Assistant Site Manager B	Site Management	Physical	15 March 2022
15	Supervisor B	Site Management	Physical	15 March 2022
16	Site Manager B	Site Management	Physical	16 March 2022
17	Project Engineer B	Site Management	Digital	16 March 2022
18	Project Manager A	Site Management	Digital	17 March 2022
19	Site Manager A	Site Management	Physical	18 March 2022
20	Supervisor C1	Site Management	Physical	22 March 2022
21	Site Manager C	Site Management	Physical	22 March 2022
22	Project Manager C	Site Management	Physical	24 March 2022
23	Supervisor C2	Site Management	Digital	31 March 2022
24	Project Manager B	Site Management	Digital	5 April 2022

2.3 Analysis of Data

To process and interpret the empirical data gathered, all interviews were recorded and transcribed verbatim (Bell et al., 2019). A conventional content analysis approach was used to analyse the data since it is appropriate for qualitative research with a large set of multifaceted data to be processed (Hsiu-Fang & Shannon, 2005). It implied that the content was coded into categories and directly derived from text data (Hsiu-Fang & Shannon, 2005). The categories were related to the research question's themes, namely 'challenges and visions with cost control', 'benefits with BIM' and 'requirements for information and model'. Hence, text pieces with the same theme and under the same category were linked together to be able to present the empirical findings in response to the research questions.

2.4 Quality Assurance

To assure quality of the collected data, the literature searches were done with finely chosen key words suitable for the research scope and references mainly from journals (Bell et al., 2019). However, the authors have had in mind that the literature quality cannot be trusted blindly even if it is peer reviewed articles and proceedings. To ensure

the quality of the theoretical data, it has been collected by critically examine whether the sources are primary, their purposes, and if they are up to date (Patel & Davidson, 2019). In addition, the reliability and validity of the empirical study was verified by the careful selection of interviewees. Furthermore, communicative validity was a strategy used for ensuring credibility (Patel & Davidson, 2019), since the respondents validated the result by reading through the report to check if there were any misunderstandings and/or incorrect information. Since the interviews were recorded and thoroughly transcribed, they can be audited for confirmation (Bell et al., 2019). The internships at two of the three reference projects once a week brought the authors closer to and gave them a greater grasp of the case organization, but it may have affected the critical view. However, distance was taken throughout the study to examine how the collected data had been managed; thus, reflexivity was applied to make sure reliable results (Bell et al., 2019). Transferability is limited since the findings are specific to the case company and are unlikely to be extended to other contexts (Bell et al., 2019), except for similar contractor organizations.

2.5 Ethics and Sustainability

Since part of the thesis is based on interviews, the respondent's personal integrity is an ethical issue. The respondents were asked for permission to record the interviews in advance, and the study's aim and scope were explained at the beginning of the interviews (Bell et al., 2019). As a further measure, the identities of the respondents have been preserved to the fullest extent feasible, as they are only identified by their professional titles. The respondents' personal information is also anonymized in the transcripts as they are deidentified. Furthermore, the transcripts and the recorded interviews are solely used for this master thesis.

The topic of this master thesis is considered to contribute to the eighth and the ninth of the United Nations sustainability goals (UN, 2021): “*Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all*” (p. 42) and “*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation*” (p. 44). Accordingly, the findings are intended to inform how BIM can be used to help with cost control, as well as to enhance a new and innovative procedure for information management in the construction phase. Thus, the intention of the study is to demonstrate how BIM may improve the case company's economic and social sustainability.

3 Theoretical Background

This chapter presents theoretical background about cost control and Building Information Modeling (BIM), their benefits and challenges, as well as requirements on information and model to facilitate cost control.

3.1 Cost Control

Cost control is a fundamental managerial activity (Lester, 2017), with the primary goal of achieving a balance between expenditure of project components and the project budget (Weisheng et al., 2019). Cost control, according to Potts (2008), comprises much more than keeping track of expenditures and generating cost reports. It is also about understanding how and why costs occur, acting in a timely manner, and controlling revenue (Potts, 2008). Periodic cost monitoring allows the project organisation to identify activities and resources whose actual costs exceed the budgeted cost at an early stage, enabling immediate adjustments to keep the budget on target (Potts, 2008). Furthermore, the total cost of the project can be estimated based on the costs registered so far, and the expected costs of completing the unfinished activities. With periodic monitoring, it is possible to not only follow-up the project but also to continue steering it forward. According to Lester (2017), a regular and up-to-date monitoring system can assist managers to identify operations expenses and assess whether they are cost-effective or not. Despite the significance of cost control, Potts (2008) express that traditionally, the project organization in contractor companies “only monitor costs rather than control costs which made their role reactive rather than proactive” (p. 198).

To control costs during the construction phase, a budget must be updated on a regular basis with the actual costs incurred to date (Project Management Institute, 2017). The budget is established early in the construction projects, and constantly revised with cost estimates until the final design is developed (Vigneault et al., 2020). Furthermore Vigneault et al. (2020) stress that the budget “*serves as the baseline against which the project’s performance can be controlled*” (p.1014). This allows the project organization to analyse how project resources are utilized and what work is done in exchange for those funds. It also adds more value to the project than simply monitoring fund expenditures without accounting for the proportion of work accomplished connected to the spending; other than to track the outflow of funds which does not tell much because it is not in relation to anything (Project Management Institute, 2017).

3.2 Building Information Modeling

Building Information Modeling (BIM) is defined as “*a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building’s life-cycle*” (Succar, 2009, p. 357). Thus, BIM is a collaboration tool for design and information management (Monteiro & Poças Martins, 2013). The fundamental word in BIM is 'information', it comprises both geometric and non-geometric data, which is exactly what is required to perform any task (Weisheng et al., 2019). BIM can be seen as a process that generates information on a building throughout its life cycle, rather than a single three-dimensional (3D) application (Brohn, 2021; Lester, 2017). A comprehensive approach of the management of building-related data is so called building information management, which is required to accomplish more efficient

processes (Brohn, 2021). Hence, the term building information management is used to stress that BIM entails not only the utilization of various technologies, but also the adoption of various processes and standards (Bolpagni et al., 2022).

Nonetheless, a building information model is a given when it comes to BIM. Both tangible and intangible components, as well as their interconnections, should be represented in a digital model; where the information is created and processed during the life cycle of the building (Brohn, 2021). *“It is so much easier to work with a BIM model and to explore the building in 3D with rich information, than looking at hundreds or thousands of drawings”*, according to Lester (2017, chapter 52, p. 512). Seeing that all essential information can be retrieved by simply clicking on an object in a BIM model.

BIM can be rich in information as it is not limited to a model (Lester, 2017). Multidimensional information can be of any sort that the user wants to obtain and control. For instance, space, time, costs, material specifications, finishes, etcetera. It *“allows the support for information-based real-time collaboration”* (Lester, 2017, chapter 52, p. 512). 'Dimensions of BIM' is a frequent term used to describe what information is necessary; however, 'BIM uses' is a better term for describing the various purposes of the required information (Bolpagni et al., 2022).

3.3 Benefits with BIM for Cost Control

Various cost control benefits of BIM have been documented in the literature. Vigneault et al. (2020) stress that it can improve the cost management processes in terms of quality, efficiency, and precision. Sacks et al. (2018) emphasize that using BIM can result in a better-planned and streamlined construction process, which decreases the risk of errors and conflicts and saves time and money for the project. A potential with BIM is that it can be used proactively for coordination of purchases and planning of the construction to identify conflicts in space and time in beforehand (Sacks et al., 2018). BIM is also being considered as a possible solution to reduce quantity take-off inaccuracy, cashflow analysis incorrectness, and overall poor cost management (Vigneault et al., 2020). In addition to a more accurate quantity take-off and cash flow analysis, BIM can also facilitate other cost control activities such as forecasting, purchasing, and contract variation management.

3.3.1 Cost Control Activities

Cost control should be done on a regular basis throughout the project's life cycle, with assessment of various economic indicators, according to Vigneault et al. (2020). BIM, in which scheduling, and costing information are linked to a digital model, allows the site management to handle cost control activities quickly and efficiently. These activities are forecasting, cash flow analysis, purchasing, and contract variation management (Vigneault et al., 2020). Forecasting is the process of comparing current costs to budgeted costs, and anticipated final costs (Vigneault et al., 2020). Thus, by using BIM where the contractor's cost and price information is linked to the model, a quick assessment of the costs so far is possible by simply isolating the finished parts to evaluate the project's total cost (Mitchell, 2012). Furthermore, faster and more accurate cash flow analysis can automatically be done by using BIM, as well as that the cash flow analysis can easily be updated when changes are made (Vigneault et al., 2020). Also, purchasing of material or elements can be done more simply since the information

needed for the purchase is represented in the model (Vigneault et al., 2020). In addition, contract variations can easily and quickly be analysed because of the dynamic link between the costing information and the model (Vigneault et al., 2020).

3.3.2 Quantity Take-Off

Quantity take-off has previously been referred to as a key activity when it comes to purchasing, but it is also an important activity throughout the whole construction process (Monteiro & Poças Martins, 2013). Quantity take-off is used in early stages of the construction process for estimation of project cost and the construction activities duration, to forecast and plan construction operations prior to the construction phase and to provide a base for cost control during the construction phase (Monteiro & Poças Martins, 2013). Sacks et al. (2018) describe that “*all BIM tools provide capabilities for extracting counts of components, area and volume of spaces, material quantities, and to report these in various schedules*” (p. 256). However, Sacks et al. (2018) further state that when the elements or components are not adequately described or lack of information, problems may emerge in obtaining precise cost estimates. Similarly, Vigneault et al. (2020) emphasize the need of having a BIM model that contains all the information needed to construct a complete quantity take-off. The inability to take-off precise quantities from the model is frequently due to the model's insufficient information structure or the fact that the components are not modelled at all (Monteiro & Poças Martins, 2013).

3.3.3 Visualization

Visualization is mentioned as a benefit of BIM for cost control in several articles (Monteiro & Poças Martins, 2013; Rohani et al., 2013; Sacks et al., 2018; Vigneault et al., 2020). Rohani et al. (2013) describe that controlling, monitoring, as well as planning of the construction process are prerequisites to succeed with construction operation. To control the process during the construction phase, it is critical to collect data that represents the construction state on a constant basis (Rohani et al., 2013). To control, the as-built progress should be continuously monitored and compared to the as-planned progress in order to identify project deviations throughout actual execution. To act on the deviation, a decision is taken based on re-illustration of current data in the form of graphs and bar charts, which are time-consuming to establish (Rohani et al., 2013). With BIM visualization, the site management is able to visualize the development of the project which can be useful from planning to controlling, in various phases of the project (Rohani et al., 2013). Furthermore, during forecasting the actual cost of each resource is compared with its related budget, where the cost variances for the different resources can be visualized thorough BIM (Elbeltagi et al., 2014).

Many contractors are unaware of or unable to specify their actual site overhead expenses, namely common costs, making it difficult to estimate and foresee them (Disney & Fahlstedt, 2021). Common costs are a part of indirect costs that is used to support a construction project. Examples of common costs include site accommodations, fencing, scaffolding, storage containers, overall lighting, machinery, etcetera (Disney & Fahlstedt, 2021). Thus, a BIM tool that manages all necessary information can assist the contractor in visualizing and evaluating planned construction stages, allowing the site management to model temporary components such as scaffolding in advance (Sacks et al., 2018). Consequently, the common costs become easier to estimate and foresee.

3.4 Challenges with BIM for Cost Control

The advantages of BIM are not without challenges. An issue with BIM for cost control is that the information requested of the site management is production specific information. According to Weisheng et al. (2019), the model provided by the design team does not always contain all the necessary information for cost control, particularly when the several specialists involved only contribute content that is relevant to their area of expertise. Similarly, according to Sacks et al. (2018), even though the engineer and architect utilize BIM in the design process, the contractor must still add construction-specific information to make the building model useful. Sacks et al. (2018) describe that early involvement of contractor with a closer collaboration increases the potential in being able to utilize BIM for cost control. This allows the contractor to ensure that the model is contained with the necessary information for cost control in the construction phase. However, to succeed with this it is important that the site management can explain to the designer what information they need and in which form. Further, Smith (2016) also explains that it is critical for the site management to be able to properly express what they want and convey the benefits to the designer.

Design consultants, such as architects and engineers, are often reluctant to give full versions of their models to contractors, which is another challenge for contractors that wants to use BIM as a cost-control tool (Smith, 2016). One reason to this may be that the model is not legally binding, which means that designers do not want to take responsibility and hand over the entire model if something could be wrong with it (Lindström, 2021; Smith, 2016). Another issue when using BIM is poor and inaccurate data. Due to lack of proper information, the BIM model falls short of its capacity in many projects. One reason is that design fees do not include allowance for fully comprehensive data input, and another reason may be that some designers and architects do not have the competence to enter the necessary information for cost control (Smith, 2016). In addition, BIM models generated rapidly with inadequate data is a dilemma, since it is a 'dumb' model just providing the illusion of being functional. Then it is up to downstream part of the project, namely the site management, to work with the 'dumb' model and develop the additional information needed for construction (Smith, 2016).

3.5 Requirements on Information and Model

A clear information specification is required to obtain all information required from one construction phase to another and from one stakeholder to another (Sacks et al., 2018). If there is a lack of BIM initiatives from clients and designers, contractors must take the lead in the BIM process if they want to reap the benefits for their own organization and better positioning themselves to profit from the emerging market of BIM adoption (Sacks et al., 2018). The requirements can be stated in BIM guides, which for example covers matters of project definition and planning, and technical specifications. Sacks et al. (2018) draw on previous studies of bSI (2014) and Keenlside (2015) which describe the implications of those matters. For example, the project definition and planning section should comprise definition of building stages and model elements, as well as BIM functions and use scenarios. Further, the technical specifications section should include requirements on modeling and information exchange, BIM object classification systems, and Level of Development.

The BIM guides are not a set of specifications for what should be modelled or by whom; “rather it is a language by which users can define these requirements for their own firms and projects” (BIMForum, 2021). Accordingly, the goal is to help organizations to specify BIM deliverables, to make it easier for design managers to inform designers what details and information they should deliver at different stages of the design phase, and to keep track of their models. Also, it enables downstream users, such as the site management, to have confidence in the information received in the model, as well as it establishes a standard that can be used for contracts and BIM execution plans (BIMForum, 2021).

3.5.1 Information Exchange and Modeling Requirements

It is of great importance that BIM users clearly state to the designers what they want and communicate the advantages of it (Smith, 2016). Accordingly, there should be a collaboration which extends from the designers to all areas of expertise in the project, to explicate what kind and form of information that is specifically required, as well as suggestions for how the model may be developed. Weisheng et al. (2019, chapter 4) explains that establishing BIM models necessitates working cohesively between all stakeholders, “to keep it compliant with existing building codes, updated, buildable, and within the proved construction budget” (p. 69). If the information exchange processes are appropriately implemented and followed, the right stakeholder can quickly get the right information and make decisions on the right basis (Brohn, 2021).

3.5.2 Object Classification Systems

Object classification systems are one of the foremost requirements to accomplish an automatic building information management process (Monteiro & Poças Martins, 2013). There is no official object classification system standard in many countries. This can result in BIM stakeholders having difficulty tracing each other's information, because neither elements nor measurements are described in the same way (Monteiro & Poças Martins, 2013).

As there are different object classification systems in the construction industry, there are several Work Breakdown Structures (WBS) in which the information can be structured (Monteiro & Poças Martins, 2013). Each element of the WBS is identified by a unique code and is usually constructed on a series of more specific levels and domains. The codes must be entered in ID or layer mode to apply the WBS to a BIM model. Furthermore, Monteiro and Poças Martins (2013) claim that to ensure the consistency of information flows, the multiple systems and documentations throughout the building's life cycle must adopt the same WBS.

In Sweden objects can be classified with the systems AMA, BSAB-series, and CoClass, which are provided by the limited company Svensk Byggtjänst, and are thus not open standards (Koch, 2017). CoClass is the newest classification system from 2016 which is based on both the BSAB-series and international standards, with the intention of replacing all other standards and creating one that is suited for BIM (Koch, 2017). Like Svensk Byggtjänst (n.d.) expresses “CoClass is created for digital information management and with CoClass everyone speaks the same language”. The language of CoClass, namely the code structure for objects, can be seen as in a hierarchy like a pyramid with main groups of information that can be added on during the building's life cycle. Starting from the top of the hierarchy is the information group ‘construction

complex', then 'construction entity', 'functional systems', 'constructive systems', and at the bottom 'components' (Svensk Byggtjänst, n.d.).

3.5.3 Building Stages and Model Elements

The building stages must have a well-defined and standard definition since it will assist all areas of expertise within the project in determining when and where information should be delivered (Ljung & Mailk, 2022). For instance, the frame completion and fixtures stage is suggested to be divided into three sub-stages: interior frame completion, fixtures, and interior. Because the stage is extensive, very precise information is required to co-read it with several types of information from various competence areas (Ljung & Malik, 2022).

In addition, if the information exchange across the different competence areas and information co-readability are to function, principles for how building elements should be modelled are required. Hence, also the building elements need to be clearly identified (Ljung & Malink, 2022). Weisheng et al. (2019) state that architectural elements like doors, windows, and internal walls, as well as structural elements such as columns, beams, and foundations, should be named according to a predetermined naming scheme. It is required for things to be collected, sorted, and analysed automatically, to generate cost analysis data. Furthermore, Weisheng et al. (2019) express that model elements should contain information like size, object location, material specificities, and its relationship to adjacent model elements.

3.5.4 BIM Functions and Uses

One of the most essential issues in BIM guides is identifying project goals and BIM uses, which is usually seen as an important step in the supplementary documents known as BIM execution plans (Sacks et al., 2018). With a simple language specifying the BIM uses, namely the function of the information and model, can support various activities throughout the life cycle of a building (Bolpagni et al., 2022). Spatial coordination, scheduling, budgeting, production planning and control, and other BIM functions, are beneficial to identify to facilitate contractors' work on the construction site.

3.5.5 Level of Development

Level of Development (LOD) is important to help actors in the construction industry to receive the information they require at a certain project phase and for an intended use (Latiffi et al., 2015; Smith, 2016). LOD defines the model's specific content requirements at a given stage of a construction project. Accordingly, depending on the BIM aims and model usage during the construction process, what objects to include in the model and their level of detail must be chosen carefully (Sacks et al., 2018). Thus, LOD helps contractors to define and express the intended content and accuracy of information in phases such as the design and the construction (Smith, 2016).

Many construction companies make demands on LOD in their organizational or project specific BIM execution plans (Sacks et al., 2018). Weisheng et al. (2019) emphasize the significance of establishing procedures and standards for acquiring objects with the required LOD. Lower LODs are often applied for design (100-300), while higher LODs are used for construction (300-400) and turnover (500). The LODs applied for construction represent geographical information such as "*size, location, orientation,*

and configuration information” as well as non-graphic information such as “*material, cost, and manufacturer*” (Weisheng et al., 2019, chapter 4, p. 60). Sacks et al. (2018) highlight that LOD 400 is to be required for facilitating the production control; and that it is critical to decide ahead of time in the BIM execution plan what information to include or exclude to prevent wasting modeling time. The different levels of LOD can be described in general terms like (Lester, 2017, chapter 52, p. 514):

- LOD 100 – “*A graphically represented object mainly used for cost.*”
- LOD 200 – “*A generic object with approximate size, shape, and location.*”
- LOD 300 – “*Design-specified object with full specific, size, shape, and location*”
- LOD 350 – “*Actual object model with full specification, size, shape, location.*”
- LOD 400 – “*Similar to 350, plus all relevant project information and finishes.*”
- LOD 500 – “*Similar to 400 including a site-verified reports, test certificates, and CE marking information.*”

LOD is related to level of detail, where the latter defines input as the level of details included in the model components, whereas LOD defines dependable output as the extent to which the model's users can rely on the information (Latiffi et al., 2015). Thus, LOD is “*similar to a ‘common language’ for BIM users to understand the information in BIM more specifically*” (Weisheng et al., 2019, chapter 2, p. 25).

Specifically specified LOD requirements reflects the level of detail in for example quantity take-off, and thus the expectations on accuracy for cost estimates (Sacks et al., 2018). It is a good approach to specify the level of detail that the information input should have, based on the purpose for which it will be used (Monteiro & Poças Martins, 2013; Saks et al., 2018). However, while additional detail may lead to more correct forecasts and so on, too much detail can jeopardize the modelling and the linking of information, since the modelling will take more time. “*Thus, determining the appropriate level of detail of model to meet their purposes is critical for efficient project implementation*” (Sacks et al., 2018).

4 Case Company Description

This chapter depicts the case company Skanska’s organizational structure and information exchange in their two housing districts in Gothenburg. In addition, it is described how the organization currently manage cost control in the construction phase. The case description is a summary of the empirical data gathered during the interviews with the support functions and the site managements.

4.1 The Organization’s Structure and Information Exchange

“The project manager is a central figure within the information exchange between the design and the construction phase”, says District Manager A, and several other respondents agree. However, there are a lot of competence areas involved either direct or indirect in the cost control in the construction phase. Based on all interviews, the different roles connected to cost control and their involvement in the organization is illustrated in a simplified manner in Figure 1.

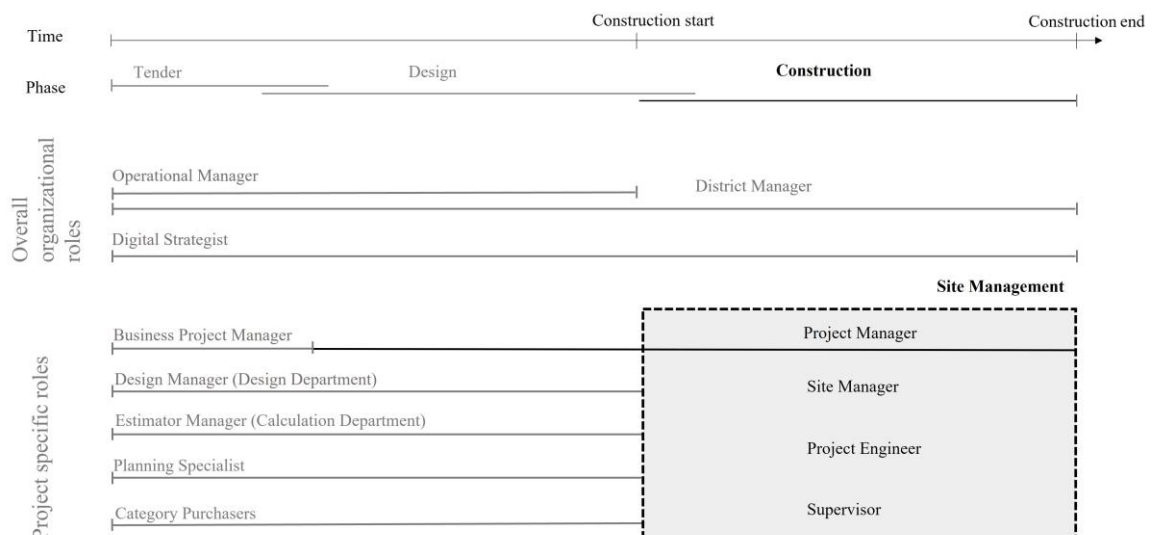


Figure 1. The different roles of the case company that exchange information connected to cost control and their general involvement in the different phases of the building process. (Authors' own figure)

Furthermore, to comprehend what data for cost control is shared between the support functions' areas of expertise and the site management, Figure 2 depicts a flow chart over the information exchange, based on the authors' perceptions derived from all interviews.

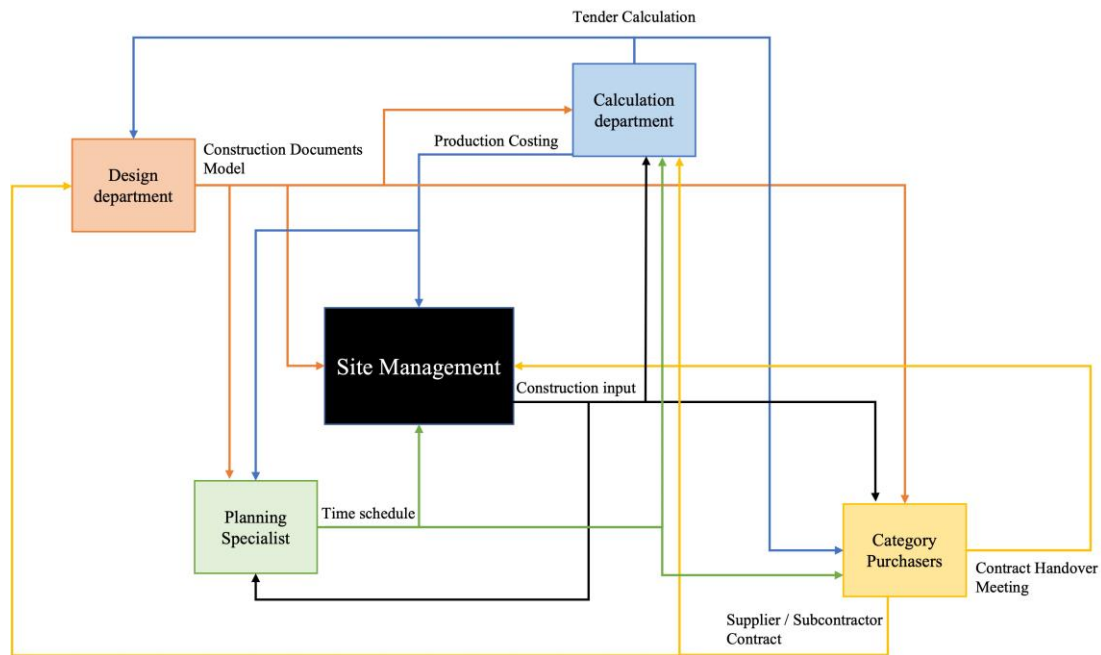


Figure 2. Information exchange between different areas of competence, with a focus on information required for site management to cost control in construction phase. (Authors' own figure)

4.2 Requirements Specification for Model and Information

Skanska has a guide, similar to a BIM guide, with requirements specification for model and information management for all the designers, installers, and prefabrication suppliers to enable co-reading of information and quicker extraction of information from the models.

Though, what has been set in the requirements specification is not always followed; “in some way it seems completely incomprehensible to read, so it always goes wrong in some way as the requirements specification is not good enough for people to understand what their task is”, says the Design Manager. Consequently, the respondent concludes that they need to be stricter, “since it is a contract document, you must attempt to follow it”.

Another shortcoming with the requirements specification is that Skanska only describes how they want the information structured in ideal conditions. The Planning Specialist explains that the conditions unfortunately are different from project to project, so there must be adoptions in the guide for each project.

The future development plan for Skanska’s requirements specification is to make sure more disciplines’ information is co-readable. Hence, Ljung and Malik (2022) state in an internal document that Skanska must clearly involve the calculation department with its calculations, the planning specialist with its schedule, and the site management with its construction planning.

4.3 Cost Control

The respondents at the case company gave overall a similar picture of cost control in the housing production. The distribution of financial responsibility within the project varies, partly between districts and partly between projects. In District A, the financial responsibility is distributed more evenly within the site management, meaning that the

supervisors have a greater responsibility over the resources within their assigned tasks. In District B, on the other hand, it is more common for site managers to take more of an overall responsibility for the on-site finances and the supervisors controls their activities on site. Several respondents believed that because everyone in the project has an impact on the economy, everyone should have some responsibility over it. For instance, supervisors make a lot of financial decisions every day and *“it would be difficult to get control of the costs if they did not know what those decisions imply financially”* (Project Manager A). However, as regards the support functions, most of them do not consider themselves to be as involved and to not have so much of an impact on the cost control, even if they generate information needed for cost control.

Many of the respondents described cost control as in that the project is provided with a bag of money which is distributed over the different project resources, such as building components like gypsum, reinforcement, etcetera. The distribution of money can be called budget; and cost control is about being aware of the budget, understanding what is included in the scope and then setting goals and sub-goals in line with the budget to control towards them, to achieve the desired outcome. Furthermore, the respondents stated that it is a matter of continuously following up the costs, keeping track of what has been produced and relating it to the expenditures, i.e., what proportion of the total cost has been consumed related to the construction progress. However, it was highlighted that it is important to identify changes in costs as early as possible, to understand the cause of change in order to take appropriate actions.

4.3.1 Cost Control Activities

In the interviews with site management, control of common costs, purchasing, contract variation management, and forecasting were cost control activities identified to be performed at the case company.

4.3.1.1 Control of Common Costs

Common costs is a cost category that is difficult to control according to the respondents. Commonly, the projects begin with a basic strategy for its larger common costs, namely scaffolding, building hoist, tower crane and telescopic loaders. Further, during the construction phase, the respondents described it as a matter of trying to keep track of the common costs, not so much about controlling them. Moreover, since there is no established process for disposing of common costs in the company, different housing projects dispose their common costs in different ways. For instance, it is not obvious how different types of common costs should be declared in the production costing which also makes it hard to follow-up and get an overview of the costs. Furthermore, one of the respondents described that *“common costs for me is somewhere a resource that improves the conditions for people to do their work [...] It is everything around for a job to be performed”* (Supervisor C2), which illustrates the challenge of common costs.

4.3.1.2 Purchasing

Purchasing is an essential cost control activity that includes both material and labour purchases. Commonly, the supervisors at the case company make the purchases themselves for their own elements, but larger purchases like facades, are often made by a project engineer. To be able to perform good procurements, it is essential to comprehend the client's contract, the tender request documentation, and the

construction documents, as well as comparing the budgeted cost with quote prices. According to the respondents, in the frame completion and fixtures stage, it is extra important to get the right product at the right number to the right place at the right time to have a good production flow. Thereof, to achieve this it is essential to have the right and sufficient information about the purchase. Furthermore, the respondents express that when it comes to purchasing of subcontractors, cost control entails analysing the budget, comprehending the scope of work set in the contract, and ensuring that the purchased subcontractor fulfils the scope of work specified in the construction document. Otherwise, the subcontractor is contracted at a price that does not encompass the complete scope of work, resulting in additional costs and contract variations.

Quantifying is closely connected to purchasing and has a direct impact on cost control since an incorrect quantity can be very expensive; either because it incurs costs for materials that is not required, or the skilled workers are unable to finish their work on time due to a shortage of material. The method of quantifying varies between the respondents, some uses pen and paper, others use the PDF drawing Bluebeam Revu, and a few masters to take-off quantities directly from the model. Regardless of method, the quantities in a construction project are quantified several times by different competence areas. For instance, the calculation department quantifies every single component of the project when making the production costing. The Estimator Manager emphasized that rather of re-quantifying everything, the site management could save time by using the quantities generated by the calculating department.

4.3.1.3 Contract Variation Management

When handling contract variations, it is critical to review the contract documents to evaluate whether it should be included in the scope of work or not, as well as to determine who should be responsible for the additional costs. The case company have no specific tool for managing contract variations costs, instead the site managers have their own Excel documents to keep track of respectively subcontractor's contract variations. This way of working with contract variations requires the site managers' involvement in all contract variations.

4.3.1.4 Forecasting

Forecasting is a basic cost control activity that takes place four times a year at the case company, where the site management reconcile the costs at resource level. In the periods in between the forecasts, the invoices are continuously reconciled when they arise and costs such as rental of machinery and labour are reviewed to ensure that money is not wasted unnecessarily. To determine the project's remaining cost, the site management evaluates all invoices, compares them to what has been completed, and then determines whether the estimated remaining cost is within budget. There is currently no tool or method for tracking what has been ordered, paid, or not paid. Every supervisor keep track in their own way, whether by writing it down on paper, saving order recognition, or walking out on site to check.

Cash flow is related to forecasts and is continuously analysed during the construction phase by the site management. Before the construction starts, the client and the contractor agree on a payment plan for the contractor's work. Beside this, the contractor and subcontractors establish a payment plan for the subcontractor's work. The payment plans together with other costs of for instance material, equipment, own skilled workers, etcetera, serve the foundation for the cash flow analysis. Simply, it is important to

understand for instance what an invoice from a subcontractor intend, to be able to keep track of the costs.

All in all, costs are controlled based on resource level and reconciled with the production costing, as the latter is divided into resource accounts. Therefore, the respondents underline that it is critical to allocate the invoices to the correct resource account to ensure that each resource adheres to the budget in order to be able to control the costs.

5 Result

This chapter begins by presenting the challenges and visions associated with cost control, then proceeds to the respondent's definition of BIM, challenges and benefits associated with BIM, and information and model requirements.

5.1 Challenges with Cost Control

The respondents identified several challenges with the current cost control in the construction phase. Assistant Site Manager B noted that the model was inadequate in their project, making it impossible to rely on it and difficult to get quantities directly from the model. Further, Project Engineer B stated that many architects create dumb lists, which means that the information is not linked between the various drawings, such as the layout drawing and the floor plan drawing, resulting in changes not being automatically updated and the architect having to manually update all information. The respondent has at several times found information that is contradictory in the construction documents which makes it hard to make good financial decision. Moreover, because the industry is human-centred, some architects are better at producing good construction documents than others, but it is up to Skanska to ensure that the documents are of the quality asked for (Project Manager A).

To obtain a standardized approach towards cost control within the organization, as well as to make the employees understand their position and relation to cost control is difficult, according to Project Manager C. Similarly, Project Manager B claimed that many employees follow-up rather than manage expenditures, and the respondent also mentioned the difficulty in finding time to control costs. Furthermore, Project Manager B believes that inexperienced employees find it difficult to enter the cost control field, but that there is potential in creating methods to help them do it more quickly. For instance, by releasing power and responsibilities to the employees in appropriate portions for them to grow into it. On the other hand, the respondent points out that:

It is important that the site manager keeps the total control, not someone else. Because the site manager is the one responsible, if the site manager does not have full control of the finances, I do not understand how he/she can make financial decisions. (Project Manager B)

The production costing was mentioned as a challenge by several respondents during the interviews. One issue with production costing is that it is not always apparent how many hours the calculation department has predicted for a specific activity, sometimes it is included in the material price making it difficult to quickly and easily state how many hours are required for a subcontractor, if one is to be purchased (Project Engineer B). Likewise, Supervisor C1 describes that all hours for the various resource activities are not included. The respondent further stated that they would not have won any tenders if the production costing was completely costumed for construction. The issue for the calculation department, according to Project Manager C, is that evaluating everything in detail at the tender stage is inefficient, therefore they must make a rough estimate at that time.

Another challenge with the production costing is that the calculation never gets better than the design and the design is not always complete when making the production costing (Supervisor C2). It also means that if you make purchases based on insufficient documents and an incorrect budget, it will exceed the budget. Furthermore, Site

Manager C experienced that there are some resource accounts that always exceed budget i.e., joint, plywood and timber, and explains this by stating that the experience value from the calculation department is not perfectly adequate, but that *“if you know that you have limited money, it also makes you a little cost-conscious”* (Site Manager C).

5.2 Visions with Cost Control

Numerous different perspectives existed on how cost control should be handled throughout the construction process. Assistant Site Manager B has a vision of that more people should be involved in the forecasting to make everyone more aware of cost control, not only the supervisors but also the carpenters to raise the awareness of how much things costs. Likewise, Project Manager A stated that the key is to develop a team that works together with the cost control. All decisions made in one day affect the economy and therefore *“it is important to be well-informed and dare to take the time to be well-informed”* (Project Manager A).

There are improvements to be made in how the site management handles contract variations, according to Site Manager A and Supervisor C2. Site Manager A points out that there is a lack of a tool where it is easy to send contract variation reports between subcontractors. Supervisor C2 wants to be able to track the invoices of the contract variations in a better way, making it easier to compare the additional costs. Both Site Manager C and Supervisor C2 have in previous projects used the software Power BI, which is an analysis tool that processes, analyses, and visualizes data, which they are promoting; *“it is quick, straightforward, and simple to filter information”* (Supervisor C2). That it is easy to filter information makes it quick to compare financial data of the project. The invoices can also be integrated directly into Power BI, allowing monitoring of the project's finances in real time. Because all costs are entered directly into the programme, you can simply track and monitor your finances more frequently with the tool. Supervisor C2 believes that this has a lot of value when it comes to controlling, as it is easy to follow-up costs. Power BI can also compare the received invoice with the calculation to ensure that the cost is allocated to the correct resource account and then it is easy to compare financial information, *“to play around with the information”* (Supervisor C2). Site Manager C thinks it is easier to do monthly reconciliations in Power BI, as it gives a visual information overview.

Forecasting should be better integrated into everyday work for the site management to consider it on a regular basis, implying that forecasting will be faster to perform, according to Project Manager A. Furthermore, the respondent wishes to move forward from just following-up to focus more on controlling; ensuring that decisions are well-considered and that the site management understand the financial implications.

Another vision is to obtain the information related to cost control from one place only, *“then I think it is easier to keep track of the finances because then you know exactly what should be there”* (Project Manager A). Supervisor C2 similarly stated that the information should be more easily accessible, seeing that today the information is available in several places, which makes it difficult to find the right information.

5.3 The Respondents' Definition of BIM

Most of the site management respondents, five out of eleven, define BIM as a combination of a document and model management tool (Project Engineer B; Site

Manager A; Site Manager B; Site Manager C; Supervisor C1). *“There are two different aids with BIM to ensure that what we build is right”* (Site Manager A): visualization and collision control through a model and document and issue management in a system. Furthermore, for Project Engineer B, BIM is a tool that collects all documents on a platform that is perspicuous; *“easy to see connections and effects, so to speak”*. Similarly, Site Manager C sees it as a follow-up system which, thanks to the traceability of information, can facilitate self-checks, etcetera. The latter two respondents also mention the model as an aid in BIM; *“I think it is one of the strongest complements we have today to understand construction documents like drawings”* (Project Engineer B). The respondent explains that the model is only a complement since it is not classified as a construction document.

Furthermore, three out of the eleven site management respondents defined BIM as something related to document management. Supervisor C2 defines *“BIM as a drawing management software, basically”*. Supervisor B declared having generally little experience of BIM but sees it as a digital document management tool like BIM 360. Neither is Project Manager A so familiar with BIM, but thinks it is a tool which for example facilitates inspections.

Digital document management is not what Assistant Site Manager B relates to BIM; the respondent refers to BIM more as a three-dimensional (3D) model. Project Manager B and C also define BIM as a 3D model, in addition with more dimensions of information connected to the geometry, such as time and costs. Likewise, several of the support function respondents pointed out that there are more information dimensions than a 3D model that can be handled with BIM; like the Operational Manager define BIM - it is an information structure that can be visualized in forms of a 3D model.

5.4 Challenges with BIM

For designers to understand how the site management uses their information is a challenge to overcome with BIM (Assistant Site Manager B; Project Engineer B). Even though Skanska provides the designers with a manual with requirements specification for model and information management, Skanska is not good at examining that it is followed (Design Manager; Project Manager C; Supervisor C2; Purchaser A). Instead, you will have to wage that battle when you find defective information concerns in the construction phase, according to Supervisor C2. In addition, despite that the requirements specification is good and the designers have put in some requested information, *“still, it is not specified in such a way that it is simple to work with the information”* (Project Engineer B). Supervisor C2 explains that many times, Skanska wants things that the designers do not know how to achieve, and as a result, they are unable to produce what is desired and the site management do not receive what they request. It is also a matter of when Skanska owns the model and when they will be able to start demanding it; *“it varies depending on the project, and unfortunately, in external projects it may not always feel worth fighting for stricter requirements”* than what the client had from the beginning (Project Engineer B).

Lack of trust in the model is another issue with BIM. *“Many colleagues have lost faith in models; when it first arrived, everyone was excited; but it has not worked that well, and you no longer dare to trust the information received”*, says Supervisor C2. Accordingly, one challenge of today is that there is too much information in the model which is often double and inserted in a wrong way, namely a dumb model (Project Engineer B). Furthermore, since the model is not a contract agreement, if you are

trusting it blindly, you may end yourself building something that was not requested (Assistant Site Manager B). Therefore, Supervisor B relies solely on the drawings, and the model is only used for visualization.

Not sharp enough information structure and difficulty in finding the right balance of information richness is another common challenge mentioned by the site managements. *“Skanska’s requirements specification for model and information is not quite in line with how we want to build [...] it is just like it lags a year behind all the time”* (Project Manager B). Besides, there must not be too much information in the model (Supervisor C1); *“too much information can be a bit overkill”*, in Supervisor B’s opinion. *“You have to decide how detailed the information should be, how accurate it should be or what is good enough”*, says Site Manager C. Similarly expresses the support function District Manager B that *“it is a challenge to know how detailed the model should be, so it is important to find out how much information is effective to include in the model and what information it should contain”*.

5.5 Benefits with BIM for Cost Control

Benefits of BIM include control of common costs, accurate purchases, streamlined contract variation management, and efficient forecasting, according to respondents' own experiences and beliefs in the power of BIM.

5.5.1 Control of Common Costs

A BIM tool, which connects model, schedule, and cost, can facilitate the control of common costs on site, thinks Project Manager C; *“you can playback how the construction should progress according to the schedule, and then you can visualize when it is optimal to assemble the scaffolding”*. Site Manager C also discusses that a model of the house together with a 3D site disposition plan could visualize things like scaffolding and tower crane. Similarly comments Site Manager B that the temporary equipment could have a geographical position, time, and cost connected to it, to easier see and control the common costs. Furthermore, to connect multiple dimensions of information, like the site disposition plan, model, costs, and schedule, things on site becomes more predictable and visual (Project Manager B). It may clearly visualize when there is a risk of collisions in the flow at the construction site (Project Manager B; Project Manager C). Accordingly, Project Manager B is fully convinced that it can facilitate the planning of logistics and thus also the cost control.

5.5.2 Accurate Purchases

BIM can facilitate the quantity take-off and purchasing (Assistant Site Manager B; Project Engineer B). With multiple dimensions of information coupled, Supervisor C2 considers it to be easier to check if the information is correct, and thus have more confidence in the information on which the purchases are based. Similarly says Project Engineer B that *“it would be easy to double-check objects in a model, and there is an economic gain in that”*. Hence materials will be *“purchased in the right quantity and to the right place”* and getting the material to the right place directly is important to avoid double handling and extra costs for the carry-in (Project Engineer B). Furthermore, purchases could be facilitated if production costing and model were linked to each other, namely, to be able to click on an object during the planning work and to see the cost; *“it would definitely save time, as it is not so damn easy to find in*

the production costing” (Assistant Site Manager B). Supervisor B also likes the idea of receiving information about an object in the model by clicking on it, but too much information, such as the item number, would not facilitate the purchasing.

5.5.3 Streamlined Contract Variation Management

Contract variation management can be facilitated by using BIM, like for instance the software BIM 360, which provides tools for document and issue management. The mentioned software has been used extensively in Project A to derive issues that may become contract variations and it has facilitated issue management between different subcontractors on site, so that the site management has not had to unnecessarily interfere (Site Manager B). Site Manager B continues to discuss about potential benefits with BIM; *“to derive the costs directly to who it concerns and send it from there, as well as bring the dialogue in there - that is good”*.

Similarly thinks Supervisor C2 that it would be easier for the site management if it were possible to add contract variation costs in the same way as issues is managed in BIM 360; thus, to be able to link contract variations to a geographical position in the building. In addition, Site Manager B believes that those data management software can make the *“detective work”* more efficient when managing contract variation issues; for instance, with the overlap function you can compare drawings, however you also need to read through descriptions. Thereto, BIM can facilitate the cost control in the construction phase for an inexperienced site management, as you may *“see what you have the right to charge extra work for, because you can quite easily miss it otherwise if you are not so experienced”* (Business Project Manager A). Accordingly, BIM facilitate comparison of as-planned i.e., the model, the construction documents, contracts, and tender request documents, with as-built on site.

5.5.4 Efficient Forecasting

With BIM the site managements can set performed against remaining work, to get percentages of where construction is in terms of progress linked to economy (Assistant Site Manager B; Operational Manager). With cash flow linked to schedule, could for example show how much subcontractors should invoice at a given time (District Manager B). Furthermore, the Digital Strategist believes that economic reconciliations could be more frequent and better with BIM; since information from schedule, calculation, and model more likely will be updated, compared to printed documents everywhere. Hence, the forecasting work is considered easier by getting a rapid picture of what has been completed and how much money is still available (Assistant Site Manager B; Site Manager C; Project Engineer B; Project Manager A).

To have the time schedule linked to the model would be beneficial in terms of a visual and automatic reconciliation. *“For most people it is easier to see in 3D models than it is with flat 2D drawings”*, believes Project Manager B. Consequently, it can visualize what has been built and what is left to be able to draw economic conclusions (Site Manager B). Assistant Site Manager B thinks that it would be useful to see in BIM which activities are completed, but it must not result in extra work for the site management. Moreover, Site Manager C finds it useful to be able to see consequences in the schedule if not completing activities on time.

Reconciliation can be facilitated by a software, like Power BI that links multidimensional information about costs, and in a simple way visualizes the

proportion of work paid for and done, as well as estimated remaining costs for each resource (Supervisor C2). Such visualizing tools are beneficial for forecasting, because it immediately provides exact data on how the project is progressing in comparison to the budget (Site Manager C).

5.6 Requirements on Information and Model to Facilitate Cost Control

Many of the respondents found it difficult to specify what requirements to have for information and model to facilitate cost control in the construction phase. Nevertheless, several respondents expressed like the Operational Manager that Skanska's requirements specification must be developed for both the information structure and model. Hence, filterable and linkable information, geographical position grouping, and specific item lettering are requested. It was also discussed what level of detail to require for the model.

5.6.1 Information Structure for Filtration and Linking

The structure of the information is important to get co-readable and filterable information (Digital Strategist). The Operational Manager emphasises that Skanska must think about how they want to work with designers, because it is not really on track as it is today. For example, the Design Manager explains that if Skanska does not get the architect to understand the importance of entering the correct information, thus work in the desired way, it is impossible to co-read and use the information.

Filterable information is also a request from the site management. Since *“if information is not divisible, it is terribly cumbersome”* (Project Engineer B). Project Manager A expresses that *“for the cost control, it is good to be able to filter at resource level”*. Hence, to really be able to filter the information, it is important that the budget for material and hours are separate in the calculation post.

Concerning filtration, it is requested that objects in the model are linked to information from for example the room specifications or production costing (Assistant Site Manager B). For cost control, Assistant Manager B points out that the model's details are not as vital; you do not have to see everything in detail, but it should be linked to the administrative procedures and so on. Similarly, Supervisor C1 emphasizes that even if product specifications were included in the model, the respondent still desires to check the room specifications.

Furthermore, Project Engineer B requires that the layout drawings for building components are linked to the model; because then if the architect modifies a wall in the model, the layout drawing will automatically be modified as well. Project Manager A wants information gathered for, for instance, windows; *“you should be able to take the window layout drawings and not need any other document”*.

5.6.2 Common Code Language

A common language has been discussed by several support functions; *“something that can link everything together, that can make it work in a project, but I have never really seen that we have succeeded 100%; it is quite difficult”*, says the Planning Specialist. Today Skanska's requirements specification is not so exact about how to name things in the model, for instance the names of the stairwells, but it is something that could be

added (Design Manager). Similarly says the Estimator Manager that “*the ideal language is missing to make everything work*”. A common code language may be needed to structure the information so that it for instance can be filterable in a digital tool, according to the Digital Strategist.

We must consider the whole design phase and not just the design, because if we create a code language that does not work for calculations and time scheduling, it is like we have driven into the ditch even before we have started. (Design Manager)

Accordingly, the language must be set at the start of the project, which is difficult in projects where someone else has started it before Skanska arrives (Design Manager). Similarly expresses the Digital Strategist that “*it is not even so that we can do everything from the beginning under our own direction and control*”.

In addition, to succeed in connecting and co-reading the multidimensional information, the Digital Strategist explains that Skanska must get rid of the organizational silos; “*calculation in its silo, and the planning in its silo, and production somewhere in its silo as well*”. All in all, the Digital Strategist considers that the technology is good enough to link information such as the schedule, the calculations, and the models; however, the involved disciplines and competence areas must agree on locations, activities, how to name things and so on.

Speaking of naming, objects must be named with specific letters to receive the right information about its features. It is important that it is made clear, in order to purchase the right products (Supervisor C1). Example of features that are required to be specified are whether windows must have safety glass, if inner walls shall be constructed with ordinary gypsum, fire gypsum, or wet room gypsum, etcetera (Assistant Site Manager B).

5.6.3 Grouping of Geographical Position

Geographical position connected to the building components is another common requirement requested from the site managements. Spaces of the building need to be defined in the model and connected to the correct building component (Supervisor C2). Whether the grouping should be per room, apartment, or floor level does not seem easy to define. Six respondents from all the three site managements express that quantity take-off per apartment should at least be possible in the housing production.

When building residential buildings, everything is based on apartments; thus, everything needs to be grouped by apartment, not per floor level or something like that. But imagine if you have small space blocks such as apartments, you can build it together into larger space blocks such as floor levels. (Site Manager A)

Although per apartment can be good to have as a division, it is usually more interesting per floor or stairwell for cost control, according to Site Manager C. All in all, site managements must be able to decide themselves the type of space from which they want to extract information (Supervisor C1; Project Engineer B). In addition to grouping of geographical position, the Digital Strategist considers that grouping of the building stage also is missing in the requirements specification, for Skanska to succeed with BIM.

5.6.4 Level of Detail in the Model

Requirements on information in the model are frequently brought up by the site managements. Project Manager C believes that it must not be too detailed model, but at the same time the site management is very good at managing and filtering information, so in that way the respondent sees no disadvantage with a lot of information in the model. Site Manager C thinks that Skanska must find a level that is good enough; everything does not have to be modelled in the smallest detail, but for doors, for instance, material and seizure should be shown quite detailed.

More examples of information asked for in the frame completion and fixtures stage, are requests about the material structure of the inner walls, namely type and number of gypsum and studs, as well as studs' centre-to-centre distance (Project Engineer B; Site Manager A; Supervisor C1). Supervisor C2 does not require the studs to be drawn in the model but believes that the model could be linked to a recipe that calculates the number of studs and gypsum per surface inner wall, allowing for direct and accurate quantity take-off in the model.

In addition, two respondents discuss about whether moulding should be drawn in the model. Assistant Site Manager B expresses that you might want to see the mouldings in the model, but they do not have to be drawn in much detail; instead, the information about the mouldings can be linked in the model to the room specification. Supervisor B initially does not think mouldings should be visualized in the model, but then points out that collision mouldings might be something you want to see as it is always a question of what level they should be.

6 Discussion and Analysis

This chapter interpret and explain the meaning of the results within the thesis. The analysis and discussion are carried out by comparing the interview results with the theoretical background.

6.1 Current Challenges and Visions with Cost Control

This section addresses research question two: *What are the current challenges and visions with cost control in the housing production?*

6.1.1 Deficient Information Exchange

The findings of the thesis indicate that there is a challenge of information exchange in construction projects. A possible explanation could be that there are many disciplines and areas of competence, and thus many people involved in a project, which have an impact on how well the information exchange works. An aspect of non-functioning information exchange, according to the results and the literature (Smith, 2016), is dumb information or models, which makes it difficult for the site management to trust the information since it is inadequate and sometimes contradictory. A probable outcome is that the site management may spend a significant amount of time looking for information for control and decision-making.

Another challenge described in the results are that the information needed for cost control is scattered across numerous locations, making it difficult and time consuming to obtain for the site management. This finding has not previously been described in the literature, but based on the results, the vision is that the information can be more easily accessible, and possibly obtained from a single location. Further, the findings also indicate that it is difficult for the site management to find time to control costs especially for inexperienced employees. Therefore, it is important to find tools and work processes that make it easier to obtain the information needed for cost control, not least for inexperienced employees.

6.1.2 Defective Division of Production Costing

Another issue mentioned in the result that might affect the information exchange is defective production costing due to incomplete design, indicating that the cost control is based on inaccurate data. Yet, other support functions information for production costing is also critical, as is the presence of a dialogue between the site management and the calculation department. Hence, as mentioned in the literature (Project Management Institute, 2017), to regularly update the calculation or budget becomes vital to create the right conditions for precise cost control, namely, to provide accurate data.

One interesting finding, that is related to the challenge of retrieving the right information, is that the site management finds it is difficult to control costs using the production costing. Hence, the production costing and its resources must be divided in coherence with how the site management works and controls in the construction phase. This since the structure of the production costing is of great importance for the cost control as it can facilitate reconciliation of specific stages of the production as well as aid forecasting during the project.

In the empirical findings, common costs were indicated as an example of a cost category that is poorly divided in the production costing, which seems to make it difficult to follow-up and control the costs. Drawing on the literature (Vigneault et al., 2020), it is important to have a proper budget that is easy to understand and assimilate, as it is fundamental for controlling costs. It can therefore be assumed that the information in the production costing might be hard to assimilate since it is not presented in a visually pleasing way. As a result, it probably requires more experience to absorb the production costing and understand the implications. However, another discovery clarifies why the quality of the calculations is as they are; it would be difficult to win tenders if the calculation was completely costumed for the construction phase. This can be seen as a balancing act, when the tender calculation cannot be too comprehensive or detailed in the tender phase, firstly there is too many uncertainties at the tender stage, secondly it would take too long time and be costly for the design department to put down a lot of effort on details, and thirdly the tender calculation must be done in such a way that the project can be won. At the same time, there may be flaws that impact or appear during the construction phase, such as too few hours planned on an activity that may have been missed to be revised in the production costing, making it difficult to stay within budget.

6.1.3 Support Functions' Unawareness

Both Vigneault et al. (2020) and the results emphasized that cost control is dependent on reliable and accurate information in order to control and take well informed decisions. However, consistent with the literature, this research found that support functions appear to be unaware of their impact on cost control during the construction phase. Most of the support functions are oblivious of the connection between the information they generate, and the cost control performed by the site management. As most of the data generated by the support functions is used for cost control; it is important that the support functions understand that they generate information that will aid the site management in making well-informed decisions and to avoid sub-optimization of the construction outcomes.

6.1.4 Involvement of the Supervisors

A vision mentioned in the results by District B is to get more people in the construction phase involved in the cost control, particularly the supervisors. This is already the case in District A, but in District B, the site managers retain the majority of cost control. Since the site managers traditionally have the financial responsibility at the construction site, it can be assumed to be hard for site managers to let go of the control in order to give the supervisors more responsibility of their resources and forecasts of them. At the same time, all decisions made every day affects the project economy and therefore it is important that the supervisors, who make a lot of decisions related to costs, are well versed in the project economy to understand the economic implications.

6.1.5 Compare Financial Data

To easily compare financial data is another vision mentioned in the results. The site management respondents expressed that it should be easy to track and control costs by being able to visually compare budget with actual costs for different resources. It could also benefit the site management in comparing as-planned with as-built progress during the construction phase to discover project differences, as indicated by Rohani et al. (2013). With this approach, the site management may acquire information more easily

and quickly to make decisions. Nevertheless, the financial data does not necessarily need to be visualized in a model, a graph can also be visually supportive. Furthermore, with filterable information it might be possible to compare additional costs and contract variations in a way that could make it easier to control and steer the costs.

6.2 Requirements on Information and Model for Cost Control

This section addresses research question three: *What requirements are requested on information and model for supporting cost control in the housing production?*

It is interesting to note that many of the site management respondents had difficulty to directly articulate requirements for information and model for facilitating cost control. A possible explanation for this might be that the site managements accept the fragmented information structure of today and have learnt to deal with the shortcomings. Another possible explanation for this is that there may be insufficient time for reflection and experience input to the upstream support functions, as the site management is attempting to complete their daily activities and maintain production control. This claim is backed by the authors' impression of information dissemination in the case organization in Figure 2, which shows a lack of information exchange from the site management to the design department.

6.2.1 Explicate the Required Information Use

As a result of insufficient input from the site management, it is no surprise that the design department, as previously discussed, does not grasp the information necessary for cost control within the construction phase. Because it is challenging for the design department to figure out what can be done differently in the design phase so that the site management can acquire reliable information needed for the cost control. To provide the site management with trustworthy data, the design department must be able to tell designers and architects as to what the information will be used and to what level of development and structure it should be delivered at various stages of the design phase. These findings were also reported by BIMForum (2021) and Smith (2016). In addition, it can also be suggested that other support functions than the design department adopt to those requirements for information as they also provide the site management with documents required for cost control, which also need to be trustworthy.

6.2.2 BIM Guides – Requirements Specification

BIM guides are identified to aid the establishment of information and model requirements (BIMForum, 2021; Sacks et al., 2018). Like a BIM guide, the case organization has a guide with requirements specification for information and model. However, some respondents expressed that it has some shortcomings. One of the more interesting findings is lack of quality in the requirements specification; it is not always clear what information is requested, and thus it is not always easy to understand how to structure the information to provide it in alignment with downstream requests. However, specifying needs may not be so easy; it can take time to develop and require a constant interaction with all stakeholders to arrive at a common technical language in the projects.

Furthermore, it is argued by a respondent that the requirements on the information structure is described for only ideal conditions. Ideal conditions can be seen as when Skanska from the very beginning of the project can put demands on all stakeholders' information. However, it may be a bit difficult to do so, as it is usually the client who put the demand from the beginning, especially in external projects. But regardless of the clients' initiatives, a previous study by Sacks et al. (2018) has noted the importance of contractors to take the lead in the BIM process if the benefits of BIM are to be realized. Even if it means the contractor will have to design a new model to fit the desired information structure, which can be costly especially for smaller projects with less financial resources and smaller margins.

Another weak point identified is that Skanska is bad at inspecting that their requirements are followed, which leads to defective information concerns later in the construction process, which can take a lot of effort and time from the site management in the construction phase, compared to if it was taken care of right away during the design phase.

6.2.3 Structure and Level of Development

Both empirical and theoretical evidence show that it is critical to provide requirements for information structuring in the BIM guides (bSi, 2014; Keenlside, 2015; Sacks et al., 2018). Several respondents request information to be structured in a way that makes financial data filterable and easy to find, to facilitate the cost control. Accordingly, to have standards of a common code language, namely a common technical language, appears to be useful for the information exchange amongst stakeholders, because multidimensional information may be linked and thus co-readable. On the other hand, Monteiro & Poças Martins (2013) have underlined the industry's fragmentation, as there are multiple standards for object classification systems which can make communication noisy. Also, in Sweden, where there is no open standard, certain stakeholders may be hesitant to adopt a particular classification system since it might be too costly, even if it is requested in a BIM guide.

In line with what earlier studies have highlighted as essential for structuring building information (Ljung and Malik, 2022; Monteiro and Poças Martin, 2013; Weisheng et al., 2019), findings of this study suggest grouping model parts based on their properties, such as type of component and geographical location, as well as grouping of related building stages. Furthermore, the model elements should be named according to a predetermined naming scheme. Although, consistency throughout the project is more vital than the name itself. All in all, it is beneficial not only for achieving a common technical language which is co-readable, but also for comprehending the specific properties of the objects to make efficient forecasts and correct purchases etcetera. Yet, it requires a lot of time and effort from the beginning to build a consistent technical language and code structure. But, information linkage and exchange can be done more automatically in the future with a well-thought-out and executed BIM guide of the information structure. Even if some project-specific concerns may necessitate human data processing, the housing production is still very standardized.

Considering the findings of dumb models, it is vital to recognize that there is a lack of faith in the models, which causes them to fall short of their potential. For instance, the potential of making accurate purchases with the aid of a 'smart' model. By linking construction documents and models, confidence in the models may be increased because their information can be compared easily. However, if the model is not legally

binding and marked like a construction document, it will most likely remain dumb. This aligns with the ongoing work in Sweden to develop a framework for making the model legally binding (Lindström, 2021).

Nevertheless, models should contain a specified level of development (LOD), which should be set in the requirements specification. This because LOD can be seen as a common language for all stakeholders to better comprehend the information in BIM, and to get reliable information when controlling costs in the construction phase (Sacks et al., 2018; Weisheng et al., 2019). LOD 400 can be seen as a sufficient level of development in the frame completion and fixtures phase as it includes full information specification about the objects, such as size, shape, location, fixtures, and so on. Accordingly, the results indicate that the site managements request for quite detailed information of components in the frame completion and fixtures stage, like doors, inner walls, and mouldings. However, the components do not need to be modelled in such a detail, it is enough that they are connected to other information channels, for instance room specifications and layout drawings. As a matter of fact, it is crucial not to focus solely on the model, as it is not the only source of information. To ensure consistency in the exchange of information, all sources of information should be structured in the same way (Monteiro & Poças Martins, 2013). Hence, the production costing, the time schedule, construction documents, such as layout drawings, and other documents can all be thought of as information channels that must all adhere to the same information structure. However, the LOD could be requested in different levels depending on the BIM uses and the different information channels' required information content.

6.3 Benefits with BIM for Cost Control

This section addresses research question one: *How can BIM facilitate the cost control in the construction phase?*

The empirical findings of BIM's various cost control benefits are mainly in line with what the literature states (Monteiro & Poças Martins, 2013; Rohani et al., 2013; Sacks et al., 2018; Vigneault et al., 2020). Both the literature and the results find benefits with BIM for forecasting, purchasing, managing of contract variations, and controlling of common costs. Vigneault et al. (2020) also indicate the advantages of cash flow analysis, which the site management did not specify directly as a benefit with BIM. It is likely difficult for the site management to predict how cash flow analysis can be facilitated by the use of BIM, as they did not seem to think of cash flow analysis as an own activity but rather as a part of the forecasting procedures and the daily monitoring of costs and income.

6.3.1 Control of Common Costs

There is little information in the literature about how BIM can support the control of common costs, other than that the common costs are difficult to estimate and foresee, but visualization of common costs in a model could help to make the costs more predictable (Disney & Fahlstedt, 2021; Sacks et al., 2018). The empirical findings go in line, particularly that visualization of the construction site may facilitate cost control as it gives an understanding of the required temporary equipment and other common costs. Thus, visualization could lead to improved control that allows for more proactive management of these costs. However, since a lot of the temporary equipment is difficult to place in a model, there are other ways to utilize BIM than through a model, which

may be better for controlling common costs. The common costs could be visualized in graphs that are connected to information related to it, such as invoices, estimated remaining costs, and the time schedule. With filterable information, different categories of common costs can be selected to be displayed, making it easier for the site management to compare and analyse the costs. However, as previously indicated as a challenge at Skanska, the common costs in the production costing are poorly structured, making information take-off tricky.

6.3.2 Accurate Purchases

Consistent with the literature (Monteiro & Poças Martins, 2013; Sacks et al., 2018; Vigneault et al., 2020), the site management suggested that BIM could facilitate purchasing and quantity take-off. Based on the results where self-control is emphasized, it appears critical to be able to visualize the quantities extracted from the model to ensure that it is the correct quantities. In addition, the findings show that the site management currently need to gather the necessary information for the purchases by themselves; namely by seeking through different sources of information such as model, contracts, administrative regulations, layout drawings, room specifications, etcetera, which is inefficient and time consuming. Nevertheless, BIM might ease the assessment of whether the information is correct for the purchase or not by connecting multidimensional information.

Another interesting finding is that the same type of quantities is quantified several times during a project. The empirical findings suggest that the site management could use the quantities that the calculation department provides in the production costing, which the site management are not keen on. One reason to why the site management might be hesitant to use quantities only from the production costing can be that they are just figures in a calculation sheet, making it impossible to verify that they are the correct. Another reason can be that the quantities might have been changed after the production costing was made. However, like various studies in the literature have shown, visualization appears to be a significant benefit of BIM when cost-related information is linked to the model (Monteiro & Poças Martins, 2013; Rohani et al., 2013; Sacks et al., 2018; Vigneault et al., 2020). With BIM, it is likely that site managements will be able to visualize the calculation departments quantities in the model, making it easier for them to trust and check the numbers. Accordingly, with the use of BIM and the calculation department's quantities, the number of quantity take-offs could be reduced in the construction phase, and the process would become more efficient. However, based on the results, the site management may also be hesitant to use the quantities since quantity take-off is an approach used by the site management to learn about the project; thus, it may be necessary for them to conduct their own quantity take-off.

6.3.3 Streamlined Contract Variation Management

In line with control of common cost, there are limited research on how BIM can support the contract variation management. Nevertheless, Vigneault et al. (2020) stated that BIM might make contract variation management easier and faster to assess. The results of this thesis seem to be consistent with Vigneault et al. (2020), seeing that some respondents expressed the advantages of BIM as a powerful tool for issue management as it enables tracking and comparison of contract variations. Thus, BIM could save time from the site management, who do not even need to be involved if there is an issue that can be solved between the concerned stakeholders. Furthermore, the authors also see

benefits of using BIM in the contract variation management by enabling filtering, tracking, and visual comparison of information like the subcontractors' contract price and contract variations, in graphs for instance.

6.3.4 Efficient Forecasting

As mentioned by Vigneault et al. (2020) and Mitchell (2012), utilizing BIM can lead to more precise and efficient forecasts with a quick assessment that may allow more frequent control and reconciliation. The results support the idea of efficient forecasting with BIM, as well as the benefit of visualizing and filtering information to more easily reconcile progress related to the economy. The findings show that cost information could be filterable and thus more manageable if the information is grouped in an efficient way. Filterable information may also free up time for the site management as cost information easier can be found, visualized, and compared. More time could instead be spent on proactive cost control, ensuring that the project stays on track to meet its financial objectives. However, dividing the production costing in accordance with the requirements from the site management do also take time and effort, but that is rather a responsibility of the calculation department than of the site management.

Further, the results show that the respondents frequently mentioned reactive reconciliation and follow-up when it comes to forecasting. This appears to be a critical activity on which the forecasts are based. It is interesting since controlling rather is about forecasting, namely predicting final costs, than about follow-up. But if the reconciliation goes more quickly, there is a potential benefit of using BIM since the site management could get more time to control the costs and forecast, and to work more proactively. The results also show that site management recognize a possible benefit of using BIM when it comes to monitoring cash flow and invoices more quickly by visualizing construction progress and comparing it to invoices and payment plans. Consequently, the payment plans need to be performance based in order to be able to reconcile the payments with the construction progress. Performance payment plans could also make cash flow and invoice reconciliation more reliable because it can be based on precise data rather than just the site management's gut impression.

Overall, there are multiple information sources for cost control, which could benefit of being connected and co-readable, to achieve a more proactive cost control. Perhaps BIM and cost control might even facilitate to such an extent that it can anticipate how the project will be executed to achieve the greatest outcomes.

6.4 General Benefits with BIM

All in all, a majority of the respondents saw mainly benefits with BIM directly connected to a model. Even if this thesis found that respondents' perceptions of BIM include management of information in both documents and models, which is consistent with the literature (Brohn, 2021; Lester, 2017; Monteiro & Poças Martins, 2013; Succar, 2009). The fact that they put so much emphasis on the model could be due to their previous experiences of dumb models with inaccurate data. Nonetheless, the site management respondents recognized a lot of potential in the model for enabling BIM uses like cost control throughout the construction phase, provided that they can trust the data.

A general benefit of BIM, according to the findings of this study, is that inexperienced production personnel can more easily get into the project since they can visualize what

will be built and have all the necessary information easily accessible. It appears that understanding a model is easier than understanding a drawing with related documents, since the latter seems to require more experience to understand and get an overview of the multidimensional information. This suggests that BIM could help new and/or inexperienced site management employees get into the project and work more quickly. In addition, with easy access and overview of the multidimensional information in the project, the authors believe that BIM has the potential to reduce the organization's vulnerability to unforeseen events such as pandemics, illness, parental leave, and other factors that can result in understaffed projects.

Finally, the findings indicate that the use of BIM for cost control could most likely free up time for the site management. As a matter of fact, it appears that freeing up time is the most substantial advantage, as it allows site management to focus and put more time on other tasks such as planning and being proactive. Hence, the psychosocial work environment might be improved for the site management as it can facilitate the control of the production and economy.

6.5 Limitations and Future Research Recommendations

The research aims and objectives of the thesis remained consistent throughout the study because they were carefully formulated at the beginning, implying that a common thread was maintained. However, all the delimitations were not determined at the start, making the interviews a little too broad at first. Notwithstanding, the broad scope was necessary at the beginning to understand how the case organization controls costs, in order to grasp the challenges and visions, as well as acquire some early indicators of BIM benefits, to gradually set the direction of the study.

The entire sample size of the interviews in this thesis is considered sufficient, and the interviews with support functions served as a suitable foundation. Nevertheless, because there were few interviews with the site management in District A, the sample size of the site management interviews was modest. As a result, rather than representing both housing districts in the region as intended, the result primarily depicts District B.

Despite the fact that software user interface and implementation method difficulties were frequently mentioned by respondents, these sorts of BIM requirements were not addressed because they were outside the scope of this thesis. However, these are some critical concerns to consider to fully realize the benefits of BIM, not least in terms of cost control and in the construction phase. Hence, requirements on BIM software user interface and BIM implementation would be fruitful for future research to identify.

There could be some possible bias in the literature about cost control, since there are different names for the same thing in different countries. Furthermore, within construction and cost control, there are various names for roles that have the same meaning. As a result, adapting and relating global literature to the Swedish setting, and vice versa, proved challenging. Nonetheless, because the research within the thesis topic in Sweden is too limited, it was necessary to include earlier research from around the world.

There is also limited previous research in common costs and contract variation management connected to BIM benefits, making the analysis and discussion of the findings one-sided. Furthermore, while there is a lot of literature on the requirements of BIM, it is fairly general and does not go into cost control and its activities to such an

extent. However, connections between model and information requirements and cost control are identified in the results and the discussion. Still, as the requirements for model and information discussed are quite general, it can be seen as a limitation. But it may be argued that the information and requirements for cost control become quite extensive and general because financial data permeates the entire business. As a result, assuming the general requirements for information and model are fulfilled, it could be applied to areas other than cost control within production control. Hence, future research may benefit from the identified requirements on information structure, and fill the gap with requirements on specific data for other BIM uses. For instance, logistics, which is closely related to cost control and requires financial data on purchases, quantities, and transports, as well as scheduling information for construction work and deliveries. Regarding level of development (LOD), there is limited empirical results and previous research about what LOD level is required for other information channels than the model. Hence, this is something which could be a topic for future research.

Lastly, the findings are largely generalizable and can likely be extended to companies operating in similar contexts. However, some parts of the results are very specific for the case organization and will most likely be useful mainly to Skanska.

7 Recommendations to the Case Company

First of all, Skanska must improve its requirements specification for information and model to acquire trustworthy data for cost control during the construction phase. It must be expanded, with guidelines established not only for designers, prefabrication suppliers, and installers, but also for the case company's own support functions. Accordingly, the information from the design department, the calculation department, the planning specialists, and the category purchasers should have distinct and strict requirements, as it will be used by the site management for cost control during the construction phase. The 'why' must be clearly described in the requirements specification to ensure that the stakeholders concerned comply with the requirements; namely, for them to understand for what purpose the information will be utilized. It may also be necessary to explain it directly during a project start-up meeting to emphasize the importance of all stakeholders' information and interaction.

Thereto, it is recommended that site management is included in the early stages of the building process to communicate first-hand feedback and their demands for information and model; so that difficulties are highlighted early on, and deficient information does not become a problem in the construction phase. Consequently, in accordance with the site managements demands, the requirements specification must state how information is to be structured. Thus, information and model parts must be structured in such way that the site management themselves can easily filter and take-off specifically required information for the cost control activities. For example, to ease the assimilation of information connected to cost control activities by visualizing accurate cost related information. To facilitate the cost control, and more specifically the purchases, the recommendation is to link construction documents and information necessary to the model. Thus, all required information can be found in one location, freeing up time, and ensuring accurate information take-off.

Another proposal is to establish a common technical language to use throughout the project to simplify information exchange between all project stakeholders, allowing the information to be co-read and filtered based on the information requested for cost control. For example, setting a code structure in accordance with the classifications systems in Sweden of today. Hence, by organizing the building information in groups based on properties of the building objects and associated building stages, and other essential data for cost control, like the time schedule, the information can be linked and thus easier to manage. It is also recommended to establish a consistent naming scheme throughout the projects.

Speaking of the structuring of financial data, the production costing must be more specifically divided according to how the production will be conducted to be able to control costs more accurately and benefit more from BIM. Therefore, it is recommended that the production costing have a similar structure as the time schedule with its activities and correlating geographical position, to optimize the project outcomes. In addition, the case company must develop a standardized division on common costs in the production costing for all housing projects. Allowing for comparison and analysis of different common costs categories in order to steer them in the appropriate direction to meet the project objectives.

The authors recommend linking the production costing and the model so that the quantities produced by the calculation department can be visualized in the model. It can facilitate information take-off on site by using the already extracted information, at the

same time as the site management gain a better knowledge of the project. In addition, it should also be possible to visualize the financial data in graphs, for faster and easier follow-up and reconciliation, as well as to ease the estimation of the final cost.

It is crucial that all stakeholders not only adhere to the same information structure, but also that they follow a set level of development (LOD) of the information and model. For the model in the construction phase, it is recommended to use LOD 400, because it includes information about for example object's location and fixtures. Accordingly, LOD 400 is essential in order to be able to divide objects and spaces of the building into locations of at least per apartment. For other information channels than the model, it is important to establish a standard level of LOD for each channel, as it serves as a common language for all stakeholders, to better comprehend what information to deliver at the various stages of the construction phase. Furthermore, windows and inner walls, for example, are recommended in the frame completion and fixtures stage to have their properties and names clearly shown, like what type of glass respectively gypsum they consist of, to easy find the correct data.

In addition, Skanska could include demands in the requirements specifications for the considered stakeholders to perform self-controls to ensure that the information and model requirements are met. Along with the suggestion that Skanska create better procedures for following up on whether the requirements specification is followed by all stakeholders involved. Also, that Skanska invest in one or more people in the early stages who understand what requirements to set on information and model for cost control and other production control activities, to obtain information with the development and structure required. Another suggestion is that Skanska explore declaring the model legitimate prior to the construction documents, for the site management to take-off trustworthy information for cost control from the model. All in all, it necessitates that the case company take the lead in the BIM process and put in some extra resources like mentioned above, to reap the benefits of BIM for cost control; as well as developing the models to fit with the requirements in the construction phase, not least in the projects when the client has too weak demands.

A last recommendation to the case company is to continue using BIM for issue management and derivation of contract variations, and to develop it further by enabling management of invoices between subcontractors as well as between Skanska and subcontractors.

8 Conclusion

This thesis aimed to identify the benefits of using BIM for cost control, and to determine the requirements that need to be imposed on BIM to support cost control in the construction phase. The key findings from the thesis are as follows:

How can BIM facilitate the cost control in the construction phase?

BIM can facilitate with an increased efficiency and accuracy in the cost control activities forecasting, purchasing, contract variation management, and control of common costs, during the construction phase. This since BIM can be used as a decision-making platform that ease information take-off, as in filtration, comparison, and visualization of multidimensional information, and thus leads to proactive cost control.

What are the current challenges and visions with cost control in the housing production?

Deficient information exchange and scattered information, the support functions unawareness of their impact on cost control, and defective division of production costing are identified as current challenges. While identified visions of cost control in the housing production are involvement of more employees in cost control within the site management, and to easily enable comparison of the financial data.

What requirements are requested on information and model for supporting cost control in the housing production?

Required structure and level of development (LOD) for models and information should be included in BIM guides, which should be addressed to all stakeholders to comply. More specific, the information and model parts should be structured based on the properties of the building objects and associated building stages, as well as named according to a predetermined standard. In addition, in the frame completion and fixtures stage, the model and information should adhere to a set LOD standard. Specifically, the model should adhere to LOD 400, to take-off reliable and detailed information necessary for cost control. While other information channels of cost control related data can be of the same LOD level or lower, depending on its requested information content.

Altogether, the findings of this research provide insights on how BIM can facilitate contractors to obtain a structured overview of information related to cost control in the housing production. In addition, the findings suggest requirements to demand on information and model to accomplish a common technical language between stakeholders to optimize the outcomes for each entire construction project.

This thesis contributes to the body of knowledge for BIM utilization in the construction phase as it defines what site managers in the housing production are searching for in terms of information for more efficient cost control. Accordingly, the results add knowledge to fill the gap. In addition, it lays the foundation for future research in this area, including for example BIM software's user interface, level of LOD for all information channels, and implementation of BIM among the stakeholders within the housing production. The findings can facilitate contractors in developing strategic work and plans for new and innovative ways of working by using BIM for cost control in the construction phase.

Finally, by establishing requirements on structure and level of development for information and model, BIM can facilitate site management with the cost control during the construction phase by freeing up time, as it is expected to result in a more efficient information take-off. As a result, BIM can contribute to proactive cost control, making

the cost control activities easier to perform. This in turn can contribute to social and economic sustainability by improving the psychosocial work environment and project cost performance.

9 References

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