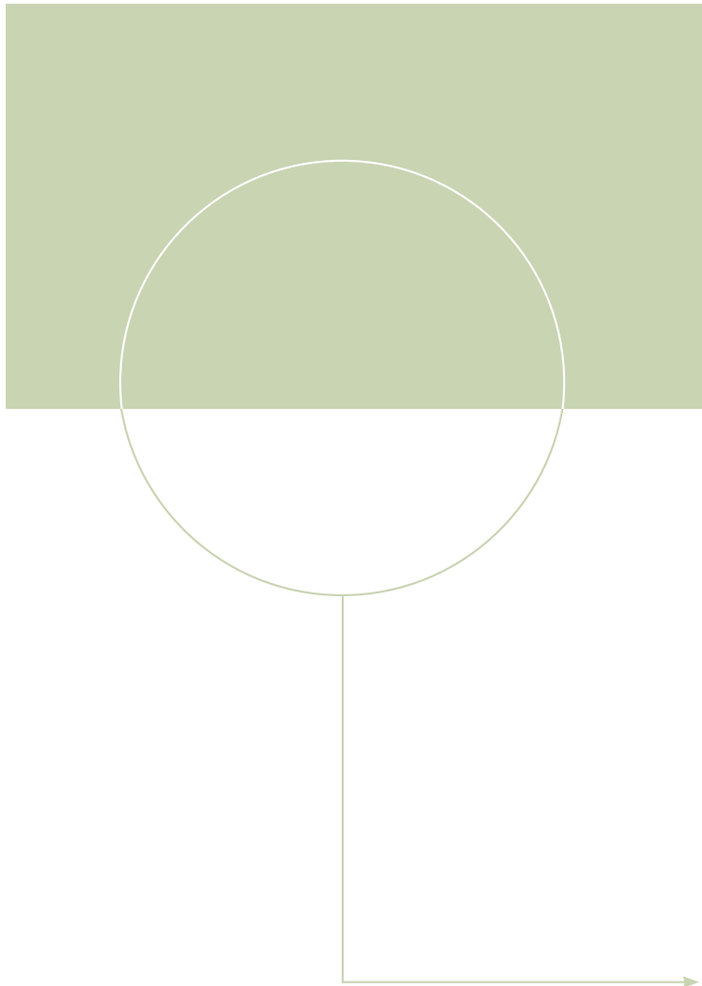


Master's thesis

2021

Saeid Morovvati

NTNU
Norwegian University of
Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

Saeid Morovvati

Model-based cost estimation for infrastructure projects: a case study

June 2021

NTNU
Norwegian University of
Science and Technology

NTNU
Norwegian University of
Science and Technology

NTNU

Norwegian University of
Science and Technology

Model-based cost estimation for infrastructure projects: a case study

Saeid Morovvati

Project Management
Submission date: June 2021
Supervisor: Ola Lædre
Co-supervisor: David Fürstenberg

Norwegian University of Science and Technology
Department of Civil and Environmental Engineering

Abstract

Digitalization has been compared to the industrial revolution in several cases (Degryse, 2016). Architecture, Engineering, and Construction (AEC) industry is one of the largest industries affected by digitalization. Digital transformation is the result of accepting and adopting digitalization that refers to changes at different levels (Parviainen et al., 2017).

Along with other components, people, process, and technology are three main cornerstones in digital transformation. Building information modeling (BIM) as a digital representation of the project is central for the technology cornerstone. Cost estimation is a crucial process in all projects. The necessity of accurate cost estimation is undeniable (Elbeltagi et al., 2014, Ma et al., 2013). However, traditional cost estimation is time-consuming, error-prone, and not efficient. Model-based cost estimation instead of traditional cost estimation can result in higher efficiency and fewer errors resulted. Several studies have focused on model-based cost estimation for buildings, but the research on Model-based cost estimation in infrastructure projects is limited (Shou et al., 2015).

This study investigates Model-based cost estimation in a Norwegian road project through semi-structured, open-ended interviews and a document study. The case was the first Norwegian infrastructure project with Integrated Project Delivery (IPD) in Norway. In this study, we used the definition of Messner et al. (2019) for BIM-used cost estimation. They defined it as "a process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimation throughout the lifecycle of a project". This study investigated cost estimation concerning the quantity takeoff and not the pricing of units. A semi-automated cost estimation in the project was identified. This study investigated model-based cost estimation concerning people, process, and technology. This research identified challenges hindering a completely automated cost estimation.

The collected data were categorized and analyzed after three cornerstones for digital transformation: people, process, and technology. This study finds current practices time-consuming, error-prone, and inefficient. However, model-based cost estimation can result in higher efficiency and fewer errors. Concerning people, relevant training and mindset identified crucial elements. Concerning process, increased workload due to integrated project delivery, time pressure, and problems with attaching correct classification codes to objects in BIM resulted in incomplete models hindering automated cost estimation. The identified hinders concerning technology were not worth mentioning. Suggested improvements include relevant training and alignment between today's object-oriented BIM and the process-oriented standard specification of work for infrastructure projects.

Sammendrag

Digitalisering har ved flere anledninger blitt sammenliknet med den industrielle revolusjonen (Degryse, 2016). Bygg, Anlegg og Eiendom (BAE) er en av de største næringene som er berørt av digitalisering. Digital transformasjon er resultatet av å akseptere og vedta digitalisering som refererer til endringer på forskjellige nivåer (Parviainen et al., 2017). Sammen med andre elementer er mennesker, prosess, og teknologi de tre hjørnesteinene i digital transformasjon. Building information modeling (BIM) er sentralt for en digital representasjon av prosjektet .

Kostnadsestimering er en avgjørende prosess i alle prosjekter. Nødvendigheten av nøyaktig kostnadsestimering er ubestridelig (Elbeltagi et al., 2014, Ma et al., 2013). Tradisjonell kostnadsestimering er imidlertid tidkrevende, utsatt for feil og ineffektiv. Modellbasert kostnadsestimering i stedet for tradisjonell kostnadsestimering kan føre til høyere effektivitet og færre feil. Flere studier har fokusert på modellbasert kostnadsestimering for bygninger, men forskningen på modellbasert kostnadsestimering i infrastrukturprosjekter er begrenset (Shou et al., 2015).

Denne studien undersøker modellbasert kostnadsestimering i et norsk veiprosjekt gjennom semi-strukturerte åpne intervjuer og dokumentanalyse. Det undersøkte veiprosjektet var det første norske med Integrated Project Delivery (IPD). I denne studien bruker vi definisjonen til Messner et al. (2019)for BIM-basert kostnadsestimering. De definerte det som "en prosess der BIM kan brukes til å hjelpe til med generering av nøyaktige mengdeuttak og kostnadsestimering gjennom hele prosjektets livssyklus".

Denne studien undersøker kostnadsestimering som mengdeuttak og ikke prising av enheter. En semi-automatisert kostnadsestimering i prosjektet ble identifisert. Denne studien undersøker modellbasert kostnadsestimering ved å se på mennesker, prosess og teknologi. Studien har identifisert utfordringer som hindrer en fullstendig automatisert kostnadsestimering.

De innsamlede dataene ble kategorisert og analysert ut fra de tre hjørnesteinene for digital transformasjon; mennesker, prosess og teknologi. Denne studien finner gjeldende praksis tidkrevende, feilutsatt og ineffektiv. Modellbasert kostnadsestimering kan imidlertid føre til høyere effektivitet og færre feil.

Når det gjelder mennesker er avgjørende elementer relevant opplæring og tankesett. Når det gjelder prosess økte arbeidsbelastningen på grunn av integrert prosjektleveranse (IPD), tidspress og problemer med å finne riktige klassifiseringskoder til objekter i BIM. Prosessen resulterte i ufullstendige modeller som hindret automatisk kostnadsestimering. De identifiserte utfordringene angående teknologi er ikke verdt å nevne. Foreslåtte forbedringer inkluderer relevant opplæring, justering av dagens objektorienterte BIM og endring av den prosessorienterte standardspesifikasjonen for arbeid for infrastrukturprosjekter.

Preface

Topic of this master thesis is selected based on the author's interest in BIM and cost estimation and suggestion of the supervisor, Professor Ola Lædre at the Department of Civil and Environmental Engineering at Norwegian University of Science and Technology (NTNU). The current work is co-supervised by Mr. David Fürstenberg, PhD candidate and BIM specialist who have had similar interests and research in this field. The current study is the resumption of TBA4530 specialization in project management and construction engineering to fulfill the subject TBA4910 Project management master's Thesis. In this study, an interview guide was developed using the shrunk and specified topic questions taken from early literature study.

The structure of this master thesis is not exactly traditional. Overall, this the readers will find three definite sections including master's thesis, a conference article, and appendix. The conference article resulted form this study has been accepted for publication in the 38th CIB W78 conference on Information and Communication Technologies for AECO in Luxembourg between 11-15 October 2021. Since the conference article and master's thesis are done collaterally. Therefore, the paper is to some extent a summery for the thesis. The writing process was second in priority solely due to paper submission deadline. However, the paper paved the way for finalizing the thesis with relative ease.

Trondheim, 29 June, 2021

_____

Saeid Morovvati

Acknowledgement

I would like to extend my utmost gratitude and acknowledgement to individuals, companies, and organizations who in many ways have contributed to bring this thesis work materialized. First and foremost, greatest state of gratitude goes to the supervisor of this work, Professor Ola Lædre at the Department of Civil and Environment Engineering, Norwegian University of Science and Technology (NTNU). His wisdom, constant support, and valuable insight helped better understanding of the topic and easing through the challenges and difficulties involved. Secondly, I would like to thank Mr. David Fürstenberg, PhD candidate at NTNU and BIM specialist whose follow up proved vital specially in arranging and participating in interviews, completion of the thesis and publishing a scientific article relating current work. Furthermore, I extend my gratitude to former senior manager Mr. Karl Oscar Sandvik for providing necessary information and interviewee suggestion which proved of immense significant during this investigation. I also would like to thanks employees of COWI (the consultant), PEAB (the contractor), and NYE VEIER (the client) in the investigated case for the time and effort they spent on the interviews and furthermore, for offering complementary documents.

Special thanks go to my dear parents who their moral support despite the long distance has been a beacon of hope and solace through ups and downs, specially in the challenging Covid-19 home office setting.

Last but not least, I dearly thank all my friends, old and new alike, for being supportive, patient, and helpful, regardless of circumstances and challenges stumbled upon.

Saeed Morovati

Jun, 2021

Table of Contents

List of Figures

List of Abbreviations (or Symbols)

AEC	Architecture, Engineering, and Construction
IPD	Integrated Project Delivery

PART 1 – MASTER THESIS

1 Introduction

In this study, the author will concentrate on automated Model-based cost estimation. This study will look into a road project and investigate essential factors in adopting automated Model-based cost estimation. It is important to mention that the study focuses on the cost estimation (process) and not cost estimate (product). This study uses the definition of the BIM-use cost estimation by Messner et al. (2019). They defined it as "a process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimation throught the lifecycle of a project".

The following chapter presents a background for the research topic and supplies the readers with introductory knowledge. Following the background subsection in the knowledge gap subsection, there is an introduction about the knowledge gap, the incantation, and the motivation behind choosing this topic. In addition, the knowledge gap will be elaborated in subchapter 3.7, Cost estimation in Norwegian Infrastructure projects. In subchapter 1.3 of this report research questions are mentioned. Following this subchapter, there are limitations of the current study, and finally, there is a reading guide for the report.

1.1 Background

Our society faces an ongoing digitalization. Tihinen et al. (2016) introduced digitalization as a major stream of alternating future affairs in society and industry. Degryse (2016) describes it as the fourth industrial revolution. Digital transformation results from accepting and adopting digitalization by organizations and refers to changes at different levels (Parviainen et al., 2017). Along with other components, several publications introduced people, process, and technology as the three main cornerstones of digital transformation within organizations. Bonnet and Nandan (2011), Westerman et al. (2014a) mention the necessity of a reliable connection between these three cornerstones.

The Architecture, Engineering, and Construction (AEC) industry is exposed to this transformation. Feng et al. (2010) and Webb (2017) identified several reasons to encourage the AEC industry to enable digitalization. According to them, construction time, quality of the product, environmental concerns, and social impacts increase digitalization demand. Recently, digital tools and workflows are more utilized in the AEC industry for designing, construction, and operating building and infrastructure assets (Borrmann et al., 2018). According to the same study, the digital transformation in the AEC industry increased productivity and reduced uncertainties.

During the past decade, Building Information Modeling (BIM) as a digital representation of projects has been promoted as the leading technology supporting digitalization in the AEC industry (Kulasekara et al., 2013, Whang and Park, 2016). According to Sacks et al. (2018), BIM can define as " a new approach to design, construction, and facilities management, in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format." BIM is using for coordinated, consistent, and computable building information management in all phases, from design and implementation to maintenance (Lee et al., 2014). Several studies revealed higher efficiency and effectiveness due to BIM use (Whang and Park, 2016, Wu

et al., 2014a). According to (Kunz and Fischer, 2012), BIM has a tremendous impact on the AEC industry.

Lee et al. (2014) defined cost estimation as "the process of predicting project cost and resource requirements." Cost estimation can be essential for a project's success, especially in the AEC industry (Elbeltagi et al., 2014, Ma and Liu, 2014). As Choi et al. (2015) mentioned, cost estimation is an effective tool for decision-making in both the early and detailed design phases of AEC projects. Several publications addressed the need for accurate cost estimation and stressed its vital role in the AEC industry (Allison et al., 2018, Andersen et al., 2016, Ebrahimi and Dowlatabadi, 2019, Ismail et al., 2016, Welde and Odeck, 2017, Firat et al., 2010). The cost estimate level of accuracy depends on the method used and the availability of cost data (Jrade and Alkass, 2001). However, cost estimation can be a manual, time-consuming, and error-prone process (Eastman et al., 2011, Holm, 2005, Ma and Liu, 2014, Monteiro and Martins, 2013). This uncertain and error-prone nature resulted in uncertainty about the results and a reduction in its reliability.

This process involves taking off quantities from drawings or models and copying-pasting the quantities into spreadsheets or cost estimation software. Quantity takeoff is one of the critical components in cost estimation, according to Monteiro and Martins (2013). It can be defined as the process of measuring and counting building elements. Several publications stressed that precise quantity takeoff is necessary for reliable cost estimation in different project phases (Liu et al., 2016, Monteiro and Martins, 2013, Whang and Park, 2016). As projects become larger and more complex, this process becomes even more time-consuming, and errors occur more often (Babatunde et al., 2019, Olsen and Taylor, 2017).

Eastman et al. (2011) mentioned that the main benefit of using BIM in cost estimation occurs during the quantity takeoff step. According to them, most BIM-based estimating tools can export quantities to an external database. They mentioned in their study that BIM allows design models to be linked to software that allows the quantity surveyor to obtain the required quantities. According to them, adopting BIM will result in around 80%-time reduction and near 10% cost reduction. The use of BIM for quantity surveying has also been studied by Boon and Prigg (2012); they noticed the ability to extract quantities directly from BIM models. They also introduced this method as a beneficial method in quantity takeoff. Hartmann et al. (2012) identified automated quantity takeoff as one of the most valuable tasks in BIM-based AEC projects. According to them, automated quantity takeoff can increase the efficiency of quantity surveying. Alufohai (2012) mentioned that the possible automation resulting from using BIM would help increase efficiency in cost estimation. Monteiro and Martins (2013) also in their study mentioned that quantity takeoff can be automated as a result of using BIM for reflecting the cost estimation. Sattineni and Bradford (2011), in their study, mentioned saving time and cost in cost estimation as a result of using automated quantity takeoff through BIM. They introduced model-based automated quantity take off a crucial way for accurate and reliable cost estimation.

Like the studies of Wu et al. (2014a) and Luth et al. (2014), several studies concentrated on applying 5D BIM in the AEC industry. There are also few studies like Ali et al. (2016) and Babatunde et al. (2019) about BIM education for quantity surveying. Elbeltagi et al. (2014) introduced a cost estimating model based on BIM. Recent studies like Alhasan et al. (2017) and Chan et al. (2018) mentioned the benefits of 5D BIM in cost estimation. While BIM shows excellent potential to solve these issues, Shou et al. (2015) report that

studies on BIM mainly focus on buildings and not on infrastructure. They mentioned that advances in BIM not only increase efficiency in buildings but also in infrastructures. They compared the extent of BIM for buildings and infrastructures. Their study revealed that most of the studies around BIM mainly focused on buildings, and research on BIM for infrastructures is lagging. After that, a few studies about automated quantity takeoff using BIM for infrastructures were published. Vitásek and Matějka (2017b), in their study, concentrated on using BIM for the automation of quantity takeoff and cost estimation in infrastructures. Their study focused on models of road constructions, and they try to mention and solve problematic parts of automated quantity takeoff. They used two case studies in their study. They conclude that even though it is beneficial and has high efficiency but automated BIM-based quantity takeoff "is highly dependent on local market budgeting systems, therefore proper push/pull strategy is required."

1.2 Knowledge Gap

As stated, cost estimation is a critical and necessary part of AEC projects. An accurate cost estimation requires an accurate quantity takeoff. However, as mentioned, traditional quantity takeoff methods are time-consuming, costly, and error-prone. These issues resulted in lower reliability in the results of quantity takeoff and cost estimation. Besides, to achieve better efficiency and effectiveness, the AEC industry is adopting digital tools. Several researchers tried to cover these issues during the past decade by using digital tools for automating quantity takeoff and cost estimation. They achieved considerable improvements in building construction projects. Moreover, several software and standards are recently being developed to cover this topic in building construction projects.

Meanwhile, as mentioned in the study of Shou et al. (2015), this research area suffers from an obvious need for infrastructure projects compared to building projects. While as Vitásek and Matějka (2017b) mentioned, infrastructure projects serve great importance and are among widely discussed topics in the public sector. This importance was also mentioned by Costin et al. (2018). They stated infrastructure projects as the backbone for any nation. They stated that ever-increasing population growth and the aging of transportation structures would magnify the need for more efficient and cost-effective methods for constructing and maintaining infrastructure projects. Creswell and Creswell (2017) also stated that, "absence of adequate research is often an indicator that exploratory research is needed." So, the first incentive to investigate this topic was the great importance of infrastructure projects, the absence of practical research on infrastructure projects, and the need to increase efficiency in this part of the AEC industry.

Moreover, the limited number of studies addressing this issue covered only the technological part and feasibility of the automated quantity takeoff and cost estimation. While adopting automated quantity takeoff and cost estimation is not just about the technological part. We need to investigate the process and people besides the technological part as the three cornerstones of digitalization. Consequently, the decision was made to expose the practical use of automated model-based cost estimation.

1.3 Research Questions

This thesis investigated model-based cost estimation for infrastructure projects. Having in mind the identified research gap, the importance of the topic, and to give the research a distinct focus, the following research questions have been identified. The author will go

through the research questions specifically in the case study and try to find the answers to cover the knowledge gap.

1. How is cost estimation practiced in infrastructure projects?
2. What is hindering automated cost estimation?
3. How can automated cost estimation be further developed?

1.4 Limitations

This study is limited to a few factors. First, the time frame of this study is a limitation to be considered. Due to time restrictions, this study is limited in terms of possible resources that could be reviewed and the number of interviews and case studies that could be undertaken. In this research, only a Norwegian road project with the Norwegian classification codes for work specification was studied. A single case within specific classifications can limit the validity of findings, but it will also allow for a more in-depth and detailed insight into a particular case. However, the specific features of the chosen case in this research, like the client's high digital ambitions and good detail level within the models, enable the possibility of being the single case study and still be of great interest as the research topic. More information on the case study under chapter 2. Research Methodology. The author believes that most of the findings and conclusions in this study are generally applicable to other projects. Even though the limitation of case study to Norwegian classification codes and workflow can limit the findings and results and needs further investigations, the study results show that most of the results are generally applicable to all projects. Even though this study is limited to twelve interviews, it covers almost all parties involved in the quantity takeoff.

Second, to produce conclusive results within this time frame, this study investigated the quantity takeoff part of cost estimation as one of the fundamental elements of cost estimation and not unit pricing. Research about unit pricing can be defined as a topic for future studies.

The third limitation is that due to the restricted time frame in this study, only the early phase of the project was investigated before the detailed design.

Finally, it is worthwhile mentioning the specific contract type in the case study. This case study used Integrated Project Delivery (IPD) as the first infrastructure project within Norway with this project delivery method. Limiting the study to this type of project delivery method means that some experiences and challenges discussed in this study are confined to this project delivery method. More information about Integrated Project Delivery (IPD) under chapter 3. Theoretical Framework.

1.5 Structure of Thesis

The outline of this report has been structured in three main parts consisting of a thesis report as the first part, a scientific article as the second part, and the appendix as the third part, presented in figure 1.

The first part is structured in the following order. The first chapter will go through the introduction, background, research questions, limitations, and structure of the report to give the readers a short guideline to the report. In the second chapter, the report will go through the theoretical Frameworks of related terms and concepts. It will explain to them to give an insight into the related terms. In the third chapter, the methodology used to perform this study will be introduced. There will also be a short introduction to the case

study and its features. Chapter four will identify the findings and then discuss the findings through interviews, case study, a document study, and literature review in chapter five. In conclusion, the chapter will present the results and summarize the results, and the author will explicitly try to answer the research questions. Finally, the report will go through some advice for future works.

The second part scientific article contains an accepted conference paper written as a part of the study. This article is accepted for the 38th CIB W78 conference on Information and Communication Technologies for AECO in Luxembourg between 11-15 October 2021.

The third and the last part contains the appendices and includes documentation and information, including the interview guide, literature evaluation process, and the pilot study report for the specialization project.

2 Research Methodology

In this research, the research questions have been investigated through performing a thorough literature review, a case study of a real state project in Norway, case-specific interviews based on semi-structured open-ended questions, and document study of the mentioned project.

The results from the literature study were used to map the current research state on the topic and were compared with findings obtained from interviews conducted with the participants involved in the case study. The results from the literature study also helped to develop the interview guide for interviews.

2.1 Qulatitative Research

As Bryman (2016) stated, research methods are often described as either qualitative or quantitative. However, in their study, Creswell and Creswell (2017) mentioned that these methods are unquestionably not as discrete as they first appear. According to them, the distinction is in the basic assumptions and research strategies used in the research. They defined qualitative research as "an approach for exploring and understanding the meaning individuals or groups ascribe to a social or human problem." Blumberg et al. (2014) introduced in-depth interviews, participant observation, and case studies as some of the common approaches for conducting qualitative research. According to Creswell and Creswell (2017), a holistic understanding of the topic aims to conduct qualitative methods. However, Samset (2014) described that this method requires more transparency, reliability, and validity. He mentioned validity, reliability, and sufficient quality as the critical elements for the success of this method. These features can be evaluated through good data consistency and good alignment of data and theory.

In this thesis, the qualitative research method was chosen to investigate the topic due to some reasons. The first reason for this decision was that since the topic was relatively new, having an in-depth evaluation of the case can be more suitable. Moreover, there was a data shortage due to being a relatively new topic. In their studies, Johnson and Christensen (2019) and Samset (2014) stated that qualitative research methods are a proper method for data shortage due to being a relatively new topic. According to them, qualitative research can be more beneficial and suited for new fields or data shortage to give a more thorough understanding. To cover the needs for more transparency, reliability, and validity as stated by Samset (2014), the convergence of the obtained data set from the theory, as well as their consistency and inter-connectivity, was examined to assure validity, reliability and quality of the data.

2.2 Research Design

This subchapter of the report explains how the problem statement was answered in this thesis. This study aims to discover what are the critical factors in adapting model-based quantity takeoff and cost estimation. For this sake, there is a great need to investigate the present methods of cost estimation in infrastructure projects, the obstacles hindering automated quantity takeoff, and the potential ways to develop this method for this goal.

The study process involves a preliminary literature review to get sufficient knowledge, see what came before, what did, and what did not work for other researchers in the same or related subject, and identify the knowledge gap. This part also resulted in defining research questions and structuring interview guide. Moreover, the literature review helped to check the validity of findings and their alignment with the literature's theoretical background.

This thesis tried to have a more in-depth insight by performing a case study in the next step. A potential case was identified and selected throughout the case study, with consultation with the supervisor and co-supervisor. Qualitative interviews and document studies were used in the case study for data collection. Document study was also used to clarify misunderstandings or misconceptions. Finally, this thesis used a color-coding structure for data classification and analysis. The chosen methods will be presented and elaborated in the following subchapters.

2.3 Literature Study

As Snyder (2019) described, a literature review is crucial for creating the theoretical framework and building conceptual models. Adler and Clark (2011) defined literature review as "the process of searching for, reading, summarizing, and synthesizing existing work on a topic or the resulting written summary of the search." Creswell and Creswell (2017) stated that a literature review is relevant and beneficial at various stages of research projects. This thesis used literature review as one of the research methods to investigate the topic, the reason behind choosing this method, strengths and weaknesses, and the process will be further explained in the next subchapters. Among different methods of searching for literature in this thesis, we used search engines, recommendations, and snowballing from reference list. More information on the search method under subchapter 2.3.3 literature search.

2.3.1 Advantages and Disadvantages of Literature Study

One of the main advantages of doing a literature review is discovering numerous theoretical perspectives that may guide the research process to be viable (Creswell and Creswell, 2017). The other advantage of performing a literature review was giving a comprehensive overview of the previous research on the topic. Nevertheless, even though literature study as a research method can cover a wide range of publications, however, the incapability of checking all the relevant literature can be introduced as a weakness for this method by the author. As mentioned earlier, this research includes part of assignments related to two courses during the preceding autumn (TBA4128 Prosjektledelse, videregående kurs, and TBA4530 Prosjektledelse og anleggsteknikk, fordypningsprosjekt), so the author tried to cover all the possible literature through two semesters to cover this issue. The other issue with the literature review worth mentioning was inferring the real meaning and intention behind what was stated in the literature. This issue tried to be solved by a deep study of related concepts, evaluating literature, and consulting with the supervisor, co-supervisor, and experts in the field.

2.3.2 Why Literature study

The literature review was used to establish knowledge, create the theoretical framework, find the knowledge gap, define the research questions, structure an interview guide and discuss findings. In this study as stated, the literature review was beneficial in several stages of the investigation. First, it helped to learn more about the topic and determine if there is a need for further investigation. Later, it helped to shift from a general idea to a

more specific topic; it gives the research a specific direction. Moreover, in this thesis, the literature review helped determine the research purpose, define the research questions, and developing the interview guide. Finally, this thesis used the literature review to evaluate and discuss the findings in the later stage. The validity, reliability, consistency, and quality of the findings were discussed through a comparison with the findings stated in other publications.

2.3.3 Literature search

As mentioned earlier in this thesis, we used search engines, recommendations, and snowballing as search methods. In this project, some of the literature was introduced and recommended to the researcher by his supervisor and co-supervisor. The rest of the literature was identified through searching by keywords in search engines. The keywords were searched in research databases and the most relevant literature was identified. Used search engines in this thesis are Google Scholar, Scopus, and NTNU's University Library, Oria. This thesis also used snowballing as one of the methods for finding relevant literature. As described by Jalali and Wohlin (2012) snowballing from reference lists of the identified articles is a recommended method for identifying additional relevant articles. Wee and Banister (2016), also mentioned snowballing as one of the search methods to find relevant literature. This study used both backward snowballing and forward snowballing beside searched in the search engines. Backward snowballing implies finding citations in a publication founded, however, forward snowballing is about identifying publications that have cited the founded publication (Jalali and Wohlin, 2012).

This study evaluated 53 potentially relevant sources identified through all the above-mentioned methods. In the next step, the author did an in-depth literature study to identify the most relevant resources. This in-depth study ended up with a total of 21 most relevant sources identified based on context relevance, objectives, validity, accuracy, and quality. The primary measure for this selection was the objectives of publications and their alignments with this research topic however this study also used a four criteria-method evaluation from the University Library at NTNU (VIKO, 2020). Having in mind credibility, objectivity, accuracy, and sustainability as the four criteria introduced by University Library at NTNU this thesis evaluated literatures answering the following questions:

- Where is the literature published? How valid is the place of publication?
- Who are the authors and what is their background?
- What are the used research methods? what kind of structure does the publication follows? And when the document has been published?

2.4 Case Study

In the next step, a case study followed the literature review. Gerring (2004) defined a case study as " an intensive study of a single unit with an aim to generalize across a larger set of units.". Feagin et al. (1991) introduced a case study as an ideal methodology for a thorough investigation. In this study, the studied case was a 7 km four-lane highway project (Figure 1). This case is a part of a road project in Norway (E6 Melhus S-Kvål). The case was the first Norwegian infrastructure project with Integrated Project Delivery (IPD). The designer, client, and contractor collaborated closely from the early phases of the project. They were co-located in the project office to improve collaboration.

The case was selected because the client had high digital ambitions and expected a mainly model-based design and construction process. Therefore, the use of drawings should be reduced. The client's high digital ambitions and the expectation of a model-based design and construction process turns this project into a perfect potential case. In addition, these reasons and the interest of the involved parties for further developments provided the necessary permissions and data for investigating this case. For the case study, Mr. Ola Lædre and Mr. David Fürstenberg, respectively, as the supervisor and co-supervisor of this thesis, helped the author with choosing the case, providing contacts and documents.

Figure 1, Case study (E6 Kvål – Melhus S), figure from Nye Veier website.

2.4.1 Advantages and Disadvantages of Case study

Several publications mention the potential benefits of a case study (Fürstenberg, 2020). One of the main advantages of a case study is that case studies are problem-centric and solution-centric. Therefore, performing a case study to investigate the topic can also be seen as a comprehensive study. Accordingly, conducting a case study will give the users the advantage of developing an in-depth understanding and looking for practical factors in detail (Feagin et al., 1991). The possibility of generalizing from a single unit across a larger set of units can also be introduced as an advantage of a case study, as mentioned in the study of Gerring (2004). However, generalizing from a single case study can sometimes be challenging.

Moreover, accessing a case, getting permissions and data from the case companies are limiting this type of research methodology. Other disadvantages of this method can be the time-consuming nature of this method and the personal interpretation of the findings. The author tried to evade misinterpretation of findings by discussing them during several meeting with his supervisor and co-supervisor.

2.4.2 Why case study

In this study, the first research question can be classified as a descriptive question according to Busch (2013) classification. Descriptive questions are mainly discussing how and why. Furthermore, according to Leonard-Barton (1990), performing a case study to investigate a topic is particularly beneficial for responding to how and why questions. Therefore, this investigation used a case study as one of the methods to investigate the topic. Moreover, as Sykes (1990) mentioned in his study, reaching some information during a study can be difficult or impossible in some cases by other research methods. However, case studies can reveal these kinds of information by an in-depth investigation. In this study, performing a case study was beneficial through an in-depth investigation of the project and reaching information that was not mentioned in literature or any document. Finally, as mentioned earlier, in this thesis interest of the involved parties in

the topic and their participation made the case study a suitable research methodology by solving its limitations.

2.5 Interviews

Semi-structured interviews are broadly used as a data collection methodology within qualitative research (McIntosh and Morse, 2015). This research used open-ended semi-structured interviews despite their resource-demanding nature. Blumberg et al. (2014) described semi-structured interviews as interviews where the interviewer can deviate from the pre-written interview guide of questions in case of need. In this thesis, the interview guide was structured based on research questions during several meetings with the supervisor and co-supervisor and after an in-depth literature review (The interview guide has been included in Appendix). During this study, the interview guide remained unchanged; however, some additional follow-up questions followed some of the questions during interviews. All interviews were through the Microsoft team. Due to the global pandemic worldwide, there were no possibilities for in-person interviews. All interviews were audio-recorded and transcribed. The transcripts were later sent to the respondents and verified by them as their representation of views.

For the interviews, Mr. Ola Lædre and Mr. David Fürstenberg, respectively, as the supervisor and co-supervisor of this thesis, and Mr. Karl Oscar Sandvik helped the author with identifying and providing contacts for interviews. The interviewees were chosen based on their practical experience and responsibility in the case study. In this thesis, reported data from the respondents are anonymous, and the interviewer only mentioned their roles and positions in case of need. Nearly half of the interviews conducted for the pilot study in the subject TBA4530 Project Management, specialization project (TBA4530 Prosjektledelse og anleggsteknikk, fordypningsprosjekt) at NTNU during the preceding autumn. The interviewees included representatives from the designer, the contractor, and the client:

- Three project managers from all three parts.
- A BIM manager.
- Two discipline leaders (road, construction).
- Two quantity surveyors from the client-side.
- Four discipline BIM coordinators (road, construction, electrical, and water and sewer)

2.5.1 Advantages and Disadvantages of Interview

A critical strength point for an interview is that the interviewer can clarify questions, expand on answers in case of need and ask for further explanations. This ability can cover unforeseen factors and help the author have better control and a broader perspective. As Kelly et al. (2010) also mentioned, the semi-structured interview's rigidity depending on the study and research questions can be different. This difference can give the interviews more flexibility and dynamic and enables the researcher to uncover more information. Polit and Beck (2010) introduced the interviewer's ability to improvise follow-up questions based on the answers as one of the main advantages of this method. Moreover, interviews can help the researcher with an understanding of real-world practices.

A challenging point in performing interviews as a data collection method can be the limited and insufficient number of respondents. In this study, this challenge tried to be considered to cover all the possible information and perspectives from different experts involved in the project. Another challenge in performing an interview in this study was the Covid-19 situation and the impossibility of having an in-person interview. The author believes that having an in-person interview could be more beneficial in discussing questions and answers. Of course, having an in-person interview could be more user-friendly. However, despite the impossibility of having in-person interviews, all interviews successfully and with acceptable quality were conducted virtually through the Microsoft team. The other challenge of this method is that the interviewer needs to have the appropriate level of knowledge to improvise follow-up questions to formulate interview questions. In this thesis, mentioned challenge tried to be covered through the knowledge gained from the literature review and the help of Mr. David Fürstenberg as the co-supervisor of this thesis.

2.5.2 Why Interviews

As DiCicco-Bloom and Crabtree (2006) mentioned in their study, data collection is a crucial part of all studies, and interviews are among the most regularly used data collection methods. According to them, semi-structured interviews are the most often used qualitative research technique. They mentioned the flexibility of this technique as one of the principal reasons to use it. Considering the qualitative research method in this study (the reasons for using a qualitative research method discussed earlier), the importance and necessity of data collection considering the topic as a relatively new concept, this study used interviews.

Moreover, as mentioned earlier, the semi-structured open-ended questions allow an in-depth response from interviewees by enabling the researchers to ask probing questions. The possibility to ask probing questions was mentioned by Turner III (2010)as a potential benefit of semi-structured open-ended interviews. Therefore, this thesis used interviews with semi-structured open-ended questions to collect data and let the participants express their viewpoints and give the flexibility to use probing questions to have an in-depth investigation.

2.6 Document study

Usually, a large amount of information always stored in the documents. Sprague Jr (1995) defined a document as "a set of information pertaining to topic, structured for human comprehension, represented by a variety of symbols, stored and handled as a unit." "Document study is a systematic procedure for evaluating documents" (Bowen, 2009b). In this research, a document study of presentations, some parts of the contract, and some organizational documents related to the topic were conducted to support findings from interviews and gain information. The documents were studied regarding the information about the case project. The documents studied in this research are as below:

- Presentations provided by NYE VEIER about the project workflow
- E6 Kvål – Melhus sentrum Kontrakt
- Presentation provided by Nye Veier "INTEGRERT PROSJEKTLEVERANSE (IPL)
- PNS-structure; Project breakdown structure (From Nye Veier)
- Main layout cost image per meter of road (From Nye Veier)

- Environmental goals (From Nye Veier)

Some of the documents were received and studied before interviews to help the interviewer discover the interesting potential insights for follow-up questions during the interviews. Furthermore, some documents were introduced and provided during the interviews by the interviewees. These additional documents were studied as the interviewees thought they would provide complementary information relevant to the topic. The documents were received through email. Due to confidentiality protocols and the importance of the documents for the companies, these documents are confidential. Therefore, they are not attached to this report.

2.6.1 Advantages and Disadvantages of Document study

As an advantage for document study, the author can mention that this method is less time and cost-consuming than the other methods. According to Salminen et al. (1997), document study needs document standardization. Usually, information is not stored in the same structure and format; this necessitates the importance of document standardization (further information about Data Analysis in the following subchapter). As another advantage of document study, we can mention that it is relatively simple to conduct. However, as mentioned in the study of Sprague Jr (1995), documents usually contain a large amount of information. However, as a disadvantage of document study, the documents also include a large amount of irrelevant data, making the data analysis process harder. Availability of documents can be a challenge for this method; however, in this study, we did not face this challenge due to the interest of the parties involved in the project and their motivation.

2.6.2 Why Document study

As we mentioned, earlier documents contain a great deal of helpful information. In this study, a document study was conducted to gain the necessary knowledge about how cost estimation was practiced in this project, the challenges, experience, and limitations with the method used in this project. This method helped the author to understand the reasons behind the methods chosen and implemented in the project. In addition, the document study provided useful information and insights regarding the contract and workflow.

2.7 Data Analysis

This thesis used "color coding" for categorizing and dividing the findings into three subdivisions of people, process, and technology (Further information about the subdivisions in chapter 4.). The interviews transcripts were reviewed several times, and different highlighting colors separated the findings from interviews into seven parts. Some data was hard to specify to only one of the subdivisions. The findings were categorized into seven colors, for seven parts as below:

- People
- Process
- Technology
- Findings related to both people and process
- Findings related to both people and technology
- Findings related to both process and technology

- Findings related to people, process, and technology

The color-coding as mentioned above is used for the findings from document study and literature review as well. This method, to some extent, helped to ease the workflow, reveal and understand the relations between different findings.

3 Theoretical Framework

This chapter is based on the study of existing literature. The aim of this chapter is to give the reader an introduction to the relevant theory.

3.1 Digitalization, and Digital transformation

Digitalization and Digital transformation, two of the most critical concepts of knowledge in recent decades, attract significant attention in different science aspects. Their vast effects on human society and industry caused an ever-growing interest in them. However, often it is hard to have a clear distinction between these two terms. Thus, a clear perspective of these terms will be a valuable and beneficial tool for their implementation.

Digitalization, one of the most significant trends changing our society with notable impacts on human life, is compared to industrial revolutions in several publications. Its fast spread sets enormous changes in all knowledge fields (Degryse, 2016, Tihinen et al., 2016). Several different definitions depending on the context have been presented for digitalization during past decades. The simplest and common one is the transformation from analog to digital. Stolterman and Fors (2004) defined digitalization as " The changes associated with the application of digital technology in all aspects of human life". According to the studies of Gassmann et al. (2014) and Henriette et al. (2015b), digitalization is known as the "Ability to turn existing products or services into digital variants, and thus offer advantages over tangible product". Moore (2015) mentioned new value creation as the result of digitalization; in his idea, only improving without any new creation was not enough.

According to Westerman et al. (2014b), digital transformation means "The use of technology to radically improve the performance of reach of enterprises". Digital transformation is more about changing roles and ways of working. Matt et al. (2015) and Parviainen et al. (2017) introduced digitalization as a necessary step to attain digital transformation . Parviainen et al. (2017) stated that Digital transformation results from accepting and adopting digitalization and digital technologies. According to them digital transformation refers to changes at different levels like process level, organization level, business domain level, and society level. Moving toward digitalization needs implementing digital capabilities as a result of technology improvement (Henriette et al., 2015a). Verhoef et al. (2021) in their study provided a multidisciplinary perspective on digital transformation. They identified digital technology, digital competition, and digital customer behavior as the three major external drivers. According to them changes in digital technologies, increasing digital competition and resulting digital customers behavior are the reasons necessitating firms to move toward digital transformation.

3.1.1 Impacts of Digitalization and Digital transformation

Profiting from digital transformation requires a proper understanding of its impacts. Parviainen et al. (2017) identified and illustrated internal efficiency, external opportunities, and disruptive change as the three most fundamental impacts of digitalization (figure2). They defined internal efficiency as improvements in the implementation method using digital means and re-planning the internal process. They

mentioned process efficiency and consistency due to eliminating manual steps and better accuracy as potential benefits of digitalization. In their study, External opportunities refer to creating new opportunities in the existing domain. They introduced improved response time and client service as the potential benefits of it. Finally, disruptive change is defined as changing roles as a result of digitalization. They mentioned the possibility of generating new business and changes in the environment as the potential benefits of digitalization in this case. Even though the impact of digitalization is definite, some industries are often struggling to adopting it. Verhoef et al. (2021) mentioned that "digital change has received most attention within specific disciplines."

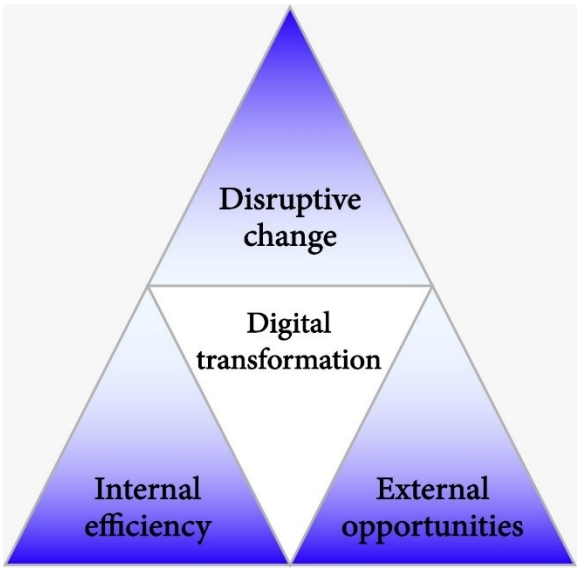


Figure 2 Digitalization impacts, Figure from Parviainen et al. (2017)

3.2 People, Process, and Technology

Along with other components, several publications introduced people, process, and technology as the three main cornerstones of digital transformation within organizations. Enegbuma et al. (2015) mentioned people, process, and technology as three components affecting BIM adaption across the construction industry. The results of their study revealed a high correlation between people, process, and technology. In their study they stated the necessity of concentrating on the relation between these three components. They identified a significant relation between these components and BIM adaptation and also among the components themselves (Figure 3).

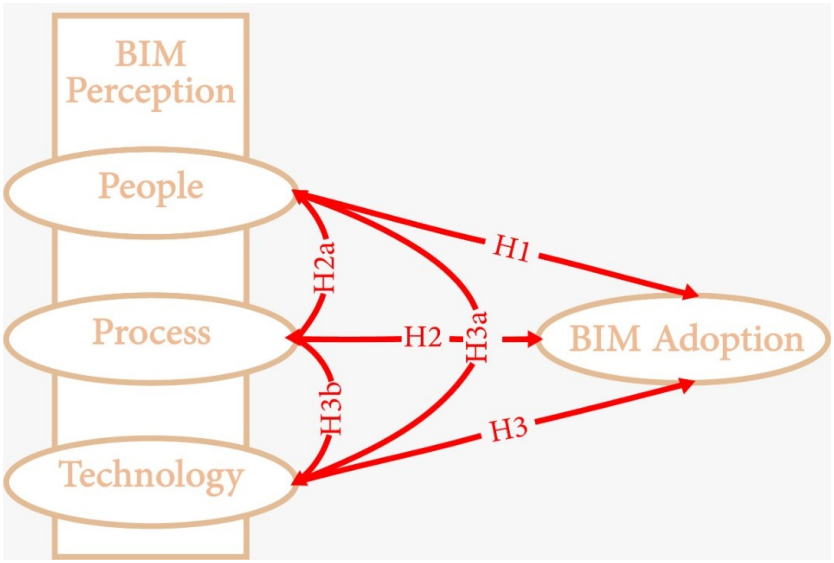


Figure 3 BIM perception model, figure from Enegbuma et al. (2015)

Mêda et al. (2020), in their study, mentioned that "The introduction of innovation processes must rely on approaches that evaluate dimensions as People, Process and Technology." According to them, "people, process and technology are essential analysis dimensions of the productive chain and involved parties." They stated that a delicate balance among these aspects is essential for the success of the process. However, their investigation revealed that the "Technological dimension" is, in general, more mature than the others. Therefore, they emphasized that efforts must concentrate on other dimensions. More concentration on technology part is also mentioned and criticized by Smartsheet (2019).

Shelbourn et al. (2007) , in their study, mentioned the necessity of embracing new ways of working for the construction industry. They stated that collaborative working is an essential part of the whole lifecycle of the construction process. They pointed out that most recent studies have mainly concentrated on the technological part; however, it is not enough. They mentioned the necessity of considering people and process besides the technological part to plan and implement collaborative working more effectively in projects. They conclude that collaboration needs people, process, and technology to come together to enable its success. In a survey carried out in the same study on the importance of people, process, and technology for effective collaboration, the results reflected 40% importance to people, 34% to processes, and 26% to technology (figure 4).

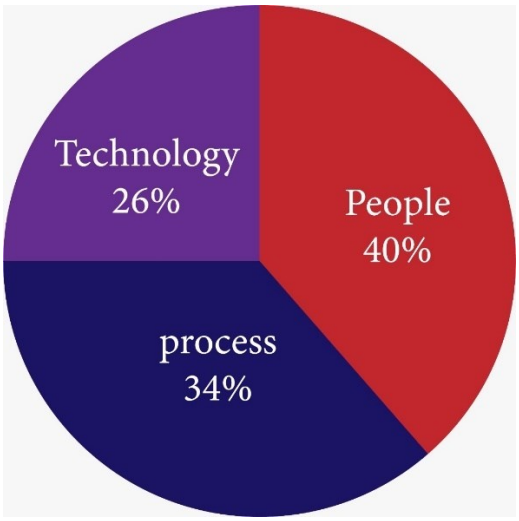


Figure 4 Importance of three key strategies in collaboration projects, figure from Shelbourn et al. (2007)

Since the mid-1960s, the people, process, and technology framework has been in use. People, process, and technology framework, also known as the golden triangle (figure 5), can help achieve harmony within an organization when purchasing or implementing new technologies. These components can be defined as below (Smartsheet, 2019):

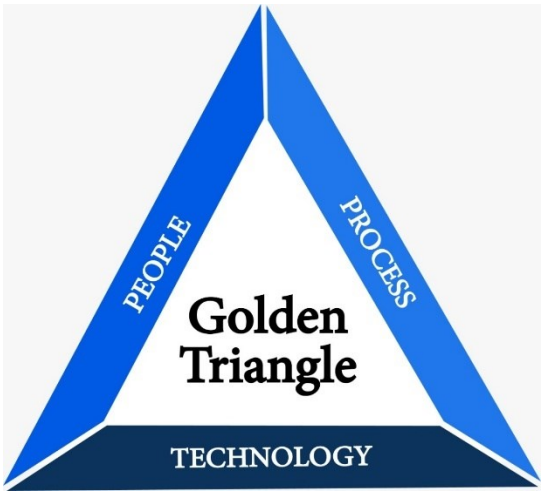


Figure 5 People, Process, and Technology framework (Golden Triangle), Figure from Smartsheet (2019)

People: The people component is sometimes considered the most crucial part of the triangle. They are those who perform a particular obligation utilizing processes and technology. For this component, the fundamental step is to find people with the proper experiences, qualifications, and attitudes.

Process: "A process is a series of actions or steps that need to happen in order to achieve a particular goal. People are ineffective without processes in place to support their decisions."

Technology: This component alone cannot help solving problems or improving efficiency. It is dependent on the support of the other two components.

3.3 Digitalization in AEC

"Construction sector digital transformation is an ongoing task engaged by the urgent goals of a more sustainable, efficient and competitive industry" (Mêda et al., 2020). The need to increase sustainability, efficiency, and competitiveness is mentioned in different publications. Jan et al. (2013a) mentioned the importance of knowledge technology and knowledge management in the construction industry. They defined the term knowledge management as the management of resources and evaluation and exploitation of knowledge in the context of problem-solving. According to Bousquet et al. (2003), poor knowledge management causes low efficiency and productivity in the construction industry. Besides, as Switzer (2008) mentioned, the success of all projects, especially complicated AEC projects, depends on better and efficient use of resources and processes. The necessity for improving efficiency is also mentioned in the study of Mêda et al. (2020). According to them, the construction industry's productivity rate is nearly four times inferior to the observed rate in manufacturing industries. They pointed out that although this productivity rate was increasing over time, it still impacts the construction industry's competitiveness, economic sustainability, and environmental sustainability. The need for higher efficiency, sustainability, and competitiveness is an initial motivation for the AEC industry to adopt digitalization and digital transformation.

Moreover, Feng et al. (2010) and Webb (2017) identified several reasons encouraging the construction industry to enable digitalization. According to them, construction time, quality of the product, environmental concerns, and social impacts increase digitalization demand. In addition, traditional physical paper plots and limited formats of digital tools cause the loss of valuable information. figure 6 illustrates the information loss through conventional workflows and compares it with digital workflows (Borrmann et al., 2018). In recent years, the AEC industry has been promoting the use of digitalization to cover mentioned shortcomings. However, as Mêda et al. (2020) also mentioned in their study, "The enthusiastic movements towards digital transformation in construction must understand the unique environment of the sector, the main barriers and the structural characteristics that have been dragging down the innovation adoption rhythm." They mentioned that despite the effort and time required for digital transformation of construction industry, it is both fundamental and feasible.

Several publications mentioned the importance of Building Information Modeling (BIM) for digital transformation in the AEC industry. In their studies, Succar and Kassem (2015) and Hjelseth (2017) mentioned BIM's adaptation strategies and its dominance in digitalization and digital transformation due to its relevance and impacts on the industry. de Couto Nascimento et al. (2016) introduced Building information modeling (BIM) as the center of moving toward digital transformation.

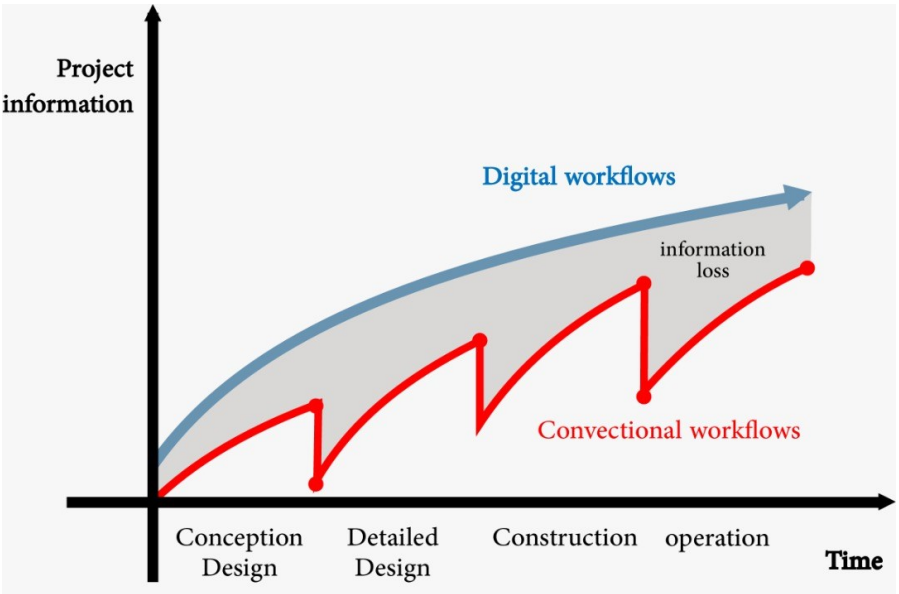


Figure 6 Loss of information caused by disruptions in the digital information flow. Figure from Borrmann et al. (2018).

3.4 Building Information Modeling (BIM)

According to Sacks et al. (2018), BIM can be defined as "a new approach to design, construction, and facilities management, in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format." During the past decade, BIM has been broadly adopted in the AEC industry. Lee et al. (2014) mentioned that BIM is used for coordinated, consistent, and computable building information management in all phases, from design and implementation to maintenance. A BIM element potentially can contain the element's installed phase, manufacturer's website, and structural properties (Wu and Zhang, 2018). This feature covers the loss of information caused by disruptions mentioned in figure 6 (Borrmann et al., 2018). According to Azhar (2011), adopting BIM can save costs in both design and implementation phases. The term "Building information modeling" for the first time was used by van Nederveen and Tolman (1992b). The concept of BIM is based on Building Product Model (BPM) as an object-oriented model (Eastman, 2018).

During the past decade, an extensive range of BIM-based software products has been published. BIM is a key technology in the AEC industry with an increasing rate of adoption and implementation (Lu, 2015). Sattineni and Bradford (2011) mentioned a rising application rate of BIM within the AEC industry. Following the emergence of BIM, it has been realized that implementing BIM can result in more efficiency (Wu et al., 2014a). Clark (2019) mentioned the combination of different stakeholder's data in one platform as a potential benefit of using BIM. BIM's potential benefits attract a lot of attention in the AEC industry in different phases and parts. As mentioned in the study of Lu (2015), including cost estimation information into the definition of BIM elements is an interesting topic for the AEC industry. The reason for this interest relies upon the capability of BIM in saving a significant amount of data.

3.5 Project Delivery method

Miller et al. (2000) defined a project delivery method as "a system for organizing and financing design, construction, operations, and maintenance activities that facilitate the

delivery of a good or service." The project delivery method sets a framework for organization, roles, and responsibilities (Engebø et al., 2020). Fischer et al. (2017) pointed out the necessity of collaboration between parties due to the complex nature of design and construction projects. They mentioned that even though there are some benchmarks as aids for owners to achieve efficiencies, the traditional delivery methods leave much to be desired. They compared traditional building methods with integrated approaches regarding teams, process, risk, compensation, communications, agreements, and behavior. Walker and Lloyd-Walker (2016) mentioned the importance of trust, commitment, and the nature of co-learning through collaboration.

3.5.1 Integrated Project Delivery (IPD)

AIA and Construction (2007) define Integrated Project Delivery (IPD) as "a project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all project participants efficiency through all phases of design, fabrication, and construction." IPD attempt to improve project outcomes through a collaboration between different parties involving in the project, and several projects and studies demonstrated its benefits (Kent and Becerik-Gerber, 2010, Lahdenperä, 2012). Several publications demonstrated the benefits and challenges of IPD as a highly collaborative process; however, only a few pointed out the key characteristics of IPD. Ghassemi and Becerik-Gerber (2011), in their study, mentioned the following characteristics as the main characteristics differentiating IPD from traditional delivery methods:

- A multi- party contract
- Early involvement of key participants
- Collaborative decision making and control
- Shared risks and rewards
- Liability waivers among key participants
- Jointly developed project goals

3.6 Classification Standards

Most AEC projects usually follow a mandatory standard specification. Due to several reasons and circumstances, these specifications are different among different countries; however, they also have some similarities. In the study case in this project and for Norwegian road projects, the Norwegian public Road administration has two standard specifications. It is obligatory to use these standard specifications. The aforementioned standards are published in two handbooks as General Specifications 1 (R761) (Norwegian Public Roads Administration, 2018a) and General Specifications 2 (R762) (Norwegian Public Roads Administration, 2018b). These handbooks could be considered as specifications and classification systems. They include several pieces of information like title, units, descriptive text, and a unique code. The parties involved in the project used these specifications as a base for mapping cost items and inserting specific unit prices for each cost item. These standard specifications are process-oriented means that they are concentrated over processes rather than objects for mapping and inserting unit prices (Fürstenberg, 2021).

3.7 Cost estimation

Lee et al. (2014) defined cost estimation as "the process of predicting project cost and resource requirements". They illustrated the general process of cost estimation as figure

7. Cost estimation is a manual and repetitive task prone to human errors (Firat et al., 2010). This uncertain and error-prone nature resulted in uncertainty about the results and a reduction in its reliability. In this study, we used the definition of Messner et al. (2019) for model-based cost estimation. They defined it as "a process in which BIM can be used to assist in the generation of accurate quantity takeoff and cost estimation throughout the lifecycle of the project". Quantity takeoff is one of the critical components in cost estimation, according to Monteiro and Martins (2013). It can be defined as the process of measuring and counting building elements. Several publications as Monteiro and Martins (2013), Liu et al. (2016), and Whang and Park (2016), in their studies stressed that precise quantity takeoff is necessary for reliable cost estimation in different project phases.

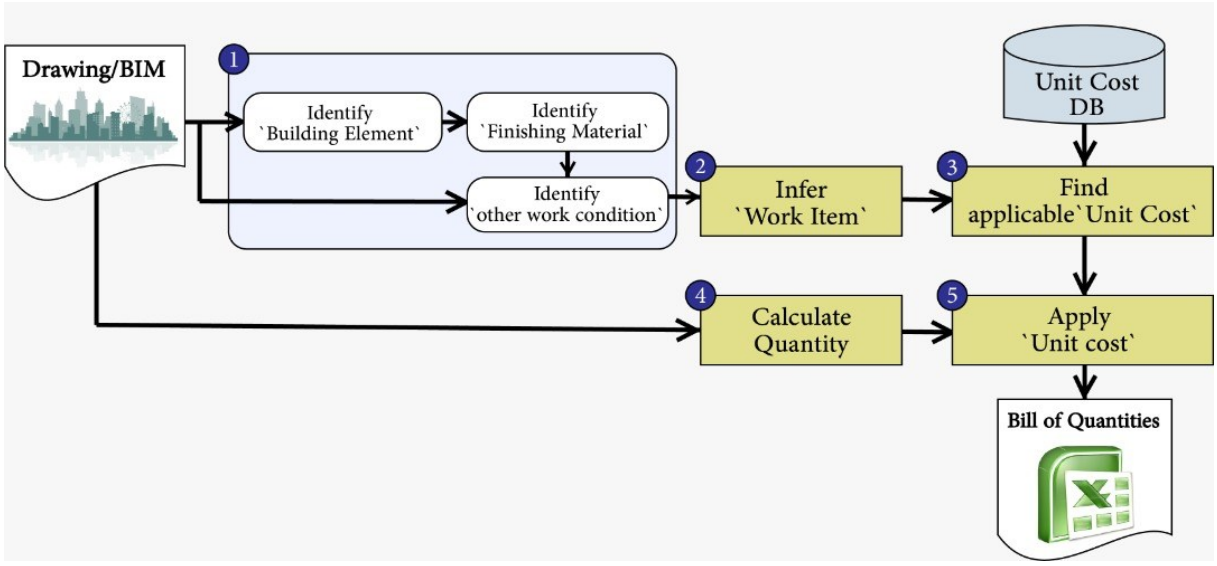


Figure 7 General process of cost estimation, figure from Lee et al. (2014)

3.7.1 Traditional Cost estimation

Traditional quantity takeoff is a manual process based on drawings or models. In this approach, estimators need to go through each different drawing sheet or 3D model and determine the quantities. Since it is based on human interpretation, wrong inputs and interpretations are common due to the task's complexity (Monteiro and Martins, 2013). This process is time-consuming, error-prone, and based on human interpretation. Several publications like Elbeltagi et al. (2014), Holm (2005), Monteiro and Martins (2013), and Sacks et al. (2018), in their studies stated that the dependency on human interpretation can ends up in different results among different quantity surveyors. Whang and Park (2016) described that the designer and contractor's quantity surveyor could come up with different quantities despite following the same documents. Interestingly, Arayici et al. (2011) compared the qualification of quantity surveyors and design teams and found that quantity surveyors are often less qualified than the design team. Jadid and Idrees (2007) showed that linking DWG files with the bill of quantities gave more reliable and accurate results than traditional methods.

3.7.2 Model-based Cost Estimation

Sattineni and Bradford (2011) stated automated quantity takeoff as one of the important BIM uses in cost estimation. According to their results, most organizations suffer from not having skilled employees in BIM with sufficient experience in cost estimating. Nagalingam et al. (2013) report an 80% reduction in spent time due to adopting BIM for

cost estimation. Sacks et al. (2018) describe BIM-based quantity takeoff as a new approach. They believe that this approach can provide more accurate results and decrease the time and costs required to do the quantity takeoff.

4 Findings

The following chapter presents findings through the interviews and the document study for the case project (as mentioned before, in total 12 interviews were conducted in this investigation, 7 interviews out of these 12 were during the pilot study for the course TBA4530 Prosjektledelse og anleggsteknikk, fordypningsprosjekt). The findings in this chapter are discussed in the next chapter concerning the findings from the literature study.

This study considers people, process, and technology to be the three main cornerstones of digital transformation, owing to their importance as mentioned in subchapter 3.2. Therefore, the findings are sorted into three subdivisions of people, process, and technology, having in mind the three research questions as below:

1. How is cost estimation practiced in infrastructure projects?
2. What is hindering automated cost estimation?
3. How can automated cost estimation be further developed?

It worth mentioning that even though the findings are sorted into the subdivisions above however they are interconnected, and some findings have relevancy to more than one of the subdivisions. This relevancy is discussed in the next chapter.

4.1 People

In the investigated case, a semi-automated cost estimation was practiced. All the interviewees directly and unanimously mentioned a semi-automated cost estimation. Moreover, some interviewees used the terms like "*a semi-automated cost estimation with a low level of automatization*" and "a *semi-automated cost estimation closer to the traditional method.*"

According to the respondents, the cost estimation involved extracting quantities from models, entering them in spreadsheets, and multiplying them with unit prices. Despite extracting quantities from models, some of the respondents mentioned that a few quantities were manually calculated. They added that these quantities have a minor share of the total quantities (around 5% of the total quantities). The quantity takeoff in the early stage is performed only for a specific list of cost items provided and requested by the contractor. These cost items are identified and agreed by the contractor and client in a collaboration as the most important cost items with a large share on the total cost of different alternatives. The list of these items is studied through document study (Main layout cost image per meter of road) received during the interviews for a more in-depth investigation. During the early phase of the project, the design team was responsible for extracting the quantities demanded by the contractor. However, in the later stage, during the detailed design phase, the contractor conducted the quantity takeoff themselves. Even though some of the interviewees from the design team (except the project manager from the design team) mentioned that the contractor did some quantity takeoff for some of the elements, they were not aware that the contractor did a through quantity takeoff in the detailed design phase.

In the early stage of the project, while all four investigated disciplines had a predefined workflow for quantity takeoff, they practiced it differently. The workflow was even practiced differently within the disciplines. Often responsible people within the disciplines applied the workflow they were most familiar with due to time restrictions. The interviewees from the design team mentioned that time restriction caused the project's feasibility to be in the priority rather than following the predefined workflow. Some respondents believe that it is impossible to adopt an automated model-based cost estimation due to time restrictions and several deliveries of quantities in this type of project delivery method.

Two challenges hindering an automated model-based cost estimation were identified considering the people component. During the interviews, the first challenge introduced and identified was little experience with model-based quantity takeoff and IPD projects. This challenge was mentioned directly by some of the respondents during the interviews. Some respondents mentioned that some people did not have enough experience with BIM and model-based quantity takeoff. So, in the case of the people component, inexperienced people with automated model-based cost estimation and, in some cases, with BIM prevented moving toward a fully automated workflow.

Moreover, according to respondents, it was their first experience working on an IPD project for some people. Respondent mentioned that this issue sometimes shifted their mindsets toward other workflows. This issue was more evident in one discipline. As mentioned by four of the respondents, "Most of the people involved in the project were more familiar with doing a traditional engineering rather than collaborating between the client, the contractor, and the consultant." The second challenge was lack of a digital mindset.

These challenges were restricting a fully automated estimation, especially for two of the disciplines. As mentioned, time limitation was explained to cause incomplete models and a shift towards a traditional mindset.

4.2 Process

Concerning processes, a semi-automated cost estimation was noticed. As mentioned by respondents, the cost estimation process included extracting quantities from models and manual copy-paste or direct exporting to spreadsheets. Concerning exporting quantities from models to spreadsheets, interviewees mentioned that the exported data needed some adjustments. Respondents explained that the need for adjustments was due to the difference between the model outputs and the demanded quantities requested by the contractor. Time pressure and unprecise mapping of prescribed cost classification codes for model objects were the main challenges.

There were clear indications that the Integrated Project Delivery method (IPD) caused an increased workload and thereby time pressure in the early phases of the project. As stated in the contract and based on the document study, this project used an integrated project delivery method (IPD) with shared responsibility among stakeholders involved. For an IPD, an agreed target price based on a sound evaluation of several alternatives is important. According to the respondents, the increased workload due to evaluating several alternatives prevented automated model-based cost estimation. Therefore, the traditional workflow was used instead of spending time on developing automated workflows. Respondents mentioned IPD and its features as one of the outstanding factors affecting adopting the cost estimation method. The increased workload in the early phase

due to IPD was explained to cause incomplete models, time restriction, and a shift towards a traditional workflow.

A mismatch between mapping of the prescribed cost classification codes to model objects was identified. While BIM is predominantly object-based, the cost classification system is process-oriented. This resulted in problems with mapping the correct classification codes to the corresponding model objects.

4.3 Technology

Regarding technology, the software used by different stakeholders in different disciplines was investigated. The design team and the contractor used different software for quantity takeoff resulting in approximately 10 % deviation in the extracted quantites. The software used by the contractor was regarded to be better suited, and the contractor became responsible for the quantity takeoff after the project's early phase. Except for this, there were no identified technology challenges worth mentioning.

5 Discussion

In this chapter, established literature and the findings from the literature study is used to discuss the findings from the interviews and document studies with the aim to answer the research questions. Furthermore, personal opinions and understanding of the author also is included. This chapter used the same subdivisions of people, process, and technology as in previous chapter with the aim to preserve consistency of the report. However, research questions are discussed in each subdivision.

5.1 People

Unanimously mentioned by the interviewees, a semi-automated cost estimation was practiced in this project. Even though this statement as their representation of view might be derived considering the whole cost estimation process regardless of the subdivision done in this research, other indicators can confirm this statement only by considering the people component. It seems that most of infrastructure projects in Norway are practicing a semi-automated method. This statement is based on the answers and the experience background of the interviewees.

In this study, the main challenge was little experience with BIM combined with a traditional mindset. This challenge affected the cost estimation in different ways and directly and indirectly lead to unmatured and simple models in the early phases. Unmatured and simple models prevented automated model-based cost estimation. Later, a detailed model suited for automated model-based quantity takeoff was produced.

The importance of education and training was undeniable. Even the respondents themselves mentioned this need. Ali et al. (2016) noted the importance of educating and training quantity surveyors to benefit from 5D BIM. According to their study, educating toward BIM framework for quantity surveyors is fundamental. Their study described the educational framework for quantity surveyors in the context of BIM implementation. Babatunde et al. (2018) also mentioned that education and BIM modeling training are crucial in architecture, engineering, and construction. Not having enough experience with model-based cost estimation result in increased workload and incomplete models. However, the increased workload can also result in unmatured and incomplete models in the early phase facing time limitations. Unmatured and incomplete models are identified as the main restriction hindering automated model-based cost estimation.

Besides training, a change of mindset is necessary. All project participants need to change mindsets and adopt model-based thinking. Lack of experience with model-based cost estimation enhanced the urge to fall back to traditional routines and being unable to take potential advantages of digitalization; the traditional routines are costly, time-consuming, and error-prone. Monteiro and Martins (2013) mentioned that traditional cost estimation is based on human interpretations that makes the results uncertain, less reliable, and more error prone.

In this case study, IPD as a new project delivery method for the project team also magnified the importance of relevant training and mindset. A change from traditional mindsets to IPD based mindset will help the project team by saving time and cost. The importance of relevant training considering IPD was also mentioned in the literature.

Ghassemi and Becerik-Gerber (2011) in their research highlighted training of individuals, procurement ability, and collaborative technology as one of the crucial criteria that must be implemented to achieve a successful transition to fully integrated project.

Implementing and transition toward IPD contracts also requires solving some critical barriers. As Ghassemi and Becerik-Gerber (2011) mentioned, one of these barriers identified from nine case studies is training. All IPD parties need to change their mindsets from a traditional mindset and adopt IPD based thinking. The need for switching from a traditional mindset also applies to cost estimation and quantity takeoff, not just as a requirement for IPD projects but also to be able to move toward automated processes and workflow. As two of the respondents also mentioned this fact, changing mindset from traditional engineering was challenging.

5.2 Process

For this study, the author adopted the following definition set from AIA and Construction (2007) "at minimum, an integrated project includes tight collaboration between the owner, architect/engineer, and builders that are ultimately responsible for construction of the project, from early design through project handover." IPD attempts to improve project outcomes through a collaboration between the different parties, and several projects and studies demonstrated its benefits (Kent and Becerik-Gerber, 2010, Lahdenperä, 2012). Enhanced collaboration was also stressed during interviews. The early involvement of contractors as a feature of IPD resulted in better collaboration and better solutions. However, it increased the design team's workload to find the best solution, especially during the early phases. Increased workload resulting from more concentration toward finding the most cost-optimized solution resulted in simplified and unmatured models before detailed design. This issue makes it hard to adopt automated model-based cost estimation in this phase. All relevant publications on this topic emphasize having a mature and detailed BIM model as a crucial factor to adapt to automated model-based cost estimation.

The respondents believe that the extra workload during the early phases was the main reason hindering automated model-based cost estimation. This issue was also identified as one of the limitations of adopting model-based cost estimation in another study (Naneva et al., 2020).

According to several publications (Matipa et al., 2009, Tiwari et al., 2009, Sunil et al., 2015, Ismail et al., 2018), automated model-based cost estimation is less time and cost-consuming than traditional and semi-automated cost estimation. In this case, the authors believe that the change in project delivery method was challenging regarding the contractor's early involvement and requesting for comparing different alternatives. Increased workload resulted in time limitation in the early phases. The authors believe that this issue can be solved by allowing more time during the early phases. In case of not having sufficient experience, this solution can also cover that issue. Naneva et al. (2020), in their study, also mentioned this limitation. However, in their research, incomplete models were not identified as a result of time limitation directly.

5.3 Technology

Regarding the technology component, this investigation identified more maturity levels comparing to the other two components. This statement is confirmed and mentioned in the literature study. As Mêda et al. (2020) mentioned in their study, "The findings evidence that "Technological dimension" is, in general, more mature than the others,

meaning that efforts must concentrate on people motivations and added value of the transformation at "process level." Smartsheet (2019) also pointed out this issue in organizations. They mentioned that technology alone is not enough to answer existing problems. They advised a more balance between all three components of the golden triangle.

Concerning technology, the software used for quantity takeoff represented a challenge. Different software has different approaches and levels of accuracy for quantity takeoff. In the studied case, the software used by the design team and software used by the contractor extracted quantities with an approximate difference of 10 % from the same model. This difference was mainly due to the different levels of accuracy and the different numerical methods used in each software for quantity takeoff. Considering this difference in the extracted quantities and since the contractor was the main responsible party for the cost estimation in this project, the responsibility of quantity takeoff was moved from the design team to the contractor. There was a need for a software that could extract more precise quantities and an agreement to use the same software among different parties involved in the project.

6 Conclusion

That accurate and reliable cost estimation is crucial in all industries, and automated cost estimation can be beneficial in several aspects was an undeniable fact during this study. This statement was mentioned in several previous studies as mentioned before and mentioned directly through the interviews by interviewees Fürstenberg and Lædre (2019). This study set out to investigate how infrastructure projects practice cost estimation, what are hindering automated cost estimation and how automated cost estimation can be further developed. The findings relate to an infrastructure project using a Norwegian standard for specification of work but are considered relevant for projects in other contexts.

When it comes to findings, current cost estimation practice with manual copy-pasting of quantities from the BIM to a spreadsheet with prices appeared to be time-consuming, error-prone, and not efficient. As an IPD project with a clear need for optimization in terms of productivity (costs) and project value for end users, the designers in this case had to spend resources on evaluation of alternative solutions. The need to evaluate different alternatives increased the workload in the early phase. The involved disciplines experienced an increased workload compared to what they expected upfront. The designers got pressured on time, so they were not able to update the models before quantity takeoff. With incomplete models, an automated cost estimation as originally intended was difficult and impossible in some cases. However, the project participants saw that automated model-based cost estimation represented a huge potential for fast evaluation of alternative solutions compared to current cost estimation practice.

Hinders for automated cost estimation were related to both people and process. Concerning people, some of the project participants seemed to possess resistance to change their way of working. Surprisingly, they seemed to miss the necessary digital mindset. In some cases, they were not motivated to change their workflow. Moreover, not having enough experience with model-based cost estimation and BIM in some cases also resulted in time pressure and shifting to traditional workflow considering feasibility of the project as the priority.

Concerning process, the increased workload – and time pressure – caused by the IPD arrangement resulted in incomplete models that hindered automated cost estimation. It worth to mention that to some extent increased workload was also due to not having enough experience with model-based quantity takeoff. In addition, problems with attaching correct classification codes from the standard specification of work to objects in BIM hindered an automated workflow. This issue was due to two main reasons, first the difference between process-oriented standard classifications and BIM as an object-oriented entity. Second reason was due to not having enough experience in some cases that makes the mapping process challenging. The identified technology hinders were not worth mentioning. The technology component identified more mature than two other components of the golden triangle.

Suggested improvements for model-based cost estimation include persistent relevant training since it takes time to get accustomed to new ways of working. The necessity of training was also mentioned in several publications. In addition, making motivation through introducing the potential benefits of the new method. Further, model-based cost

estimation requires alignment between todays object-oriented BIM and the process-oriented standard specification of work for infrastructure projects. Future studies of automated model-based cost estimation should not concentrate on technology alone but must include the main cornerstones of people and processes.

7 Further work

This study advises more investigations into the subject by considering the benefits of adopting an automated BIM-based cost estimation. For this sake, the author and his supervisor and co-supervisor discussed the possibility of a comparative study as another paper this summer. For future studies, it is suggested to investigate projects with different project delivery methods. We also suggest investigating other projects in other countries by considering the map the differences and generalizing the findings. We also suggest studying the next steps of cost estimation, considering unit pricing, and considering all life cycles of the projects, including detailed design.

References

ADLER, E. & CLARK, R. 2011. An Invitation to Social Research: How It's Done . Belmont, CA: Thomson. Wadsworth Publishing Co.

ADMINISTRATION, N. P. R. 2018a. Norwegian Public Roads Administration 2018a. R761; Prosesskode 1; Standard beskrivelse for vegkontrakter; Hovedprosess 1-7, Oslo, Directorate of Public Roads and Transport Department.

ADMINISTRATION, N. P. R. 2018b. Norwegian Public Roads Administration 2018b. R762; Prosesskode 2; Standard beskrivelse for bruer og kaier; Hovedprosess 8, Oslo, Directorate of Public Roads and Transport Department.

AIA, C. & CONSTRUCTION, M. 2007. Integrated project delivery: a working definition. The American Institute of Architects, California Council, Sacramento.

ALHASAN, S., KUMAR, B. & THANIKAL, J. V. 2017. Effectiveness of implementing 5D functions of building information modeling on professions of quantity surveying: a review. International Journal of Civil Engineering and Technology, 8, 783-800.

ALI, K. N., MUSTAFFA, N. E., KEAT, Q. J. & ENEGBUMA, W. I. 2016. Building information modelling (BIM) educational framework for quantity surveying students: The Malaysian perspective. Journal of Information Technology in Construction (ITcon), 21, 140-151.

ALLISON, M., ASHCRAFT, H., CHENG, R., KLAWENS, S. & PEASE, J. 2018. Integrated project delivery: an action guide for leaders.

ALUFOHAI, A. Adoption of building information modeling and Nigeria's quest for project cost management. FIG Working Week, 2012. 6-10.

ANDERSEN, B., SAMSET, K. & WELDE, M. 2016. Low estimates–high stakes: Underestimation of costs at the front-end of projects. International Journal of Managing Projects in Business.

ARAYICI, Y., COATES, P., KOSKELA, L., KAGIOGLOU, M., USHER, C. & O'REILLY, K. 2011. BIM adoption and implementation for architectural practices. Structural survey.

AZHAR, S. 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11, 241-252.

BABATUNDE, S. O., EKUNDAYO, D., BABALOLA, O. & JIMOH, J. A. 2018. Analysis of the drivers and benefits of BIM incorporation into quantity surveying profession. Journal of Engineering, Design and Technology.

BABATUNDE, S. O., PERERA, S., EKUNDAYO, D. & ADELEYE, T. E. 2019. An investigation into BIM-based detailed cost estimating and drivers to the adoption of BIM in quantity surveying practices. Journal of Financial Management of property and Construction.

BLUMBERG, B., COOPER, D. & SCHINDLER, P. 2014. EBOOK: Business Research Methods, McGraw Hill.

BONNET, D. & NANDAN, P. 2011. Transform to the power of digital: Digital transformation as a driver of corporate performance. report, Capgemini Consulting.

BOON, J. & PRIGG, C. Evolution of quantity surveying practice in the use of BIM–the New Zealand experience. Proceedings of the CIB International Conference on Management and Innovation for a Sustainable Built Environment, 2012. 84-98.

BORRMANN, A., KÖNIG, M., KOCH, C. & BEETZ, J. 2018. Building information modeling: why? What? How? Building information modeling. Springer.

BOUSQUET, O., BOUCHERON, S. & LUGOSI, G. Introduction to statistical learning theory. Summer School on Machine Learning, 2003. Springer, 169-207.

BOWEN, G. A. 2009. Document analysis as a qualitative research method. Qualitative research journal.

BRYMAN, A. 2016. Social research methods, Oxford university press.

BUSCH, T. 2013. Akademisk skriving for bachelor-og masterstudenter, Fagbokforl.

CHAN, I., LIU, A. & CHEN, B. Management strategies for 5D-BIM adoption in Hong Kong. Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate, 2018. Springer, 1023-1039.
CHOI, J., KIM, H. & KIM, I. 2015. Open BIM-based quantity take-off system for schematic estimation of building frame in early design stage. Journal of Computational Design and Engineering, 2, 16-25.
CLARK, M. 2019. A framework for BIM model-based construction cost estimation.
COSTIN, A., ADIBFAR, A., HU, H. & CHEN, S. S. 2018. Building Information Modeling (BIM) for transportation infrastructure–Literature review, applications, challenges, and recommendations. Automation in Construction, 94, 257-281.
CRESWELL, J. W. & CRESWELL, J. D. 2017. Research design: Qualitative, quantitative, and mixed methods approaches, Sage publications.
DE COUTO NASCIMENTO, V., DE CASTRO FERREIRA CONTI, A. C., DE ALMEIDA CARDOSO, M., VALARELLI, D. P. & DE ALMEIDA-PEDRIN, R. R. 2016. Impact of orthodontic treatment on self-esteem and quality of life of adult patients requiring oral rehabilitation. The Angle Orthodontist, 86, 839-845.
DEGRYSE, C. 2016. Digitalisation of the economy and its impact on labour markets. ETUI research paper-working paper.
DICICCO-BLOOM, B. & CRABTREE, B. F. 2006. The qualitative research interview. Medical education, 40, 314-321.
EASTMAN, C. M. 2018. Building product models: computer environments supporting design and construction, CRC press.
EASTMAN, C. M., EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors, John Wiley & Sons.
EBRAHIMI, G. & DOWLATABADI, H. 2019. Perceived challenges in implementing integrated project delivery (IPD): insights from stakeholders in the US and Canada for a path forward. International Journal of Construction Education and Research, 15, 291-314.
ELBELTAGI, E., HOSNY, O., DAWOOD, M. & ELHAKEEM, A. 2014. BIM-based cost estimation/monitoring for building construction. International Journal of Engineering Research and Applications, 4, 56-66.
ENEGBUMA, W. I., ALIAGHA, G. U. & ALI, K. N. 2015. Effects of perceptions on BIM adoption in Malaysian construction industry. Jurnal Teknologi, 77.
ENGEBØ, A., LÆDRE, O., YOUNG, B., LARSSEN, P. F., LOHNE, J. & KLAKEGG, O. J. 2020. Collaborative project delivery methods: A scoping review. Journal of Civil Engineering and Management, 26, 278-303.
FEAGIN, J. R., ORUM, A. M. & SJOBERG, G. 1991. A case for the case study, UNC Press Books.
FENG, C.-W., CHEN, Y.-J. & HUANG, J.-R. 2010. Using the MD CAD model to develop the time–cost integrated schedule for construction projects. Automation in Construction, 19, 347-356.
FIRAT, C. E., ARDITI, D., HAMALAINEN, J.-P., STENSTRAND, J. & KIIRAS, J. 2010. Quantity take-off in model-based systems.
FISCHER, M., ASHCRAFT, H. W., REED, D. & KHANZODE, A. 2017. Integrating project delivery, John Wiley & Sons.
FÜRSTENBERG, D. Information Management in AEC Projects: A Study of Applied Research Approaches. International Conference on Computing in Civil and Building Engineering, 2020. Springer, 272-284.
FÜRSTENBERG, D. & LÆDRE, O. Application of BIM design manuals: a case study. Proceedings of the 27th Annual Conference of the International Group for Lean Construction (IGLC), Dublin, Ireland, 2019. 145-156.
FÜRSTENBERG, D., T. GULICHSEN, O. LÆDRE AND E. HJELSETH. BIM-based cost estimation in a road project – proof of concept and practice. 13th European Conference on Product & Process Modeling (ECPPM), 2021.

GASSMANN, O., FRANKENBERGER, K. & CSIK, M. 2014. Revolutionizing the business model–St. Gallen business model navigator. Management of the Fuzzy Front End of Innovation, 18 (3), 89–97.
GERRING, J. 2004. What is a case study and what is it good for? American political science review, 341-354.
GHASSEMI, R. & BECERIK-GERBER, B. 2011. Transitioning to integrated project delivery: Potential barriers and lessons learned. Lean construction journal.
HARTMANN, T., VAN MEERVELD, H., VOSSEBELD, N. & ADRIAANSE, A. 2012. Aligning building information model tools and construction management methods. Automation in construction, 22, 605-613.
HENRIETTE, E., FEKI, M. & BOUGHZALA, I. 2015a. The shape of digital transformation: a systematic literature review. MCIS 2015 proceedings, 431-443.
HENRIETTE, E., FEKI, M. & BOUGHZALA, I. 2015b. The shape of digital transformation: a systematic literature review. MCIS 2015 proceedings, 10, 431-443.
HJELSETH, E. 2017. BIM understanding and activities.
HOLM, L. 2005. Construction cost estimating: process and practices, Prentice Hall.
ISMAIL, N. A. A., IDRIS, N. H., RAMLI, H., SAHAMIR, S. R. & ROOSHDI, R. R. R. M. 2018. Sustainable BIM-based cost estimating for quantity surveyors. Chemical Engineering Transactions, 63, 235-240.
ISMAIL, N. A. A. B., DROGEMULLER, R., BEAZLEY, S. & OWEN, R. A review of BIM capabilities for quantity surveying practice. Proceedings of the 4th International Building Control Conference 2016 (IBCC 2016)[MATEC Web of Conferences, Volume 66]:, 2016. EDP Sciences, 1-7.
JADID, M. N. & IDREES, M. M. 2007. Cost estimation of structural skeleton using an interactive automation algorithm: A conceptual approach. Automation in construction, 16, 797-805.
JALALI, S. & WOHLIN, C. Systematic literature studies: database searches vs. backward snowballing. Proceedings of the 2012 ACM-IEEE international symposium on empirical software engineering and measurement, 2012. IEEE, 29-38.
JAN, S.-H., HO, S.-P. & TSERNG, H.-P. 2013. Applications of building information modeling (BIM) in knowledge sharing and management in construction. International Journal of Civil and Environmental Engineering, 7, 828-832.
JOHNSON, R. B. & CHRISTENSEN, L. 2019. Educational research: Quantitative, qualitative, and mixed approaches, Sage publications.
JRADE, A. & ALKASS, S. 2001. A conceptual cost estimating computer system for building projects. AACE International Transactions, IT91.
KELLY, S. E., BOURGEAULT, I. & DINGWALL, R. 2010. Qualitative interviewing techniques and styles. The SAGE handbook of qualitative methods in health research, 307-326.
KENT, D. C. & BECERIK-GERBER, B. 2010. Understanding construction industry experience and attitudes toward integrated project delivery. Journal of construction engineering and management, 136, 815-825.
KULASEKARA, G., JAYASENA, H. S. & RANADEWA, K. Comparative effectiveness of quantity surveying in a building information modelling implementation. The Second World Construction Symposium, 2013. 101-107.
KUNZ, J. & FISCHER, M. 2012. Virtual design and construction: themes, case studies and implementation suggestions. Center for Integrated Facility Engineering, Stanford University.
LAHDENPERÄ, P. 2012. Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. Construction management and economics, 30, 57-79.
LEE, S.-K., KIM, K.-R. & YU, J.-H. 2014. BIM and ontology-based approach for building cost estimation. Automation in construction, 41, 96-105.
LEONARD-BARTON, D. 1990. A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites. Organization science, 1, 248-266.

LIU, H., LU, M. & AL-HUSSEIN, M. 2016. Ontology-based semantic approach for construction-oriented quantity take-off from BIM models in the light-frame building industry. Advanced Engineering Informatics, 30, 190-207.
LU, Q. 2015. Evaluation of the BIM adoption for civil infrastructure and development of a 5D BIM financial decision making framework.
LUTH, G. P., SCHORER, A. & TURKAN, Y. 2014. Lessons from using BIM to increase design-construction integration. Practice periodical on structural design and construction, 19, 103-110.
MA, Z. & LIU, Z. 2014. BIM-based intelligent acquisition of construction information for cost estimation of building projects. Procedia Engineering, 85, 358-367.
MA, Z., WEI, Z. & ZHANG, X. 2013. Semi-automatic and specification-compliant cost estimation for tendering of building projects based on IFC data of design model. Automation in Construction, 30, 126-135.
MATIPA, W. M., KELLIHER, D. & KEANE, M. 2009. A strategic view of ICT supported cost management for green buildings in the quantity surveying practice. Journal of financial management of property and construction.
MATT, C., HESS, T. & BENLIAN, A. 2015. Digital transformation strategies. Business & Information Systems Engineering, 57, 339-343.
MCINTOSH, M. J. & MORSE, J. M. 2015. Situating and constructing diversity in semi-structured interviews. Global qualitative nursing research, 2, 2333393615597674.
MÊDA, P., SOUSA, H., GONÇALVES, M., CALVETTI, D., DIAS, P. & CAMARGO, F. 2020. PEOPLE, PROCESS, TECHNOLOGY IN CONSTRUCTION 4.0-BALANCING KNOWLEDGE, DISTRUST AND MOTIVATIONS.
MESSNER, J., ANUMBA, C., DUBLER, C., GOODMAN, S., KASPRZAK, C., KREIDER, R., LEICHT, R., SALUJA, C. & ZIKIC, N. 2019. BIM Project Execution Planning Guide (v. 2.2).
MILLER, J. B., GARVIN, M. J., IBBS, C. W. & MAHONEY, S. E. 2000. Toward a new paradigm: Simultaneous use of multiple project delivery methods. Journal of Management in Engineering, 16, 58-67.
MONTEIRO, A. & MARTINS, J. P. 2013. A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. Automation in construction, 35, 238-253.
MOORE, S. 2015. Digitalization or Automation—Is There a Difference. Haettu, 7, 2017.
NAGALINGAM, G., JAYASENA, H. S. & RANADEWA, K. Building information modelling and future quantity surveyor's practice in Sri Lankan construction industry. Second World Construction Symposium, 2013. 81-92.
NANEVA, A., BONANOMI, M., HOLLBERG, A., HABERT, G. & HALL, D. 2020. Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context. Sustainability, 12, 3748.
OLSEN, D. & TAYLOR, J. M. 2017. Quantity take-off using building information modeling (BIM), and its limiting factors. Procedia engineering, 196, 1098-1105.
PARVIAINEN, P., TIHINEN, M., KÄÄRIÄINEN, J. & TEPPOLA, S. 2017. Tackling the digitalization challenge: how to benefit from digitalization in practice. International journal of information systems and project management, 5, 63-77.
POLIT, D. F. & BECK, C. T. 2010. Generalization in quantitative and qualitative research: Myths and strategies. International journal of nursing studies, 47, 1451-1458.
SACKS, R., EASTMAN, C., LEE, G. & TEICHOLZ, P. 2018. BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers, John Wiley & Sons.
SALMINEN, A., KAUPPINEN, K. & LEHTOVAARA, M. 1997. Towards a methodology for document analysis. Journal of the American Society for Information Science, 48, 644-655.
SAMSET, K. F. 2014. Prosjekt i tidligfasen: valg av konsept, Fagbokforl.
SATTINENI, A. & BRADFORD, R. H. 2011. Estimating with BIM: A survey of US construction companies. Proceedings of the 28th ISARC, Seoul, Korea, 564, 569.

SHELBOURN, M., BOUCHLAGHEM, N., ANUMBA, C. & CARRILLO, P. 2007. Planning and implementation of effective collaboration in construction projects. Construction Innovation.
SHOU, W., WANG, J., WANG, X. & CHONG, H. Y. 2015. A comparative review of building information modelling implementation in building and infrastructure industries. Archives of computational methods in engineering, 22, 291-308.
SMARTSHEET. 2019. Everything You Need to Know about the People, Process, Technology Framework [Online]. Available: https://www.smartsheet.com/content/people-process-technology [Accessed].
SPRAGUE JR, R. H. 1995. Electronic document management: Challenges and opportunities for information systems managers. MIS quarterly, 29-49.
STOLTERMAN, E. & FORS, A. C. 2004. Information technology and the good life. Information systems research. Springer.
SUCCAR, B. & KASSEM, M. 2015. Macro-BIM adoption: Conceptual structures. Automation in construction, 57, 64-79.
SUNIL, K., PATHIRAGE, C. & UNDERWOOD, J. The importance of integrating cost management with building information modeling (BIM). 2015. International Postgraduate Research Conference (IPGRC 2015).
SWITZER, C. 2008. Time for change: empowering organizations to succeed in the knowledge economy. Journal of Knowledge Management.
SYKES, W. 1990. Validity and reliability in qualitative market research: A review of the literature. Journal of the Market Research Society.
TIHINEN, M., KÄÄRIÄINEN, J., AILISTO, H., KOMI, M., PARVIAINEN, P., TANNER, H., TUIKKA, T. & VALTANEN, K. 2016. The Industrial Internet in Finland: on route to success?
TIWARI, S., ODELSON, J., WATT, A. & KHANZODE, A. 2009. Model based estimating to inform target value design. AECBytes" Building the Future.
TURNER III, D. W. 2010. Qualitative interview design: A practical guide for novice investigators. The qualitative report, 15, 754.
VAN NEDERVEEN, G. A. & TOLMAN, F. P. 1992. Modelling multiple views on buildings. Automation in Construction, 1, 215-224.
VERHOEF, P. C., BROEKHUIZEN, T., BART, Y., BHATTACHARYA, A., DONG, J. Q., FABIAN, N. & HAENLEIN, M. 2021. Digital transformation: A multidisciplinary reflection and research agenda. Journal of Business Research, 122, 889-901.
VIKO, N. U. L. 2020. Finding sources [Online]. Available: https://innsida.ntnu.no/wiki/-/wiki/Norsk/Finne+kilder [Accessed].
VITÁSEK, S. & MATĚJKA, P. Utilization of BIM for automation of quantity takeoffs and cost estimation in transport infrastructure construction projects in the Czech Republic. IOP Conference Series: Materials Science and Engineering, 2017. IOP Publishing, 012110.
WALKER, D. H. & LLOYD-WALKER, B. M. 2016. Understanding the motivation and context for alliancing in the Australian construction industry. International Journal of Managing Projects in Business.
WEBB, S. P. 2017. Knowledge management: Linchpin of change, Routledge.
WEE, B. V. & BANISTER, D. 2016. How to write a literature review paper? Transport Reviews, 36, 278-288.
WELDE, M. & ODECK, J. 2017. Cost escalations in the front-end of projects–empirical evidence from Norwegian road projects. Transport Reviews, 37, 612-630.
WESTERMAN, G., BONNET, D. & MCAFEE, A. 2014a. Leading digital: Turning technology into business transformation, Harvard Business Press.
WESTERMAN, G., BONNET, D. & MCAFEE, A. 2014b. The nine elements of digital transformation. MIT Sloan Management Review, 55, 1-6.
WHANG, S. & PARK, S. M. 2016. Building Information Modeling (BIM) for project value: Quantity take-off of building frame approach. International Journal of Applied Engineering Research, 11, 7749-7757.

WU, J. & ZHANG, J. AUTOMATED BIM OBJECT CLASSIFICATION TO SUPPORT BIM INTEROPERABILITY. CONSTRUCTION RESEARCH CONGRESS 2018: SUSTAINABLE DESIGN AND CONSTRUCTION AND EDUCATION, 2018.

WU, S., WOOD, G., GINIGE, K. & JONG, S. W. 2014. A TECHNICAL REVIEW OF BIM BASED COST ESTIMATING IN UK QUANTITY SURVEYING PRACTICE, STANDARDS AND TOOLS. JOURNAL OF INFORMATION TECHNOLOGY IN CONSTRUCTION, 19, 534-562.

Appendix

Appendix A

Interview Guide

Automated BIM-Based Cost Estimation

Introduction to interviewer

I am Saeid Morovvati, a current master student at NTNU, studying Project management in civil engineering specialization. As for my academic background, I have a bachelor's and a master's degree in Civil engineering (structural engineering). This interview is regarding my master thesis and specialization project at the Department of Civil and Transport Engineering. The study is supervised by Ola Lædre (Professor at the Department of Civil and Transport Engineering), and David Fürstenberg (Ph.D. candidate NTNU/COWI). I will review BIM-Based cost estimation, process, experiences, advantages, disadvantages, and the potential to implement and develop it for infrastructure projects. This topic has been chosen due to the research gap in this field and the potential for further digitalization improvements in the AEC industry.

General information

- This interview will be sent to the respondents before the interview to give them an insight into the questionnaire.
- This interview is meant to be audio recorded. In case of any conflict of interest in this regard, please notify the interviewer.
- A summarized report of the interview will be written and sent to the respondent to confirm and prevent any misunderstanding.
- Reported data from the respondents will be anonymous, and the interviewer will only mention their roles and positions in case of need.
- In case of need for further information or clarification, the interviewer will contact the respondent.

Introduction to respondent

- Please introduce yourself, and your organization including:
- The main activity area of organization
- Your position and role in the organization
- Your experiences in cost estimation and BIM-based Cost estimation
- Your experience regarding model-based design

Respondent's contact information

- Full name:
- Position and organization:
- Preferred contact way in case of need:
- Email:

- Mobile:

Automated BIM-Based Cost Estimation

Among different factors the interviewer noticed during literature study, he finds these factors most relevant influencing the adaptation of BIM-base cost estimation in AEC industry. The main idea of these questions is to find out:

1. **How cost estimation and especially BIM-based Cost estimation is practiced?**
2. **What are the experiences, challenges, pros, cons, and limitations of these factors facing BIM-base cost estimation?**
3. **How can we achieve 100% automatization in cost estimation?**

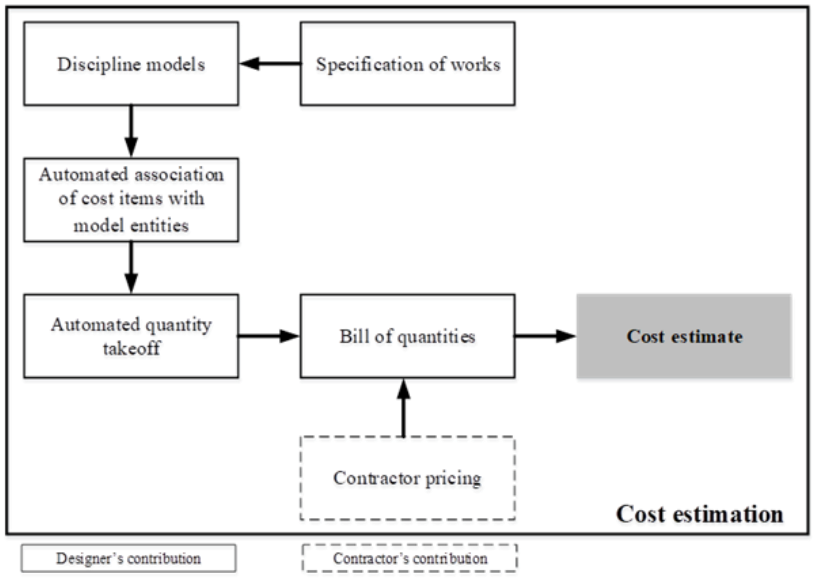


Figure 8: Overall contribution in cost estimation
source: Fürstenberg et al. (2021)

This study is not restricted to the end product (cost estimate); here, we are trying to investigate the process (cost estimation) that results in the product (cost estimate) as well.

Automated BIM-Based Cost Estimation

1. In your opinion, how does the project delivery method affect the cost estimation process?
2. Who is involved in the process of cost estimation?
3. How is cost estimation practiced in this project?
4. To which degree is the cost estimation process automated?
5. Which stakeholder is responsible for the different parts of the cost estimation (Quantity takeoff, bill of quantities, pricing)?
6. What kind of software is used in the process?
7. How did you assess the level of detail of the BIM model in this project?
8. In your opinion, how important are open file formats, e.g., IFC, for establishing an automated cost estimation?
9. How did you map cost items to the BIM entities?
10. How did you identify suitable cost items in the model?
11. How did you manage the dynamic changes in the project with regards to cost estimation?
12. How did you involve additional parameters in cost estimation (e.g. WBS, temporary structures, and unmodeled items and assumptions)?
13. Did you implement environmental costs in the BIM model?
14. How reliable do you consider the current cost estimation method?
15. How efficient is the current method used in this project compared to other cost estimation types (e.g. quantity take-off from 2D drawings or qualitative methods like m^2 bridge deck or meter road)?

In case that you feel there are other factors affecting adaptation of ACE which the interviewer did not mentioned about please let us know.
Is there anything you would like to add?

- **Acknowledgement**

  In advance, I would like to mention that I appreciate your attention, and I am grateful for your sincere participation in this survey.

Appendix B

Conference Paper

Model-based cost estimation for infrastructure projects: a case study

Saeid Morovvati, saeidm@stud.ntnu.no
Norwegian University of Science and Technology (NTNU), Trondheim, Norway

David Fürstenberg, david.furstenberg@ntnu.no
Norwegian University of Science and Technology (NTNU), Trondheim, Norway and COWI, Bergen, Norway

Ola Lædre, ola.ladre@ntnu.no
Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Abstract
The architecture, Engineering, and Construction industry faces an ongoing digitalization. This study investigates how infrastructure projects practice cost estimation, what is hindering automated cost estimation, and how automated cost estimation can be further developed. A case study with integrated project delivery was studied. The collected data were categorized and analyzed after three cornerstones for digital transformation: people, process, and technology. This study finds current practices time-consuming, error-prone, and inefficient. However, model-based cost estimation can result in higher efficiency and fewer errors. Concerning people, relevant training and mindset identified crucial elements. Concerning process, increased workload due to integrated project delivery, time pressure, and problems with attaching correct classification codes to objects in BIM resulted in incomplete models hindering automated cost estimation. The identified hinders concerning technology were not worth mentioning. Suggested improvements include relevant training and alignment between today's object-oriented BIM and the process-oriented standard specification of work for infrastructure projects.

Keywords: Digitalization, Cost estimation, BIM, Model-based, Infrastructure projects

Introduction
Our society faces an ongoing digitalization. Tihinen et al. (2016) introduced digitalization as a major stream of alternating future affairs in society and industry. Degryse (2016) describes it as the fourth industrial revolution. Digital transformation results from accepting and adopting digitalization by organizations and refers to changes at different levels (Parviainen et al., 2017). Along with other components, several publications introduced people, process, and technology as the three main cornerstones of digital transformation within organizations. Bonnet and Nandan (2011), Westerman et al. (2014a) mention the necessity of a reliable connection between these three cornerstones.

As one of the world's largest sectors, the Architecture, Engineering, and Construction (AEC) industry is exposed to this transformation. Feng et al. (2010) and Webb (2017) identified several reasons to encourage the AEC industry to enable digitalization. According to them, construction time, quality of the product, environmental concerns, and social impacts increase digitalization demand. Consequently, within a short period, Building Information Modeling (BIM) as a digital representation of projects has been promoted as the leading technology for digitalization in the AEC industry (Kulasekara et al., 2013, Whang and Park, 2016). Several studies revealed higher efficiency and effectiveness due to BIM use (Whang and Park, 2016), even though there are more benefits that can be unleashed (see for example Fürstenberg and

Lædre, 2019). According to Kunz and Fischer (2012), BIM has a tremendous impact on the AEC industry.

Cost estimation can be essential for a project's success, especially in the AEC industry (Elbeltagi et al., 2014, Ma and Liu, 2014). As mentioned by Choi et al. (2015), cost estimation is an effective tool for decision-making in both the early and detailed design phases of AEC projects. Several publications addressed the need for accurate cost estimation and stressed its vital role in the AEC industry (Allison et al., 2018, Andersen et al., 2016, Ebrahimi and Dowlatabadi, 2019, Ismail et al., 2016, Welde and Odeck, 2017). However, cost estimation can be a manual, time-consuming, and error-prone process (Eastman et al., 2011, Holm, 2005, Ma and Liu, 2014, Monteiro and Martins, 2013). This process involves taking off quantities from either drawings or models and copy-pasting the quantities into spreadsheets or cost estimation software. As projects become larger and more complex, quantity takeoff becomes even more time-consuming, and errors occur more often (Babatunde et al., 2019, Olsen and Taylor, 2017). While BIM shows great potential to solve these issues, Shou et al. (2015) report that studies on BIM mainly focus on buildings and not on infrastructure.

Considering the potential benefits of automated quantity takeoff and the absence of practical research on infrastructure projects, model-based cost estimation for infrastructure projects is investigated through the following research questions:

- How is cost estimation practiced in infrastructure projects?
- What is hindering automated cost estimation?
- How can automated cost estimation be further developed?

This study has some limitations. First, it investigates the quantity takeoff part of cost estimation and not unit pricing. Second, only one project with the Norwegian classification codes for the specification of work was studied. The third limitation is that only the early phase – before detailed design – was investigated.

Finally, it is worth mentioning that the investigated case is the first infrastructure project in Norway to use Integrated Project Delivery (IPD). In Norway, IPD is only applied once before, as described by Aslesen et al. (2018) and Simonsen et al. (2019). The novelty of this project delivery method may confines the validity of some of the discussed experiences and challenges.

Previous work described in literature

Digitalization, one of the most significant trends changing our society with notable impacts on human life, is compared to industrial revolutions in several publications. Its fast spread sets enormous changes in all knowledge fields (Degryse, 2016, Tihinen et al., 2016). Several different definitions depending on the context have been presented for digitalization during past decades. The simplest and common one is the transformation from analog to digital. According to the studies of Gassmann et al. (2014) and Henriette et al. (2015b), digitalization is known as the "Ability to turn existing products or services into digital variants, and thus offer advantages over tangible product". Moore (2015) mentioned new value creation as the result of digitalization; in his idea, only improving without any new creation was not enough. However, in some studies, digitalization is defined as the connection of people, process, and data. According to Westerman et al. (2014b)Westerman et al. (2014b)Westerman et al. (2014b), digital transformation means "The use of technology to radically improve the performance of reach of enterprises". Digital transformation is more about changing roles and ways of working. Digital transformation results from accepting and adopting digitalization and digital technologies (Parviainen et al., 2017). Feng et al. (2010) and Webb (2017) identified several reasons encouraging the construction industry to enable digitalization. According to them, construction time, quality of the product, environmental concerns, and social impacts increase digitalization demand.

Lee et al. (2014) defined cost estimation as "the process of predicting project cost and resource requirements". Cost estimation is a manual and repetitive task prone to human errors (Firat et al., 2010). This uncertain and error-prone nature resulted in uncertainty about the results and a reduction in its reliability. In this study, we used the definition of Messner et al. (2019) for model-based cost estimation. They defined it as "a process in which BIM can be used to assist in the generation of accurate quantity takeoff and cost estimation throughout the

lifecycle of the project". Quantity takeoff is one of the critical components in cost estimation, according to Monteiro and Martins (2013). It can be defined as the process of measuring and counting building elements. Several publications stressed that precise quantity takeoff is necessary for reliable cost estimation in different project phases (Liu et al., 2016, Monteiro and Martins, 2013, Whang and Park, 2016).

Traditional quantity takeoff is a manual process based on drawings or models. In this approach, estimators need to go through each different drawing sheet or 3D model and determine the quantities. Since it is based on human interpretation, wrong inputs and interpretations are common due to the task's complexity (Monteiro and Martins, 2013). This process is time-consuming, error-prone, and based on human interpretation. The dependency on human interpretation can result in different results among different quantity surveyors (Elbeltagi et al., 2014, Holm, 2005, Monteiro and Martins, 2013, Sacks et al., 2018). Whang and Park (2016) described that the designer and contractor's quantity surveyor could come up with different quantities despite following the same documents. Interestingly, Arayici et al. (2011) compared the qualification of quantity surveyors and design teams, and found that quantity surveyors are often less qualified than the design team. Jadid and Idrees (2007) showed that linking DWG files with the bill of quantities gave more reliable and accurate results than traditional methods.

Building Information Modeling (BIM) is important for digital transformation in the AEC industry. According to Sacks et al. (2018), BIM can be defined as "a new approach to design, construction, and facilities management, in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format". During the past decade, BIM has been broadly adopted in the AEC industry. BIM is using for coordinated, consistent and computable building information management in all phases – from design and implementation to maintenance (Lee et al., 2014). Following the emergence of BIM, it has been realized that implementing BIM can result in more efficiency (Wu et al., 2014b).

Sattineni and Bradford (2011) mentioned a rising application rate of BIM within the AEC industry. They stated automated quantity takeoff as one of the important BIM uses in cost estimation. According to their results, most organizations suffer from not having skilled employees in BIM with sufficient experience in cost estimating. Nagalingam et al. (2013) report an 80% reduction in spent time due to adopting BIM for cost estimation. Sacks et al. (2018) describe BIM-based quantity takeoff as a new approach. They believe that this approach can provide more accurate results and decrease the time and costs required to do the quantity takeoff.

Method and Case Description

This study investigates model-based cost estimation in a Norwegian road project through a literature review, a document study, and a case study. As Snyder (2019) described, a literature review is crucial for creating the theoretical framework and building conceptual models. The literature review was used to establish knowledge, create the theoretical framework, find the knowledge gap, define the research questions, structure an interview guide and discuss findings.

A case study followed the literature review. Several publications mention the potential benefits of case study (i.e. Fürstenberg 2020). Gerring (2004) defined a case study as "an intensive study of a single unit with an aim to generalize across a larger set of units". Feagin et al. (1991) introduced a case study as an ideal methodology for a thorough investigation. The studied case was a 7 km four-lane highway project. The case was the first Norwegian infrastructure project with Integrated Project Delivery (IPD). The designer, client, and contractor collaborated closely from the early phases of the project. They were co-located in the project office to improve collaboration. The case was selected because the client had high digital ambitions and expected a mainly model-based design and construction process. The use of drawings should be reduced.

Semi-structured interviews are broadly used as a data collection methodology within qualitative research (McIntosh and Morse, 2015). This research used open-ended semi-structured interviews despite their resource-demanding nature. The semi-structured open-

ended questions allowed an in-depth response from interviewees by enabling the researchers to ask probing questions. The possibility to ask probing questions is mentioned by Turner III (2010) as a potential benefit of semi-structured open-ended interviews. The open-ended questions let the participants express their viewpoints. All interviews were through the Microsoft team. Due to the global pandemic worldwide, there were no possibilities for in-person interviews.

The interviewees included representatives from the designer, the contractor, and the client:

- Three project managers from all three parts
- BIM manager
- Four discipline leaders (road, construction, electrical, and water and sewer)
- Three quantity surveyors from the client-side
- Four discipline BIM coordinators (road, construction, electrical, and water and sewer)

Findings

This study considers people, processes and technology to be the three main cornerstones of digital transformation. It answers three questions, namely: how do infrastructure projects cost estimate cost, what are hindering automated cost estimation and how can automated cost estimation be further developed.

People

In the investigated case, semi-automated cost estimation was practiced. The estimation involved extracting quantities from models, entering them in spreadsheets and multiplying them with unit prices. A few quantities were manually calculated. While all four investigated disciplines had a predefined workflow for quantity takeoff, they practiced it differently. The workflow was even practiced differently within the disciplines. Often the disciplines applied the workflow they were most familiar with due to time restriction.

Two challenges hindering an automated model-based cost estimation were identified. The first challenge was little experience with model-based quantity takeoff. The second challenge was lack of a digital mindset. These challenges were a restricting a fully automated estimation, especially for two of the disciplines. Time limitation was explained to cause incomplete models and a shift towards a traditional mindset.

Process

Concerning processes, a semi-automated cost estimation was noticed. Time pressure and unprecise mapping of prescribed cost classification codes for model objects were the main challenges. There were clear indications that the Integrated Project Delivery method (IPD) caused an increased workload and thereby time pressure in the early phases of the project. For an IPD, an agreed target price based on a sound evaluation of several alternatives is important. According to the respondents, the workload due to evaluating several alternatives prevented automated model-based cost estimation. Traditional workflow was used instead of spending time on developing automated workflows.

A mismatch between mapping of the prescribed cost classification codes to model objects was identified. While BIM is predominantly object-based, the cost classification system is process-oriented. This resulted in problems with mapping the correct classification codes to the corresponding model objects.

Technology

Regarding technology, the software used by different stakeholders in different disciplines was investigated. The design team and the contractor used different software for quantity takeoff resulting in approximately 10 % deviation. The software used by the contractor was regarded to be better suited, and the contractor became responsible for the quantity takeoff after the project's early phase. Except for this, there were no identified technology challenges worth mentioning.

Discussion

People

In this case, the main challenge was little experience with BIM combined with a traditional mindset. This, directly and indirectly, lead to unmatured and simple models in the early phases. Later, a detailed model suited for automated model-based quantity takeoff was produced.

The importance of education and training was undeniable. Even the respondents themselves mentioned a need. Ali et al. (2016) noted the importance of educating and training quantity surveyors to benefit from 5D BIM. According to their study, educating toward BIM framework for quantity surveyors is fundamental. Their study describes the educational framework for quantity surveyors in the context of BIM implementation. Babatunde et al. (2018) also mentioned that education and BIM modeling training are crucial in architecture, engineering, and construction. Not having enough experience with model-based cost estimation result in increased workload and incomplete models. However, the increased workload can also result in unmatured and incomplete models in the early phase facing time limitations. Unmatured and incomplete models are identified as the main restriction hindering automated model-based cost estimation.

Besides training, a change of mindset is necessary. All project participants need to change mindsets and adopt model-based thinking. Lack of experience with model-based cost estimation enhanced the urge to fall back to traditional routines and being unable to take potential advantages of digitalization; the traditional routines are costly, time-consuming, and error-prone.

In this case study, IPD as a new project delivery method for the project team also magnified the importance of relevant training and mindset. A change from traditional mindsets to IPD based mindset will help the project team by saving time and cost.

Implementing and transition toward IPD contracts also requires solving some critical barriers. As Ghassemi and Becerik-Gerber (2011) mentioned, one of these barriers identified from nine case studies is training. All IPD parties need to change their mindsets from a traditional mindset and adopt IPD based thinking. The need for switching from a traditional mindset also applies to cost estimation and quantity takeoff, not just as a requirement for IPD projects but also to be able to move toward automated processes and workflow. As two of the respondents also mentioned this fact, changing mindset from traditional engineering was challenging.

Process

IPD attempts to improve project outcomes through a collaboration between the different parties, and several projects and studies demonstrated its benefits (Kent and Becerik-Gerber, 2010, Lahdenperä, 2012). Enhanced collaboration was also stressed during interviews. The early involvement of contractors as a feature of IPD resulted in better collaboration and better solutions. However, it increased the design team's workload to find the best solution, especially during the early phases. Increased workload resulting from more concentration toward finding the most cost-optimized solution resulted in simplified and unmatured models before detailed design. This issue makes it hard to adopt automated model-based cost estimation in this phase. All relevant publications on this topic emphasize having a mature and detailed BIM model as a crucial factor to adapt to automated model-based cost estimation.

The respondents believe that the extra workload during the early phases was the main reason hindering automated model-based cost estimation. This issue was also identified as one of the limitations of adopting model-based cost estimation in another study (Naneva et al., 2020).

According to several publications (Matipa et al., 2009, Tiwari et al., 2009, Sunil et al., 2015, Ismail et al., 2018), automated model-based cost estimation is less time and cost-consuming than traditional and semi-automated cost estimation. In this case, the authors believe that the change in project delivery method was challenging regarding the contractor's early involvement and requesting for comparing different alternatives. Increased workload resulted in time

limitation in the early phases. The authors believe that this issue can be solved by allowing more time during the early phases. In case of not having sufficient experience, this solution can also cover that issue. Naneva et al. (2020), in their study, also mentioned this limitation. However, in their research, incomplete models were not identified as a result of time limitation directly.

Technology

Regarding technology, the software used for quantity takeoff represented a challenge. Different software has different approaches and levels of accuracy for quantity takeoff. The software used by the design team and software used by the contractor extracted quantities with an approximate difference of 10 %. Therefore, the responsibility of quantity takeoff was moved from the design team to the contractor. There was a need for software that could extract more accurate quantities and an agreement to use the same software with different parties involved in the project.

Conclusion

This study set out to investigate how infrastructure projects practice cost estimation, what are hindering automated cost estimation and how automated cost estimation can be further developed. The findings relate to a infrastructure project using a Norwegian standard for specification of work but are considered relevant for projects in other contexts.

When it comes to findings, current cost estimation practice with manual copy-pasting of quantities from the BIM to a spreadsheet with prices appeared to be time-consuming, error-prone, and not efficient. As an IPD project with a clear need for optimization in terms of productivity (costs) and project value for end users, the designers in this case had to spend resources on evaluation of alternative solutions. The involved disciplines experienced an increased workload compared to what they expected up front. The designers got pressured on time, so they were not able to update the models before quantity takeoff. With incomplete models, an automated cost estimation as originally intended was difficult. However, the project participants saw that automated model-based cost estimation represented a huge potential for fast evaluation of alternative solutions compared to current cost estimation practice.

Hinders for automated cost estimation were related to both people and process. Concerning people, some of the project participants seemed to possess resistance to change their way of working. Surprisingly, they seemed to miss the necessary digital mindset. Concerning process, the increased workload – and time pressure – caused by the IPD arrangement resulted in incomplete models that hindered automated cost estimation. In addition, problems with attaching correct classification codes from the standard specification of work to objects in BIM hindered an automated workflow. The identified technology hinders were not worth mentioning.

Suggested improvements for model-based cost estimation include persistent relevant training since it takes time to get accustomed to new ways of working. Further, model-based cost estimation requires alignment between todays object-oriented BIM and the process-oriented standard specification of work for infrastructure projects. Future studies of automated model-based cost estimation should not concentrate on technology alone but must include the main cornerstones of people and processes.

For future studies it is suggested to investigate projects with different project delivery methods. We also suggest studying next steps of cost estimation and considering unit pricing and considering all life cycle of the projects including detailed design.

References

2020. Facts about E6 Kvål–Melhus. *NyeVeier.*

ADLER, E. & CLARK, R. 2011. An Invitation to Social Research: How It's Done . Belmont, CA: Thomson. Wadsworth Publishing Co.

ADMINISTRATION, N. P. R. 2018a. *Norwegian Public Roads Administration 2018a. R761; Prosesskode 1; Standard beskrivelse for vegkontrakter; Hovedprosess 1-7, Oslo, Directorate of Public Roads and Transport Department.*

ADMINISTRATION, N. P. R. 2018b. *Norwegian Public Roads Administration 2018b. R762; Prosesskode 2; Standard beskrivelse for bruer og kaier; Hovedprosess 8, Oslo, Directorate of Public Roads and Transport Department.*

AIA, C. & CONSTRUCTION, M. 2007. Integrated project delivery: a working definition. *The American Institute of Architects, California Council, Sacramento*.

ALHASAN, S., KUMAR, B. & THANIKAL, J. V. 2017. Effectiveness of implementing 5D functions of building information modeling on professions of quantity surveying: a review. *International Journal of Civil Engineering and Technology,* 8**,** 783-800.

ALI, K. N., MUSTAFFA, N. E., KEAT, Q. J. & ENEGBUMA, W. I. 2016. Building information modelling (BIM) educational framework for quantity surveying students: The Malaysian perspective. *Journal of Information Technology in Construction (ITcon),* 21**,** 140-151.

ALLISON, M., ASHCRAFT, H., CHENG, R., KLAWENS, S. & PEASE, J. 2018. Integrated project delivery: an action guide for leaders.

ALUFOHAI, A. Adoption of building information modeling and Nigeria's quest for project cost management. FIG Working Week, 2012. 6-10.

ANDERSEN, B., SAMSET, K. & WELDE, M. 2016. Low estimates–high stakes: Underestimation of costs at the front-end of projects. *International Journal of Managing Projects in Business*.

ARAYICI, Y., COATES, P., KOSKELA, L., KAGIOGLOU, M., USHER, C. & O'REILLY, K. 2011. BIM adoption and implementation for architectural practices. *Structural survey*.

AZHAR, S. 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering,* 11**,** 241-252.

BABATUNDE, S. O., EKUNDAYO, D., BABALOLA, O. & JIMOH, J. A. 2018. Analysis of the drivers and benefits of BIM incorporation into quantity surveying profession. *Journal of Engineering, Design and Technology*.

BABATUNDE, S. O., PERERA, S., EKUNDAYO, D. & ADELEYE, T. E. 2019. An investigation into BIM-based detailed cost estimating and drivers to the adoption of BIM in quantity surveying practices. *Journal of Financial Management of property and Construction*.

BLUMBERG, B., COOPER, D. & SCHINDLER, P. 2014. *EBOOK: Business Research Methods*, McGraw Hill.

BONNET, D. & NANDAN, P. 2011. Transform to the power of digital: Digital transformation as a driver of corporate performance. *report, Capgemini Consulting*.

BOON, J. & PRIGG, C. Evolution of quantity surveying practice in the use of BIM–the New Zealand experience. Proceedings of the CIB International Conference on Management and Innovation for a Sustainable Built Environment, 2012. 84-98.

BORRMANN, A., KÖNIG, M., KOCH, C. & BEETZ, J. 2018. Building information modeling: why? What? How? *Building information modeling.* Springer.

BOUSQUET, O., BOUCHERON, S. & LUGOSI, G. Introduction to statistical learning theory. Summer School on Machine Learning, 2003. Springer, 169-207.

BOWEN, G. A. 2009a. Document analysis as a qualitative research method. *Qualitative research journal,* 9**,** 27.

BOWEN, G. A. 2009b. Document analysis as a qualitative research method. *Qualitative research journal*.

BRYMAN, A. 2016. *Social research methods*, Oxford university press.

BUSCH, T. 2013. *Akademisk skriving for bachelor-og masterstudenter*, Fagbokforl.

CHAN, I., LIU, A. & CHEN, B. Management strategies for 5D-BIM adoption in Hong Kong. Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate, 2018. Springer, 1023-1039.

CHOI, J., KIM, H. & KIM, I. 2015. Open BIM-based quantity take-off system for schematic estimation of building frame in early design stage. *Journal of Computational Design and Engineering,* 2**,** 16-25.
CLARK, M. 2019. A framework for BIM model-based construction cost estimation.
COSTIN, A., ADIBFAR, A., HU, H. & CHEN, S. S. 2018. Building Information Modeling (BIM) for transportation infrastructure–Literature review, applications, challenges, and recommendations. *Automation in Construction,* 94**,** 257-281.
CRESWELL, J. W. & CRESWELL, J. D. 2017. *Research design: Qualitative, quantitative, and mixed methods approaches*, Sage publications.
DE COUTO NASCIMENTO, V., DE CASTRO FERREIRA CONTI, A. C., DE ALMEIDA CARDOSO, M., VALARELLI, D. P. & DE ALMEIDA-PEDRIN, R. R. 2016. Impact of orthodontic treatment on self-esteem and quality of life of adult patients requiring oral rehabilitation. *The Angle Orthodontist,* 86**,** 839-845.
DEGRYSE, C. 2016. Digitalisation of the economy and its impact on labour markets. *ETUI research paper-working paper*.
DICICCO‐BLOOM, B. & CRABTREE, B. F. 2006. The qualitative research interview. *Medical education,* 40**,** 314-321.
EASTMAN, C. M. 2018. *Building product models: computer environments supporting design and construction*, CRC press.
EASTMAN, C. M., EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*, John Wiley & Sons.
EBRAHIMI, G. & DOWLATABADI, H. 2019. Perceived challenges in implementing integrated project delivery (IPD): insights from stakeholders in the US and Canada for a path forward. *International Journal of Construction Education and Research,* 15**,** 291-314.
ELBELTAGI, E., HOSNY, O., DAWOOD, M. & ELHAKEEM, A. 2014. BIM-based cost estimation/monitoring for building construction. *International Journal of Engineering Research and Applications,* 4**,** 56-66.
ENEGBUMA, W. I., ALIAGHA, G. U. & ALI, K. N. 2015. Effects of perceptions on BIM adoption in Malaysian construction industry. *Jurnal Teknologi,* 77.
ENGEBØ, A., LÆDRE, O., YOUNG, B., LARSSEN, P. F., LOHNE, J. & KLAKEGG, O. J. 2020. Collaborative project delivery methods: A scoping review. *Journal of Civil Engineering and Management,* 26**,** 278-303.
FEAGIN, J. R., ORUM, A. M. & SJOBERG, G. 1991. *A case for the case study*, UNC Press Books.
FENG, C.-W., CHEN, Y.-J. & HUANG, J.-R. 2010. Using the MD CAD model to develop the time–cost integrated schedule for construction projects. *Automation in Construction,* 19**,** 347-356.
FIRAT, C. E., ARDITI, D., HAMALAINEN, J.-P., STENSTRAND, J. & KIIRAS, J. 2010. Quantity take-off in model-based systems.
FISCHER, M., ASHCRAFT, H. W., REED, D. & KHANZODE, A. 2017. *Integrating project delivery*, John Wiley & Sons.
FÜRSTENBERG, D. Information Management in AEC Projects: A Study of Applied Research Approaches. International Conference on Computing in Civil and Building Engineering, 2020. Springer, 272-284.
FÜRSTENBERG, D. & LÆDRE, O. APPLICATION OF BIM DESIGN MANUALS: A CASE STUDY.
FÜRSTENBERG, D. & LÆDRE, O. Application of BIM design manuals: a case study. Proceedings of the 27th Annual Conference of the International Group for Lean Construction (IGLC), Dublin, Ireland, 2019. 145-156.
FÜRSTENBERG, D., T. GULICHSEN, O. LÆDRE AND E. HJELSETH. BIM-based cost estimation in a road project – proof of concept and practice. 13th European Conference on Product & Process Modeling (ECPPM), 2021.
GASSMANN, O., FRANKENBERGER, K. & CSIK, M. 2013. The St. Gallen business model navigator.

GASSMANN, O., FRANKENBERGER, K. & CSIK, M. 2014. Revolutionizing the business model–St. Gallen business model navigator. Management of the Fuzzy Front End of Innovation, 18 (3), 89–97.
GERRING, J. 2004. What is a case study and what is it good for? *American political science review***,** 341-354.
GHASSEMI, R. & BECERIK-GERBER, B. 2011. Transitioning to integrated project delivery: Potential barriers and lessons learned. *Lean construction journal*.
HARTMANN, T., VAN MEERVELD, H., VOSSEBELD, N. & ADRIAANSE, A. 2012. Aligning building information model tools and construction management methods. *Automation in construction,* 22**,** 605-613.
HENRIETTE, E., FEKI, M. & BOUGHZALA, I. 2015a. The shape of digital transformation: a systematic literature review. *MCIS 2015 proceedings***,** 431-443.
HENRIETTE, E., FEKI, M. & BOUGHZALA, I. 2015b. The shape of digital transformation: a systematic literature review. *MCIS 2015 proceedings,* 10**,** 431-443.
HJELSETH, E. 2017. BIM understanding and activities.
HOLM, L. 2005. *Construction cost estimating: process and practices*, Prentice Hall.
HWANG, Y.-S. 2004. Automatic quantity takeoff from drawing through IFC model. *Architectural Institute of Korea,* 20**,** 89-97.
ISMAIL, N. A. A., IDRIS, N. H., RAMLI, H., SAHAMIR, S. R. & ROOSHDI, R. R. R. M. 2018. Sustainable BIM-based cost estimating for quantity surveyors. *Chemical Engineering Transactions,* 63**,** 235-240.
ISMAIL, N. A. A. B., DROGEMULLER, R., BEAZLEY, S. & OWEN, R. A review of BIM capabilities for quantity surveying practice. Proceedings of the 4th International Building Control Conference 2016 (IBCC 2016)[MATEC Web of Conferences, Volume 66]:, 2016. EDP Sciences, 1-7.
JADID, M. N. & IDREES, M. M. 2007. Cost estimation of structural skeleton using an interactive automation algorithm: A conceptual approach. *Automation in construction,* 16**,** 797-805.
JALALI, S. & WOHLIN, C. Systematic literature studies: database searches vs. backward snowballing. Proceedings of the 2012 ACM-IEEE international symposium on empirical software engineering and measurement, 2012. IEEE, 29-38.
JAN, S.-H., HO, S.-P. & TSERNG, H.-P. 2013a. Applications of building information modeling (BIM) in knowledge sharing and management in construction. *International Journal of Civil and Environmental Engineering,* 7**,** 828-832.
JAN, S.-H., HO, S.-P. & TSERNG, H.-P. 2013b. Applications of building information modeling (BIM) in knowledge sharing and management in construction. *International Journal of Civil, Structural, Construction and Architectural Engineering,* 7.
JOHNSON, R. B. & CHRISTENSEN, L. 2019. *Educational research: Quantitative, qualitative, and mixed approaches*, Sage publications.
JRADE, A. & ALKASS, S. 2001. A conceptual cost estimating computer system for building projects. *AACE International Transactions***,** IT91.
KELLY, S. E., BOURGEAULT, I. & DINGWALL, R. 2010. Qualitative interviewing techniques and styles. *The SAGE handbook of qualitative methods in health research***,** 307-326.
KENT, D. C. & BECERIK-GERBER, B. 2010. Understanding construction industry experience and attitudes toward integrated project delivery. *Journal of construction engineering and management,* 136**,** 815-825.
KULASEKARA, G., JAYASENA, H. S. & RANADEWA, K. Comparative effectiveness of quantity surveying in a building information modelling implementation. The Second World Construction Symposium, 2013. 101-107.
KUNZ, J. & FISCHER, M. 2012. Virtual design and construction: themes, case studies and implementation suggestions. *Center for Integrated Facility Engineering, Stanford University*.
KWON, O., JO, C.-W. & CHO, J.-W. 2011. Introduction of BIM quality standard for quantity take-off. *Journal of the Korea Institute of Building construction,* 11**,** 171-180.

LAHDENPERÄ, P. 2012. Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction management and economics,* 30**,** 57-79.
LEE, S.-K., KIM, K.-R. & YU, J.-H. 2014. BIM and ontology-based approach for building cost estimation. *Automation in construction,* 41**,** 96-105.
LEONARD-BARTON, D. 1990. A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites. *Organization science,* 1**,** 248-266.
LIU, H., LU, M. & AL-HUSSEIN, M. 2016. Ontology-based semantic approach for construction-oriented quantity take-off from BIM models in the light-frame building industry. *Advanced Engineering Informatics,* 30**,** 190-207.
LU, Q. 2015. *Evaluation of the BIM adoption for civil infrastructure and development of a 5D BIM financial decision making framework.*
LUTH, G. P., SCHORER, A. & TURKAN, Y. 2014. Lessons from using BIM to increase design-construction integration. *Practice periodical on structural design and construction,* 19**,** 103-110.
MA, Z. & LIU, Z. 2014. BIM-based intelligent acquisition of construction information for cost estimation of building projects. *Procedia Engineering,* 85**,** 358-367.
MA, Z., WEI, Z. & ZHANG, X. 2013. Semi-automatic and specification-compliant cost estimation for tendering of building projects based on IFC data of design model. *Automation in Construction,* 30**,** 126-135.
MA, Z., ZHANG, X., WU, S., WEI, Z. & LOU, Z. Framework design for BIM-based construction cost estimating software. Proceedings of the CIB W, 2010. 2010.
MATIPA, W. M., KELLIHER, D. & KEANE, M. 2009. A strategic view of ICT supported cost management for green buildings in the quantity surveying practice. *Journal of financial management of property and construction*.
MATT, C., HESS, T. & BENLIAN, A. 2015. Digital transformation strategies. *Business & Information Systems Engineering,* 57**,** 339-343.
MCINTOSH, M. J. & MORSE, J. M. 2015. Situating and constructing diversity in semi-structured interviews. *Global qualitative nursing research,* 2**,** 2333393615597674.
MÊDA, P., SOUSA, H., GONÇALVES, M., CALVETTI, D., DIAS, P. & CAMARGO, F. 2020. PEOPLE, PROCESS, TECHNOLOGY IN CONSTRUCTION 4.0-BALANCING KNOWLEDGE, DISTRUST AND MOTIVATIONS.
MESSNER, J., ANUMBA, C., DUBLER, C., GOODMAN, S., KASPRZAK, C., KREIDER, R., LEICHT, R., SALUJA, C. & ZIKIC, N. 2019. BIM Project Execution Planning Guide (v. 2.2).
MILLER, J. B., GARVIN, M. J., IBBS, C. W. & MAHONEY, S. E. 2000. Toward a new paradigm: Simultaneous use of multiple project delivery methods. *Journal of Management in Engineering,* 16**,** 58-67.
MONTEIRO, A. & MARTINS, J. P. 2013. A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. *Automation in construction,* 35**,** 238-253.
MOORE, S. 2015. Digitalization or Automation—Is There a Difference. *Haettu,* 7**,** 2017.
NAGALINGAM, G., JAYASENA, H. S. & RANADEWA, K. Building information modelling and future quantity surveyor's practice in Sri Lankan construction industry. Second World Construction Symposium, 2013. 81-92.
NANEVA, A., BONANOMI, M., HOLLBERG, A., HABERT, G. & HALL, D. 2020. Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context. *Sustainability,* 12**,** 3748.
OLSEN, D. & TAYLOR, J. M. 2017. Quantity take-off using building information modeling (BIM), and its limiting factors. *Procedia engineering,* 196**,** 1098-1105.
PARVIAINEN, P., TIHINEN, M., KÄÄRIÄINEN, J. & TEPPOLA, S. 2017. Tackling the digitalization challenge: how to benefit from digitalization in practice. *International journal of information systems and project management,* 5**,** 63-77.
POLIT, D. F. & BECK, C. T. 2010. Generalization in quantitative and qualitative research: Myths and strategies. *International journal of nursing studies,* 47**,** 1451-1458.

SACKS, R., EASTMAN, C., LEE, G. & TEICHOLZ, P. 2018. *BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers*, John Wiley & Sons.
SALMINEN, A., KAUPPINEN, K. & LEHTOVAARA, M. 1997. Towards a methodology for document analysis. *Journal of the American Society for Information Science,* 48**,** 644-655.
SAMSET, K. F. 2014. *Prosjekt i tidligfasen: valg av konsept*, Fagbokforl.
SATTINENI, A. & BRADFORD, R. H. 2011. Estimating with BIM: A survey of US construction companies. *Proceedings of the 28th ISARC, Seoul, Korea,* 564**,** 569.
SHELBOURN, M., BOUCHLAGHEM, N., ANUMBA, C. & CARRILLO, P. 2007. Planning and implementation of effective collaboration in construction projects. *Construction Innovation*.
SHOU, W., WANG, J., WANG, X. & CHONG, H. Y. 2015. A comparative review of building information modelling implementation in building and infrastructure industries. *Archives of computational methods in engineering,* 22**,** 291-308.
SMARTSHEET. 2019. *Everything You Need to Know about the People, Process, Technology Framework* [Online]. Available: https://www.smartsheet.com/content/people-process-technology [Accessed].
SNYDER, H. 2019. Literature review as a research methodology: An overview and guidelines. *Journal of Business Research,* 104**,** 333-339.
SPRAGUE JR, R. H. 1995. Electronic document management: Challenges and opportunities for information systems managers. *MIS quarterly***,** 29-49.
STOLTERMAN, E. & FORS, A. C. 2004. Information technology and the good life. *Information systems research.* Springer.
SUCCAR, B. & KASSEM, M. 2015. Macro-BIM adoption: Conceptual structures. *Automation in construction,* 57**,** 64-79.
SUNIL, K., PATHIRAGE, C. & UNDERWOOD, J. The importance of integrating cost management with building information modeling (BIM). 2015. International Postgraduate Research Conference (IPGRC 2015).
SWITZER, C. 2008. Time for change: empowering organizations to succeed in the knowledge economy. *Journal of Knowledge Management*.
SYKES, W. 1990. Validity and reliability in qualitative market research: A review of the literature. *Journal of the Market Research Society*.
TIHINEN, M., KÄÄRIÄINEN, J., AILISTO, H., KOMI, M., PARVIAINEN, P., TANNER, H., TUIKKA, T. & VALTANEN, K. 2016. The Industrial Internet in Finland: on route to success?
TIWARI, S., ODELSON, J., WATT, A. & KHANZODE, A. 2009. Model based estimating to inform target value design. *AECBytes" Building the Future*.
TKÁČ, M. & MESÁROŠ, P. Potential of 3D laser scanning in construction in connection with Building Information Modelling. Increasing the efficiency of construction through modern methods of construction, Scientific paper proceedings, 2015. 103-110.
TURNER III, D. W. 2010. Qualitative interview design: A practical guide for novice investigators. *The qualitative report,* 15**,** 754.
VAN NEDERVEEN, G. A. & TOLMAN, F. 1992a. Modelling multiple views on buildings. *Automation in Construction,* 1**,** 215-224.
VAN NEDERVEEN, G. A. & TOLMAN, F. P. 1992b. Modelling multiple views on buildings. *Automation in Construction,* 1**,** 215-224.
VERHOEF, P. C., BROEKHUIZEN, T., BART, Y., BHATTACHARYA, A., DONG, J. Q., FABIAN, N. & HAENLEIN, M. 2021. Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research,* 122**,** 889-901.
VIKO, N. U. L. 2020. *Finding sources* [Online]. Available: https://innsida.ntnu.no/wiki/-/wiki/Norsk/Finne+kilder [Accessed].
VITÁSEK, S. & MATĚJKA, P. Utilization of BIM for automation of quantity takeoffs and cost estimation in transport infrastructure construction projects in the Czech Republic. IOP Conference Series: Materials Science and Engineering, 2017a.

VITÁSEK, S. & MATĚJKA, P. Utilization of BIM for automation of quantity takeoffs and cost estimation in transport infrastructure construction projects in the Czech Republic. IOP Conference Series: Materials Science and Engineering, 2017b. IOP Publishing, 012110.
WALKER, D. H. & LLOYD-WALKER, B. M. 2016. Understanding the motivation and context for alliancing in the Australian construction industry. *International Journal of Managing Projects in Business*.
WEBB, S. P. 2017. *Knowledge management: Linchpin of change*, Routledge.
WEE, B. V. & BANISTER, D. 2016. How to write a literature review paper? *Transport Reviews,* 36**,** 278-288.
WELDE, M. & ODECK, J. 2017. Cost escalations in the front-end of projects–empirical evidence from Norwegian road projects. *Transport Reviews,* 37**,** 612-630.
WESTERMAN, G., BONNET, D. & MCAFEE, A. 2014a. *Leading digital: Turning technology into business transformation*, Harvard Business Press.
WESTERMAN, G., BONNET, D. & MCAFEE, A. 2014b. The nine elements of digital transformation. *MIT Sloan Management Review,* 55**,** 1-6.
WESTERMAN, G., CALMÉJANE, C., BONNET, D., FERRARIS, P. & MCAFEE, A. 2011. Digital Transformation: A roadmap for billion-dollar organizations. *MIT Center for Digital Business and Capgemini Consulting,* 1**,** 1-68.
WHANG, S. & PARK, S. M. 2016. Building Information Modeling (BIM) for project value: Quantity take-off of building frame approach. *International Journal of Applied Engineering Research,* 11**,** 7749-7757.
WU, J. & ZHANG, J. Automated BIM object classification to support BIM interoperability. Construction Research Congress 2018: Sustainable Design and Construction and Education, 2018.
WU, S., WOOD, G., GINIGE, K. & JONG, S. W. 2014a. A technical review of BIM based cost estimating in UK quantity surveying practice, standards and tools. *Journal of Information Technology in Construction,* 19**,** 534-562.
WU, S., WOOD, G., GINIGE, K. & JONG, S. W. 2014b. A technical review of BIM based cost estimating in UK quantity surveying practice, standards and tools. *Journal of Information Technology in Construction (ITCon),* 19**,** 534-562.

Appendix c

Specialization project report

TBA4530, Project Management and Construction Engineering, Specialization Project

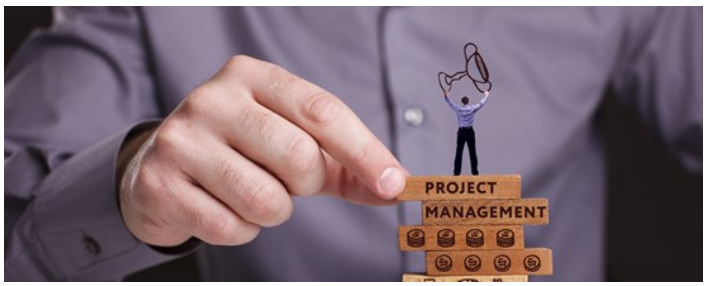
pecialization project report

tomatic BIM-based cost estimation for infrastructure projects

Author: Saeid Morovvati

Supervisor: Ola Lædre

Co-supervisor: David Fürstenberg



Contents

NTNU
Kunnskap for en bedre verden

Abstract

Digitalization with significant impact on human society undoubtedly is one of the most exciting topics in past decades. It attracts many attentions in different industries by the aid of using it to increase efficiency. Architecture, Engineering, and Construction (AEC) industry is one of the largest industries in human society. Digital transformation in the AEC industry opened new beneficial knowledge areas toward this industry. Building information modelling as a digital representation of the project with a considerable amount of information can be considered the core of this transformation. AEC industry consumes a significant amount of energy and resources. The need for accurate cost estimation to have an efficient process and better use of resources and energy is undeniable. Attempts to achieve this goal resulted in changing from traditional cost estimation toward a BIM-based cost estimation. This study will look into how automated BIM-based cost estimation practiced in a real case project and will try to identify challenges and limitations toward adopting a fully automated BIM-based cost estimation.

1 Introduction

While we are moving forward in the twenty-first century, the practice of science is moving forward digitalization. Digitalization has been identified as one of the main trends changing society and business in the near and long-term future (Tihinen et al., 2016). The impact of digitalization is significant; it has been compared to the industrial revolution in several publications (Degryse, 2016). Digitalization in the construction industry is an inevitable affair. Over the past decade, evolution and development through digitalization resulted in increased efficiency in different sectors of this industry. Similarly, digitalization in the Architecture, Engineering, and Construction (AEC) industry opened new knowledge areas toward this industry. Recently, digital tools and workflows are more utilized in the AEC industry for designing, construction and operating building and infrastructure assets (Borrmann et al., 2018). According to the same study the digital transformation in the AEC industry increased productivity and reduced uncertainties.

Building Information Modeling (BIM) can be admitted as the main advent toward digital transformation in the AEC industry. According to Sacks et al. (2018), BIM can define as " a new approach to design, construction, and facilities management, in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format". During the past decade, BIM has been broadly adopted in the AEC industry. BIM is using for coordinated, consistent and computable building information management in all phases, from design and implementation to maintenance (Lee et al., 2014). Following the emergence of BIM, it has been realized that moving forward BIM can result in more efficiency (Wu et al., 2014b). As a result, the AEC industry is facing a growing interest in BIM.

Cost estimation is an essential element in all industries, especially in construction projects concerned by all Architecture, Engineering, and Construction (AEC) industry participants. Cost estimation can be defined as approximating the costs of the resources needed to complete the scope of work specified for a project. The cost estimate level of accuracy depends on the method used and availability of cost data (Jrade and Alkass, 2001). Cost estimation is a useful tool in the decision-making process in both the early phase of the project and the detailed design phase (Choi et al., 2015). Quantity takeoff is one of the fundamental factors in cost estimation, it has a direct relationship with cost estimation. Having in mind all these facts, efficient and accurate quantity takeoff and cost estimation are crucial in projects.

Traditionally and based on its definition, cost estimation has been a manual and repetitive task prone to human errors (Firat et al., 2010). This uncertain and error-prone nature resulted in uncertainty about the results and a reduction in its reliability. However, several facts emphasize the importance of accurate cost estimation and its necessity for the project. As Elbeltagi et al. (2014) mentioned, project managers need a reliable cost estimation to develop financial management plans. Fürstenberg and Lædre (2019) also mentioned the importance of exact and reliable information about the project's planned assets, especially for cost drivers. The other issue about the traditional cost estimation is its inefficiency facing dynamic changes in the project and its time-consuming and costly nature. Having these in mind, the need to move forward a more automated procedure for cost

estimation is crucial. This automated method is expected to provide a more straightforward, though more detailed, and precise cost estimation. In order to solve traditional 2D-based cost estimation problems research on other methods of cost estimation and automated quantity takeoff has been start (Hwang, 2004). The advent of building information modeling (BIM) enables a potential solution to these problems. Studies around automated BIM-based quantity takeoff for building projects revealed its benefits and high efficiency in cost estimation. However, studies around infrastructure road projects are few.

In this study, the author will concentrate on automated BIM-based cost estimation. This study will look into a road project and investigate essential factors in adopting automated BIM-based cost estimation. It is important to mention again that the study focuses on the cost estimation (process) and not cost estimate (product). This study uses the definition of the BIM-use cost estimation by Messner et al. (2019). As shown in figure 1, designers play an essential role in the product's process. In this study, the author will look into designer's perspective and investigate designer's role in cost estimation.

.

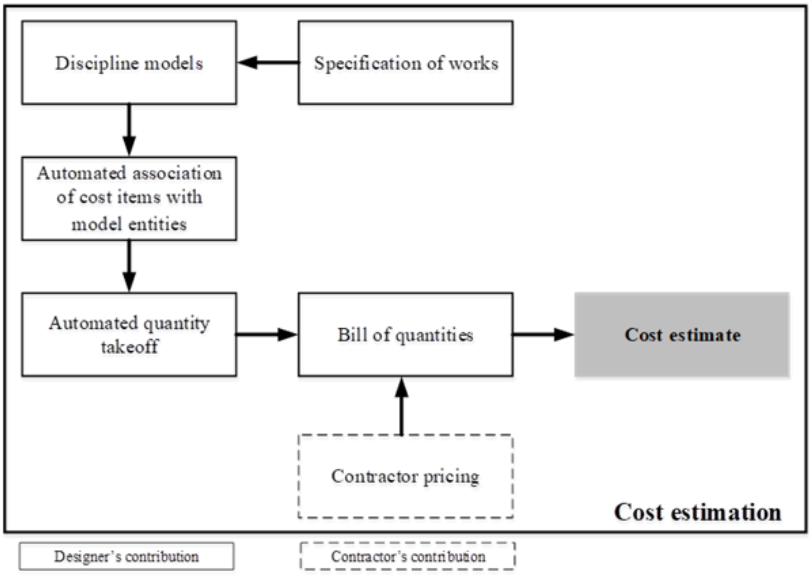


Figure 9, Overall contribution in cost estimation, source: Fürstenberg et al. (2021)

1.1 Background

Eastman et al. (2011), mentioned that, the main benefit of using BIM in cost estimation occurs during the quantity takeoff step. According to them most of BIM based estimating tools can export quantities to an external database. They mentioned in their study that, BIM allows design models to be linked to software that

allows the quantity surveyor to obtain the required quantities. The use of BIM for quantity surveying also has been studied by Boon and Prigg (2012), they noticed the ability to extract quantities directly from BIM models and they also introduced this as e beneficial method in quantity takeoff. Hartmann et al. (2012) identified automated quantity takeoff as one of the most useful tasks in BIM-based AEC projects. According to them automated quantity takeoff can increase efficiency of quantity surveying. Alufohai (2012) mentioned that, the possible automation as a result of using BIM will help increase efficiency in cost estimation. Monteiro and Martins (2013) also in their study mentioned that quantity takeoff can be automated as a result of using BIM for reflecting the cost estimation. Sattineni and Bradford (2011) in their study mentioned saving time and cost in cost estimation as a result of using automated quantity takeoff through BIM. They introduced BIM based automated quantity take off a crucial way for an accurate and reliable cost estimation.

Eastman et al. (2011) mentioned about the error-prone nature of cost estimation, and then he stated that BIM as an advantage offers a better cost estimation considering errors. According to the study of adopting BIM will result in around 80% time reduction and near 10% cost reduction. Several studies like studies of Wu et al. (2014b) and Luth et al. (2014) concentrated on applying 5D BIM in the AEC industry. There are also few studies like Ali et al. (2016) and Babatunde et al. (2018) about BIM education for quantity surveying. Elbeltagi et al. (2014) introduced a cost estimating model based on BIM. Recent studies like, Alhasan et al. (2017), and Chan et al. (2018) in their studies mentioned about the benefits of 5D BIM in cost estimation.

Shou et al. (2015) mentioned that advances in BIM not only increase efficiency in buildings but also in infrastructures. Their compared the extent of BIM for buildings and infrastructures. Their study revealed that most of studies around BIM mainly focused on buildings and research on BIM for infrastructures in lagging. After that a few studies about automated quantity takeoff using BIM for infrastructures published. Vitásek and Matějka (2017a) in their study concentrated toward using BIM for automation of quantity takeoff and cost estimation in infrastructures. In their study they focused on models of road constructions and they try to mention and solve problematic parts of automated quantity takeoff. They used two case studies in their study. They conclude that even though it is beneficial and has a high efficiency but automated BIM-based quantity takeoff "is highly dependent on local market budgeting systems, therefore proper push/pull strategy is required".

1.2 Research Gap

As mentioned, cost estimation is a crucial and essential part of AEC projects. An accurate cost estimation requires a precise quantity takeoff. However, traditional quantity takeoff methods are time-consuming, costly and error prone. These issues resulted in lower reliability in the results of quantity takeoff and consequently cost estimation. On the other side, the AEC industry is adapting to the digitalization wave to keep its competitive advantage and achieve higher efficiency. This is where the AEC industry and several researchers tried to cover these issues by automating quantity takeoff and cost estimation. They achieved considerable improvements in building construction projects, and several software and standards are recently developing to

cover this topic. At the same time, Infrastructure construction projects are among the widely discussed public discussion subjects. However, as mentioned in the study of Shou et al. (2015) and comparing to building projects, BIM research areas suffer from an obvious need in infrastructures. Moving forward digitalization and the need to increase efficiency in this part of the AEC industry initiated the first idea to move forward to this topic. Therefore, this study is looking for how cost estimation is practiced in infrastructure road projects.

1.3 Research Questions

Having in mind the identified research gap, and to give the research a distinct focus, the following research questions have been identified. The author will go through the research questions specifically in the case study and try to find the answers. Meanwhile this study will identify the important factors for adopting BIM based cost estimation.

1) How BIM-based cost estimation is practiced?
2) What are the challenges and limitations of these factors facing BIM-base cost estimation?

It is important to mention again that, here the study focus on the cost estimation (process) and not cost estimate (product). The designers play an important role in the process that will result in the product.

1.4 Limitations of the Study

This study is limited through a few factors. First, due to one semester time restriction, this study is limited in terms of possible resources that could be reviewed. The second limitation is about the number of interviews that could be undertaken during the time restriction to obtain information. We also need to mention that due to the global pandemic worldwide, there was no possibility of an in-person interview. All interviews were through the Microsoft team. The third limitation is that this study is based on the designer's perspective and no other stakeholders. So, the contractor and the client point of view is not considered in this project. This study only investigates into road and construction disciplines due to time restriction to perform all interviews and being aware that these two disciplines share a big part of cost in infrastructure projects. The author will investigate other discipline in further works. Last but not least, we can mention the specific contract type in the case study. This case study uses Integrated Project Delivery (IPD), the first infrastructure project in Norway, with this type of project delivery method. This means that some experiences and challenges discussed in this study is confined to this type of project delivery method.

1.5 Structure of the Report

This report will go through a real project as the case study in Norway with a high digitalization ambition, making it unique. This study's main objective is to identify how BIM-based cost estimation, the process of cost estimation has been performed in this project, what were the challenges, experiences, pros, and cons related to this method. In the second chapter, the report will go through the theoretical backgrounds of related terms and concepts. It will explain them to give an insight into the related terms. In the third chapter, the

methodology used to perform this study will be introduced. There will also be a short introduction to the case study and its features. Chapter four will identify the findings and then discuss the findings through interviews, case study, a document study, and literature review. Finally, in conclusion, the chapter will present the results and summarize the results, and the author will try to explicitly answer the research questions. This study is a pilot study, and it will go deep in the master thesis about the topic.

2 Theory

This chapter is to introduce the theory relevant to understanding this study for readers. This chapter begins with an introduction and brief overview of the concepts and terms related to this study and explain them.

2.1 Digitalization and Digital transformation

Digitalization and Digital transformation, two of the most critical concepts of knowledge in recent decades, attract significant attention in different science aspects. Their vast effects on human society and industry caused an ever-growing interest toward them. That human society feels a necessity to move toward them in all aspects of life is undeniable. Should we realize their advantages and roles in achieving higher efficiency and better use of resources, we will ponder over them much more scrupulously. These terms are the topic of debates among experts. However, often it is hard to have a clear distinction between these two terms. Thus, a clear perspective of these terms will be a useful and beneficial tool for their implementation.

2.1.1 Digitalization

Digitalization, one of the most significant trends changing our society with notable impacts on human life, is compared to industrial revolutions in several publications. Its fast spread sets enormous changes in all knowledge fields (Tihinen et al., 2016, Degryse, 2016). Several different definitions depending on the context have been presented for digitalization during past decades. The simplest and common one is the transformation from analogue to digital. Stolterman and Fors (2004) defined digitalization as " The changes associated with the application of digital technology in all aspects of human life". According to the studies of Gassmann et al. (2013) and Hartmann et al. (2012) digitalization is known as " Ability to turn existing products or services into digital variants, and thus offer advantages over tangible product". Moore (2015) mentioned new value creation as the result of digitalization, in his idea only improving without any new creation was not enough. However, in some studies, digitalization defined as the connection of people, process, and data.

2.1.2 Digital transformation

According to Westerman et al. (2014b)Westerman et al. (2014)Westerman et al. (2014b) , digital transformation means " The use of technology to radically improve the performance of reach of enterprises". Digital transformation is more about changes in the ways of working and roles. Digital transformation is the result of accepting and adopting digitalization and digital technologies (Parviainen et al., 2017). In their studies, they mentioned that digital transformation refers to changes at different levels. According to their work, digital transformation can happen at the process level, organization level, business domain level, and society level. Moving toward digitalization needs implementing digital capabilities as a result of technology improvement (Henriette et al., 2015a).

2.2 Impacts of Digitalization and Digital transformation

Profiting from digital transformation requires a proper understanding of its impacts. Parviainen et al. (2017) identified and illustrated the three most fundamental impacts of digitalization, as shown in figure 2. They defined internal efficiency as improvements in the implementation method using digital means and re-planning the internal process. They mentioned process efficiency and consistency due to eliminating manual steps and better accuracy as potential benefits of digitalization. In their study, External opportunities refer to creating new opportunities in the existing domain. They introduced improved response time and client service as the potential benefits of it. Lastly, they defined disruptive change as changing roles as a result of digitalization. They mentioned the possibility of generating new business and changes in the environment as the potential benefits of digitalization in this case. Even though the impact of digitalization is definite, some industries are often struggling to adapt it.

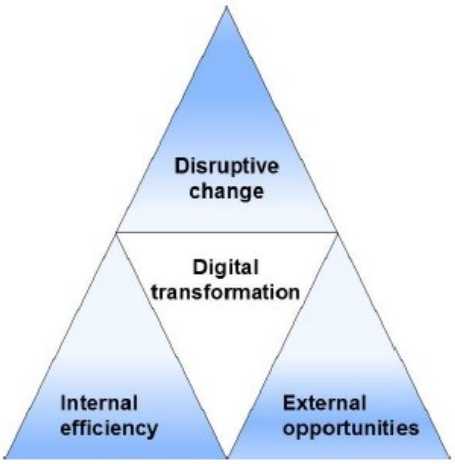


Figure 10 Digitalization impacts Figure from (Parviainen et al., 2017)

2.3 Digitalization in AEC industry

AEC industry is one of the biggest industries which exposed to rapid environmental changes. On the other side, this industry's dynamic and complicated nature requires more efficient solutions to survive and progress. Human societies development, large scale projects, growing population, and limited resources attract much attention toward this developing industry. All these developments and larger and complicated projects exposed the AEC industry to an increasing amount of data. Analyzing and dealing all these large amounts of data either is not possible or is so inefficient. Nowadays, the success of all project, especially complicated AEC projects, depends on better and efficient use of resources and processes (Switzer, 2008).

Facts above highlight the importance of moving toward digitalization and digital transformation to keep a competitive advantage in this ever-growing market. Jan et al. (2013b) confirmed the importance of knowledge technology, and knowledge management in the construction industry. They defined the term "knowledge management" as management of resources and evaluation and exploitation of knowledge in the context of

problem-solving. According to Bousquet et al. (2003), poor knowledge management causes low efficiency and productivity in the construction industry. Feng et al. (2010), and Webb (2017) identified several reasons encouraging the construction industry moving forward digitalization. According to them, construction time, quality of the product, environmental concerns and social impacts increase digitalization demand. In the last decade, AEC industry is adopting more digital tools for different phases however comparing to other industries it falls behind. Traditional physical paper plots and limited formats of digital tools cause loss of valuable information. figure 3 illustrate the information loss through conventional workflows and compare it with digital workflows. (Borrmann et al., 2018). All these in mind in recent years AEC industry have been promoting the use of digitalization to cover all there gaps. de Couto Nascimento et al. (2016) introduced Building information modeling (BIM) as the center of moving toward digital transformation.

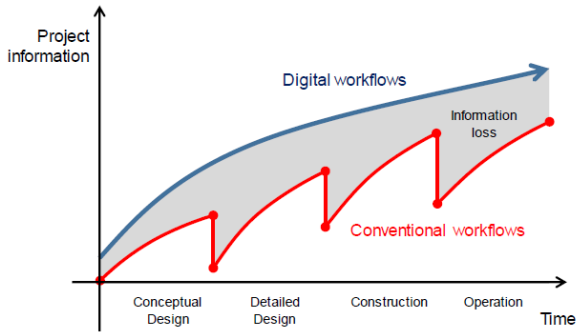


Figure 11 Loss of information caused by disruptions in the digital information flow.

picture taken from Borrmann et al. (2018)

2.4 Building Information Modeling (BIM)

Building information modelling (BIM) is a model-based process used for more efficient planning, designing, implementing, and managing construction projects (Tkáč and Mesároš, 2015). It is a complete digital representation of the project with considerable information. Its development through past decades turns BIM a key technology in the AEC industry. BIM not only contain geometric data, but it can store a significant amount of information. A BIM element potentially can contain the element's installed phase, manufacturer's website, and structural properties (Wu and Zhang, 2018), this feature covers the loss of information caused by disruptions as mentioned in figure 3 (Borrmann et al., 2018). The term "Building information modeling" for the first time was used by van Nederveen and Tolman (1992a). However, in recent years an extensive range of BIM-based software products have been published. All these advantages attract a lot of attention toward BIM in the AEC industry in different phases and parts.

Automated cost estimation and quantity takeoff are two of the outstanding features of adopting to BIM models in all industries and especially in AEC industry. Ma et al. (2010) introduced a framework for BIM-based construction cost estimation using Chinese standards. According to Azhar (2011), adopting BIM can save cost in both design and implementation phases.

2.5 Cost Estimation

2.5.1 Traditional cost estimation

Lee et al. (2014) defined the cost estimation as " the process of predicting project cost and resource requirements". They illustrated the general process of cost estimation as figure 4. However, traditional cost estimation for AEC projects starts with calculating quantities, and it is a time-consuming task. Traditional cost estimation usually uses 2D drawings to calculate the quantities. It is prone to human errors, and in case of changes, the cost estimator needs to do the whole process again. So, in term of dynamic changes which is a standard part of construction projects, it is inefficient.

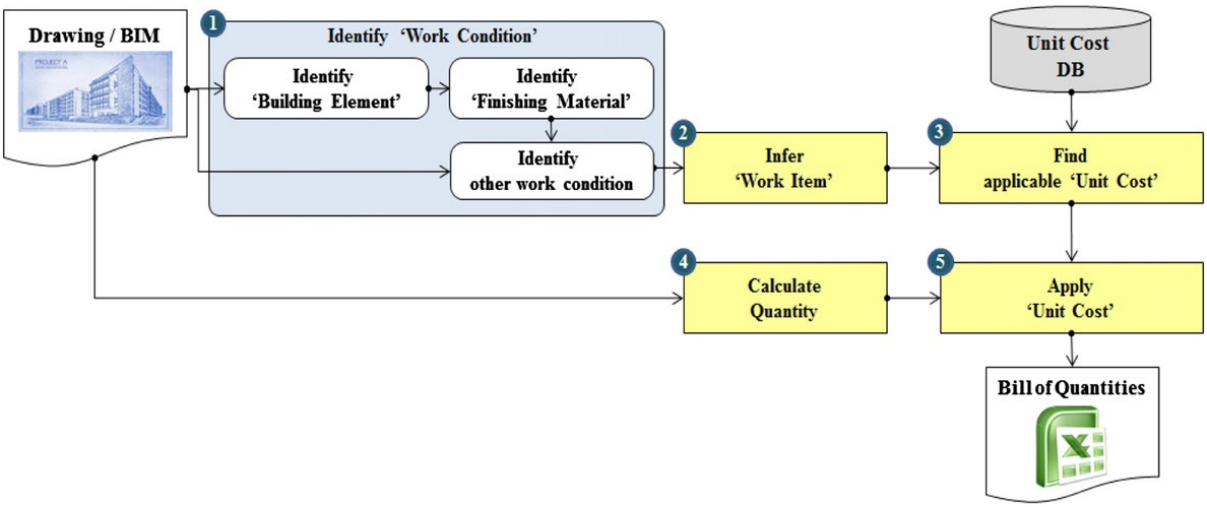


Figure 12, General process of cost estimation, picture taken from Lee et al. (2014)

2.5.2 BIM-based cost estimation

The development of BIM resulted in the automation of cost estimation. By using BIM, the process of cost estimation to a great degree facilitated. BIM enables models to be linked to cost estimation software to calculate the final cost by multiplying quantities with unit prices. Several BIM-based approaches developed during past decades. Wu et al. (2014b) mentioned about three main approaches. Exporting quantities from BIM to estimating software, linking the BIM tool directly with estimating software, and using BIM quantification tools. In their study, they mentioned about inadequate information, issues related to data exchange, and lack of standardization and inappropriate pricing format as the challenges of BIM-based estimation.

3 Methodology and Case description

In this research, the research questions will be investigated through performing a case study of a real state project in Norway, case-specific interviews based on semi-structured open-ended questions, a document study of the mentioned project, and literature review of publications in the field of BIM-based cost estimation.

3.1 Literature review

In this project, some literature was introduced to the researcher by his supervisor and co-supervisor. The rest of the identified literature was through the search by keywords. The keywords were searched in research databases (Scopus, Google Scholar, etc.) and the most relevant literature identified. The author also used backwards snowballing according to (Wee and Banister, 2016). A literature review focusing on the BIM-based cost estimation was carried. In the next step, the author did an in-depth literature study.

Among the wide variety of papers, 39 relevant documents were screened and specified to look more in-depth (Table). After an in-depth assessment, 17 articles related to the research topic to the researcher identified. Finally, the researcher tried to evaluate ten papers out of those 17 based on context relevance, objectives, validity, and quality. The primary measure for this selection was the objectives of publications and their alignments with his research topic. The researcher attempted to use various publications during 2000 and 2020 to cover all the possible improvements, developments, and promotions in this topic.

3.1.1 Advantages and Disadvantages of Literature review

As an advantage of the literature review, it is covering a wide range of publications. Through a literature study, it is possible to access all the relevant publications and identify research gaps and omissions for further studies. In this project, the author used these advantages to do a thorough, complete, and in-depth literature study on the identified publications. As a weakness for literature study, the author can mention about the incapability to be sure that the authors checked all the relevant literature in the topic. The author can also say about the problem with inferring the real meaning and intention behind what is stated in the literature review. This issue can be solved by evaluating literature and consulting with supervisor and experts in the field.

Data base and Search engines		
Oria	*Scopus*	*Google Scholar*

Keyword			
BIM-based Cost estimation	*7*	*22*	*35*
BIM-Based Automatic cost estimation	*4*	*4*	*21*

Table 1 Literature review results

In conclusion, the author finds 39 unique, relevant literature related to his research scope. Including three articles by using the snowballing method and 36 articles from database and search engines.

3.1.2 Why Literature review?

That literature review has a significant part in all academic research is an undeniable fact. The first step in most theoretical studies is to begin a literature review to see what came before, what did, and what did not work for other researchers in the same or related subject. In this study, the author benefits from a literature study in different ways. First, the literature review was done to get to know the theory, topic and its perspective. It enables the author to understand the concepts, methods, and to identify research gaps. Then, the literature review intended to gain insight into the field and be a base for writing an interview guide. After identifying the research gap to cover it, the author used the literature review as a base to set the interview questions and write an interview guide. Finally, it is considered a tool and base for discussing the findings of the research.

3.2 Case Study

A case study according to Gerring (2004) is defined as " an intensive study of a single unit with an aim to generalize across a larger set of units". Feagin et al. (1991) introduced a case study as an ideal methodology to do a thorough investigation. In this project, a real state project from Norway is going to be studied. This case is a part of a road project in Norway, E6 Melhus S-Kvål. "The new road will be built partly where today's E6 is located and partly in a completely new route. They are going to extend the width of the E6 between Melhus center and Skjerdingstad and build a new line from Skjerdingstad to the south of Kvål center."(2020). The client of this project is NyeVeier. This project can be considered unique due to its delivery method. The contract between the contractor (PEAB) and designer (COWI) is the first IPD (Integrated Project Delivery) project to be implemented in Norway's road construction projects. This contract means client, contractor, and consultant involvement in a trust-based atmosphere in all phases of the project. This kind of agreement needs full transparency between the stakeholders mentioned above.

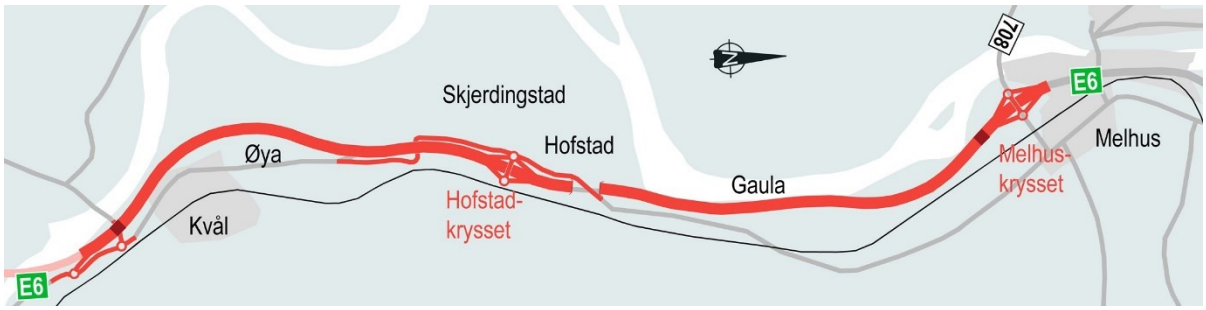


Figure 13, Case study (E6 Kvål – Melhus S) taken from NyeVeier website.

3.2.1 Advantages and Disadvantages of Case study

One of the main advantages of a case study is that case studies are problem-centric and solution-centric. Performing a case study as a methodology to investigate into a topic can also be seen as a comprehensive study. This will give the users advantage of developing an in-depth understanding an looking for effective factors in detail. However, generalizing findings from a case study and also getting permissions and data from the case company are the factors limiting this type of research methodology. Other disadvantages of this method can be the time-consuming nature of this method and personal interpretation of the findings.

3.2.2 Why case study?

According to Leonard-Barton (1990), performing a case study to investigate a topic is particularly beneficial for responding to how and why questions about the topic. Here in this research, the first research question is a how question making it a suitable case for performing a case study to answer the first research question. On the other hand, as Sykes (1990) mentioned in his study, reaching some information can be difficult or impossible in other methods. In this research, it is also true, and there is some kind of information that neither are mentioned in literature nor at any document. This is where a need for doing a case study to gain that information is crucial.

Last but not least, as we know, there is a gap between practical and academic knowledge. There are several terms and concepts that are true, according to academia. However, they are not 100% achievable in practice due to environmental effects and uncontrolled uncertainties. So, doing a case study can look in-depth and reveal unseen and undocumented information.

3.3 Case specific Interviews

The case study was based on a semi-structured open-ended interview. The interview questions were designed in a general way so they can cover all interviewers with different positions, different responsibility, and different backgrounds. Questions may expand during the interview to fit according to the expertise of various parties involved in the project. The interviewers were conducted through Microsoft team due to the covid-19 situation in the world and the impossibility of face-to-face interviews due to the worldwide pandemic. David

Furstenberg, as co-supervisor in this project, helped the author to identify and contact respondents. The respondents are all involved in the case study in different positions and different disciplines. The interview will be sent to the respondents before the interview to give them an insight into the questionnaire. A summarized report of the interview will be written and sent to the respondent to confirm and prevent any misunderstanding. Reported data from the respondents will be anonymous. The interviewer will only mention their roles and positions in the case study. The interview participants are listed in table 2.

Position	Number of participants	
Project manager	1	
BIM manager	2	
Discipline leader	2	Road Discipline & Construction Discipline
Discipline BIM coordinators	2	Road Discipline & Construction Discipline

Table 2 Interview participants

3.3.1 Advantages and Disadvantages of Interview

A critical strength point for an interview is that the interviewer can clarify questions, expand on answers in case of need and ask for further explanations. This can cover unforeseen factors and help the author have better control and a broader perspective. As Kelly et al. (2010) also mentioned, the semi-structured interviews' rigidity depending on the study and research questions can be different. Polit and Beck (2010) introduced the interviewer's ability to improvise follow-up questions based on the answers as one of the main advantages of this method. A weak point in performing an interview is the limited number of respondents in this project due to time restriction. Another limitation in performing an interview is the Covid-19 situation and the impossibility of having an in-person interview. The author believes that having an in-person interview could be more beneficial in discussing questions and answers. Of course, having an in-person interview could be more user-friendly. Another limitation for this method is that the interviewer needs to have the appropriate level of knowledge to improvise follow-up questions in case of need and formulate interview questions.

3.3.2 Why Interview?

Data collection is a crucial part of all studies, and interviews are among the most regularly used data collection methods. According to DiCicco-Bloom and Crabtree (2006), semi-structured interviews are the most often used qualitative research technique. They also mentioned about the flexibility of this technique as one of the principal reasons to use it. Having in mind that automated BIM-based cost estimation is a relatively new concept and all its effecting factors are not identified, having an interview could reveal unforeseen factors. It can also give insights into other relevant concepts. Due to having the semi-structured format, flexibility can be the critical feature since interviewers are from different backgrounds. Last but not least, interviewers have a

direct connection with the research questions. They performed the method, and they dealt with the advantages, disadvantages, and limitations in the method. These are not documented elsewhere, and only the people with direct involvement in the project can reveal them.

3.4 Document study

Usually, a large amount of information always stored in the documents. Sprague Jr (1995)defined a document as “a set of information pertaining to topic, structured for human comprehension, represented by a variety of symbols, stored and handled as a unit.” Information is an essential part of any study, but they need to be readable, achievable and analyzable. “Document study is a systematic procedure for evaluating documents” (Bowen, 2009a). The author conducted a document study of the documents available to him. Several documents were studied regarding the case project, including some parts of the contract and several slides. These documents were obtained through email.

3.4.1 Advantages and Disadvantages of Interview

As an advantage for document study, the author can mention that this method is less time and cost-consuming than the other methods. Availability of documents can be a limitation for this method. According to Salminen et al. (1997) document study needs document standardization. Information is not stored in the same structure and format; this necessitates the importance of document standardization. Another limitation in this methodology is that some of the documents are in Norwegian in this project. The author is not a native Norwegian and can have difficulties understanding the correct means; this issue will be covered by asking help from native Norwegians in case of need or asking from his supervisor and co-supervisor.

3.4.2 Why Document study?

As we mentioned, earlier documents contain a great deal of useful information, in this study document study practiced gaining the necessary knowledge about how they practiced cost estimation in this project, the challenges, experience and limitations with the method used in this project. This method can help the author to understand the reasons behind the way they did the project this way and can give insights about chosen methods.

4 Findings and Discussions

Again, it is essential to mention that this study concentrates on the cost estimation (process) and not cost estimate (product). This study uses the definition of the BIM-use cost estimation by Messner et al. (2019). This project looks into how cost estimation practiced in the case study as a project with high ambitions of digitalization and try to answer the research question based on findings from the case study. The author expected an automated BIM-based cost estimation for this project before the investigation due to high-quality BIM models and high digitalization ambitions in this project. The author was aware that COWI, as the designer, has experience with working with automated BIM-based cost estimation. A summary of findings from interviews, case study, and documents study will be identified in this section. Afterwards, the findings will be discussed and compared to the literature review. During discussing the findings, the author will also try to answer research questions as much as possible. The author will mention the effects of each finding in How cost estimation practiced and then identify challenges, experiences, and limitations resulting from each factor. However, since answering research questions, it is necessary to consider all findings and not just special effects. Research questions will be answered in the conclusion part comprehensively.

4.1 Project Delivery Method

As stated in the contract and based on the document study, this project used an integrated project delivery method (IPD) with shared responsibility among stakeholders involved. According to interviews and based on respondents' answers, one of the most outstanding factors affecting how quantity takeoff and the cost estimation practiced in this project (E6 Kvål – Melhus S) and in general can be the project delivery method. This project only mentions about the findings related to cost estimation (process). It worth to mention again that this project is the first infrastructure IPD project experience in Norway.

Most interviewees mentioned that the Integrated Project Delivery method (IPD), due to some features makes it hard or even impossible in some cases to adapt Automated BIM-based quantity takeoff and cost estimation. The majority of respondents mentions this topic; they unanimously agreed on it as a restricting factor in adapting automated BIM-based quantity takeoff and cost estimation. Most of them stated some features of IPD like early involvement of contractor as a restricting factor toward moving to fully automated BIM-based cost estimation. Most of them introduced the project delivery method as the predominant factor in choosing the quantity takeoff and cost estimation method. According to respondents, heavy workload as a result of IPD caused is several issues preventing adapting automated BIM-based cost estimation. According to respondents, heavy workload resulted in simple and unmatured models in early phase, unintentional mistakes in some calculations and the necessity to control the calculations.

4.1.1 Discussions regarding Project Delivery Method

IPD attempt to improve project outcomes through a collaboration between different parties involving in the project and several projects and studies demonstrated its benefits (Kent and Becerik-Gerber, 2010,

Lahdenperä, 2012). These benefits and advantages of using IPD were also evident during interviews. Almost all respondents mentioned about high efficiency regarding finding better solutions through a close collaboration between different parties. However, it seems using this method resulted in some challenges preventing adopting automated BIM-based cost estimation. Early involvement of entrepreneur and contractor as a feature of IPD resulted in better collaboration and higher efficiency in finding better solutions. However, it increased the design team's workload.

Early involvement of entrepreneur and contractor underlined cost optimization and the project's feasibility perspective more into the design phase. Challenging nature of cooperation to find the best solution and early involvement of entrepreneur and contractor due to this type of project delivery method puts more efforts on designing process at least in early phase. Asking for comparing several designing alternatives in terms of cost estimation from the contractor side in the early phase and before detailed planning increased the design team's workload. However, refereeing to the definition of IPD projects and while the benefits are shared with different parties, the author believes that this concern should not be only from the contractor side. The design team needs to change their mindsets from other usual types of project delivery method and adopt IPD based thinking in implementing the project. We will discuss the mindsets in the next finding.

Increased workload resulting from more concentration toward finding the most cost-optimized solution resulted in simplified and unmatured models before detailed design, makes it hard to adopt automated BIM-based cost estimation in this phase. However, all relevant publications in this topic emphasize having a mature and detailed BIM model as a crucial factor to adapt to automated BIM-based cost estimation. Nevertheless, as the author mentioned, this issue was in the early phase before detailed design. The respondents believes that this is the main result of introducing IPD as a restriction toward automated BIM-based cost estimation from the design team. This issue also identified as one of the limitations of adopting BIM-based cost estimation in the study (Naneva et al., 2020).

The author believes that even though both the design team and contractor side are well experienced and experts in this field, there is always a possibility of facing human errors due to high workload. One of the main reasons to move forward automated BIM-based cost estimation is to reduce and eliminate human-based errors. According to respondents in some cases due to a heavy workload, there were some unintentional miscalculations in quantity takeoff. Another respondent also mentioned overlaps in some models, which resulted in double quantities. He mentioned the necessity to control the quantities. However, according to the concept of digitalization and as mentioned in most of the relevant publications, one of the main goals to move forward, digitalization is to reduce human errors and limit errors to systematic errors to make them reliable and repeatable (Ma et al., 2013).

In conclusion, and by considering only the project delivery method, cost estimation practiced in a semi-automated way. Project delivery method resulted in increased workload on the design team and in early phase. By considering several deliveries of quantities during the project, increased workload resulted in unmatured

and incomplete models. Incomplete models were the main restriction in adopting automated BIM-based cost estimation.

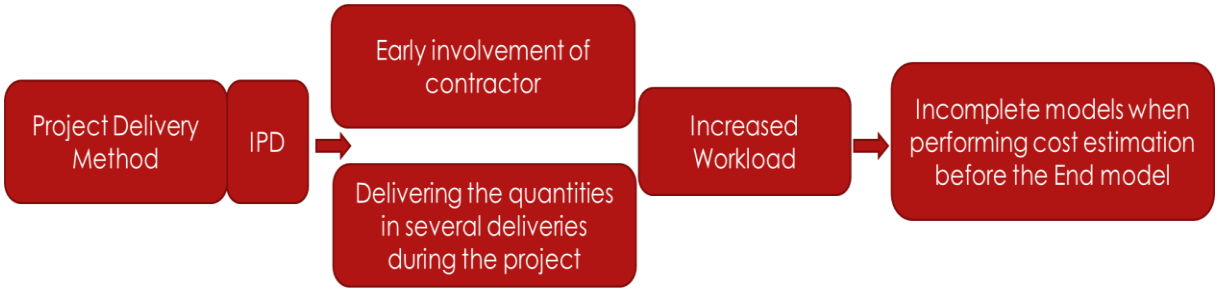


Figure 14, Results of Project Delivery method in case study according to findings from Interviews

4.1.2 IPD and research questions

How BIM-based cost estimation practiced in this project? Trying to answer the first research question considering only this factor, this project practiced a semi-automated cost estimation. According to respondents, quantity takeoff practiced in a semi-automated way in this project. Even though there were some hand calculations as well but mostly quantities extracted from models. Most of the respondents introduced IPD as a restriction toward automatic BIM-based cost estimation. However, the author believes that even though quantities are extracted from the model, it was closer to traditional cost estimation. The reason behind this thought is that as two of the respondents mentioned, the list of quantities demanded from the contractor in some cases contains elements that need further hand calculations. For example, in one case, the contractor may ask for concrete volume for every single column in a specific bridge. However, the design team extracted the total volume of concrete. These kinds of format differences will also increase the workload. This issue can be solved by defining a predefined format beforehand.

The author wants to mention that, even though this process might be seen as a semi-automated quantity takeoff in the first look, this can be named a low automation level. Manual copy-paste of quantities and only reporting pre-required quantities can be the source of human errors in quantity takeoff and cost estimation (Firat et al., 2010). Participants have different definitions of what is automated and semi-automated BIM-based cost estimation. This fact will highlight the necessity to have a training section toward digitalization and its concepts. This need can also be seen in (Babatunde et al., 2019) work. We will discuss about training in the next part.

What are the experiences, challenges and limitations of these factors facing BIM-base cost estimation? According to findings, increased workload, simple and unmatured models in early phase and before detailed model was the challenges regarding IPD toward adopting BIM-based cost estimation. We can also summarize the challenges, and limitations of project delivery method according to figure 6. Most of respondents believe

that concentration toward cost optimization from contractor side puts the priority toward considering feasibility rather than automating cost estimation and workflow. They do believe that increased workload and considering several alternatives limited the possibility to have a completely automated BIM-based cost estimation. However, as the author mentioned before, in IPD projects, design team also need to be cost concern. The author believes that this issue to some extent can be a result of different mindset rather than IPD based mindset. We will discuss about mindset in the next part.

4.2 Time restriction

Next important finding from interviews was time limitation, introduced as a barrier in practicing automated BIM-based cost estimation. Unanimously mentioned by respondents, time limitation restricted the practice of automated BIM-based cost estimation. Most of the respondents mentioned the tight schedule and time restriction as barriers to adopting automated BIM-based cost estimation. Some of the respondents believes that it is impossible to adopt to automated BIM-based cost estimation due to time restriction and several deliveries of quantities in this type of project delivery method. According to one of the respondents due to limited time for the design phase and before finalizing the model, the focus was more into the project's feasibility rather than automating.

Some respondents mentioned that the tight schedule and putting many efforts in the early phase resulted in time shortage in the detailed modelling phase as well. This also restricted the possibility to concentrate on automated BIM-based cost estimation after early phase. Another important point mentioned by respondents was that they believe that quantities were asked very early in the project. Early requests for quantities and several deliveries during modelling and finalizing the models limited the possible time to automate quantity takeoff. Some participants feel that semi-automated quantity takeoff or quantity takeoff from models and exporting them to Excel sheets is less time-consuming than automated BIM-based cost estimation. Some respondents also mentioned that the tight schedule and putting many efforts in the early phase resulted in time shortage in the detailed modelling phase. This also restricted the possibility to concentrate on automated BIM-based cost estimation. So, in conclusion they introduced time limitation in both early phase and after that as a barrier toward automated BIM-based cost estimation.

4.2.1 Discussions regarding Time restriction

First, to compare what some of the interviewees believe with publications and literature. According to interviews, they do believe that automated BIM-based cost estimation is time-consuming and semi-automated method is more beneficial in IPD projects. Nevertheless, the author should mention that, interviewees believe that automated BIM-based cost estimation is a more efficient method in terms of cost and time but in other project delivery methods. According to several publications, automated BIM-based cost estimation is less time and cost-consuming than traditional and semi-automated cost estimation (Matipa et al., 2009, Tiwari et al., 2009, Sunil et al., 2015, Ismail et al., 2018). However, the author could not find any literature regarding implementing automated BIM-based cost estimation in an IPD project or any publication regarding this topic.

In this case, the author believes that two main points are worth to mention. First, the project delivery method's change faced a challenge regarding the contractor's early involvement and requesting for comparing different alternatives. Increased workload resulting from this matter and just comparative intention of different alternatives ended up with time limitation in the early and detailed planning phases. The author believes that this issue can be solved by considering a more suitable time plan in the planning phase. Second, according to respondents, due to this time shortage and insufficient experience with automating cost estimation, different people responsible in different parts did the quantity takeoff according to the method they were familiar with. The intention behind acting in this way was to save time. The author believes that not having enough experience in performing and preparing for automated cost estimation beside time limitation resulted in not practicing automated BIM-based cost estimation.

Considering all these mentioned issues, time limitation and tight schedule can also be introduced as a restricting factor toward implementing fully automated BIM-based cost estimation. The main issue was that time limitation resulted in incomplete models in the time of cost estimation. Here we need to mention again that this project has high-quality BIM models. Naneva et al. (2020) in their study also mentioned this limitation. However, in their study incomplete models were not identified as a result of time limitation directly. The quality of the BIM model and its level of detail are essential factors toward automated BIM-based cost estimation. This factor has unanimously mentioned by all relevant publications so that the author will take this as an undeniable factor. (Kwon et al., 2011) suggested ways of securing the quality of BIM model for accurate quantity takeoff. Previously mentioned, in this study, according to all respondents and document study, the level of detail for BIM models was enough to perform automated BIM-based cost estimation after the detailed design. However, cost estimation practiced in several deliveries during completing the models.

However, this finding is also in close relation with the project delivery method. Time limitation can be a direct result of increased workload. Respondents directly or indirectly mentioned time restriction due to IPD, but this issue also needs further investigations. The author firmly believes that, even though the time can be a restricting factor, it can be solved for the next project. Training design team and quantity surveyors and a time plan considering the automating process can be suggested to solve this restriction. We will discuss the need for training in next part.

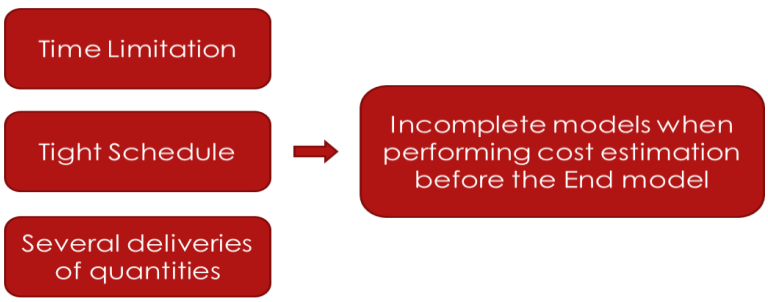


Figure 15, findings and result regarding Time limitation

4.2.2 Time restriction and research questions

How BIM-based cost estimation practiced in this project? The answer to this question is also similar to the answer considering the project delivery method. According to respondents, cost estimation in this project practiced in a semi-automated way. Time limitation was introduced as a restriction in applying automated BIM-based cost estimation. However, investigation toward time restriction can only answer whether it was a restricting factor or not and how to solve it. Discussing regard time limitation can explain the reason behind choosing the method.

What are the experiences, challenges and limitations of these factors facing BIM-base cost estimation? As mentioned above, according to respondents, time plan was a limitation in applying automated BIM-based cost estimation in this case. Not having enough time and experience in using automated BIM-based cost estimation was challenging for some departments to adopt this method. Incomplete models in the time of cost estimation were the main limitation. Due to tight schedule and time limitation, the design team could not put the correct process codes into the model when requesting cost estimation data. Even though this challenge was also due to early cost estimation due to the project delivery method, time limitation was also entirely related.

4.3 Training and Mindsets

After discussing the two above mentioned factors, this project's last finding is about training and mindsets. Despite those two factors that most were related to the process of moving toward digitalization, this factor is more related to people. According to respondents from different departments, quantity takeoff was not practiced the same way, in some cases, even in the same department. Different people for different parts did the quantity takeoff according to the method they were familiar with. Another respondent also mentioned that some people did not have enough experience with BIM and automated quantity takeoff. So, in case of people, inexperienced people with automated BIM-based cost estimation and in some cases, with BIM prevented moving toward fully automated workflow. The other related finding in this case study was mindsets. This factor also was a restricting factor toward a fully automated process; it affects efficiency in some cases. According to respondents, it was their first experience working on an IPD project for some people, which sometimes shifted their mindsets toward other workflows. This issue was more evident in one discipline. Time limitation and tight schedule were the main reason that resulted in shifting to the traditional mindset.

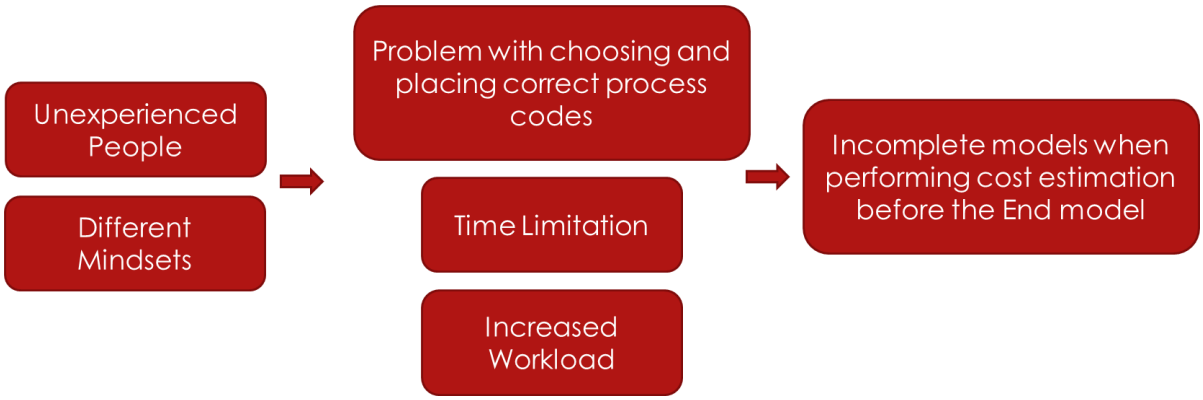


Figure 16, Finding and results regarding Training and mindsets.

4.3.1 Discussions regarding Training and Mindsets

Implementing and transition toward IPD contracts require solving some critical barriers. According to Ghassemi and Becerik-Gerber (2011), one of these barriers identified from nine case study is training. Engineers and all IPD project parties need to change their mindsets from a traditional mindset and adopt IPD based thinking. The need for changing from a traditional mindset also applies to cost estimation and quantity takeoff not just as a requirement for IPD projects, but also to be able to move toward automated process and workflow. As two of the respondents also mentioned this fact, changing mindset from traditional engineering was challenging. Ali et al. (2016) mentioned the importance of educating and training for quantity surveyors to be able to benefit from 5D BIM. According to their study, educating toward BIM framework for quantity surveyors is fundamental. Their study describes the educational framework for quantity surveyors in the context of BIM implementation. Babatunde et al. (2018)also mentioned that education and BIM modelling training is crucial in architecture, engineering, and construction industry.

The importance of education and training is undeniable in this study. Even the respondents themselves mentioned a need in this subject. Not having enough experience with BIM-based process can result in increased workload as well. The increased workload can result in unmatured and incomplete models which identified as the main restriction toward moving to automated BIM-based cost estimation. However, not having enough experience itself can directly result in unmatured models too. This issue can also result in problems with choosing and placing correct process codes in the early phases of the project, making automated BIM-based cost estimation hard or impossible to implement. This issue has a direct impact on the results.

4.3.2 Training and Mindsets and research questions

How BIM-based cost estimation practiced in this project? Completing the answer to this question from the first two findings, this finding also mentioned restrictions that lead to a semi-automated quantity takeoff. However, the quantity takeoff can be considered semi-automatically. However, with this information, the

author cannot comment on cost estimation end result. Even though the main body of cost estimation is quantity takeoff but to answer this question, there is a need to investigate the contractor side. The author will develop this study for his master thesis and look into cost estimation from the contractor perspective in the near future. Considering only people as a factor in judging about the process of quantity takeoff, the author believes that even though quantities to a great level extracted from BIM models but in some cases, training factor affect it.

What are the experiences, challenges and limitations of training and Mindsets facing BIM-base cost estimation? In this case, the main challenges and limitations were not having enough experience and shifting of mindsets to the traditional workflow. This issue, directly and indirectly, leads to unmatured and simple models in early phases and before the detailed model. However, the author should mention several deliveries of quantity in this project according to respondents. The final model, the detailed model, was suitable to perform an automated BIM-based quantity takeoff. However, since the quantity takeoff performed during the development of the model in this project, it was impossible to do an automated BIM-based quantity takeoff and consequently, a fully automated BIM-based cost estimation.

5 Conclusion

That accurate and reliable cost estimation is crucial in all industries. That automated cost estimation can be beneficial in several aspects is an undeniable fact. During this study, this fact was also mentioned by all respondents. It can increase efficiency by saving time and cost. It is also a good tool toward eliminating human based errors in cost estimation. However, several factors can affect adopting automated cost estimation in projects. We can categorize these factors into three main categories, technology, process and people. There was no issue with the technology part in this study according to interviews and findings from other methodologies. This study's main findings are about two major concepts, the process of cost estimation and the people who are performing it. In the first look, these two terms are in close relation and restrictions in the process can result from people who are performing it. These two terms are also closely interdependent. However, in this project, the author can mention the project delivery method and time limitation as to the main restrictions in the process independently from the people.

This study investigated a case study of an infrastructure project and tried to answer the following research questions.

1) How BIM-based cost estimation is practiced?
2) What are the experiences, challenges and limitations of these factors facing BIM-base cost estimation?

As a brief answer to the first question, in this project, BIM-base cost estimation performed in a semi-automated way. However, extracting quantities from models and manual copy-pasting and adjusting them decreased the level of automation for cost estimation in the project. As mentioned even though this project has a high ambitious of digitalization, but cost estimation was not automated efficiently. The reason behind this will be answered in the second question.

As an answer to second research question this study can mention about two main challenge and limitation. First, Inability to place correct process codes into the volumes in the early phases and incomplete and unmatured models can be introduced as the most direct reasons restricting automated BIM-based cost estimation. Inability to place correct process codes into the volumes can have several reasons. It can result from inexperienced people, different mindsets, and it can be related to the standards. This inability can .result in unmatured and incomplete models. As mentioned in the literature, the complete model is the basis of accurate cost estimation. This issue was one of the main reasons preventing moving toward automated cost estimation in the early phase. However, by proceeding toward the final model, this issue has been solved, but it was late in the project. This issue can be solved for future projects by more experiences trained people.

Incomplete and unmatured models was the other factor preventing a completely automated BIM-based cost estimation. This can also be a result of inability to place correct process codes into the volumes in the early phases. As mentioned these terms are closely interdependent. However, in this case this issue was also due to increased workload and time limitation. Increased workload was the result of comparing several alternatives in order to find the most economical solution. This issue introduced as the reason of project delivery method and early involvement of contractor. Demanding for quantities while the final model was not ready resulted in not being able to do automated BIM-based cost estimation. It worth to mention that increased workload and time limitation can also be the result of inexperienced people and Mindsets. As the author mentioned these reasons are closely interdependent. A summary of limitations and challenges illustrated in figure 9.

This study advises more investigations into the subject by considering the benefits of adopting an automated BIM-based cost estimation. This study would like to mention that these limitations can be solved by training and some adjustments in the planning phase. However, the experience gained from this project for the design team and a necessity for training and preparing mindsets to move forward automated BIM-based cost estimation can be beneficial for the project and all stakeholders involved.

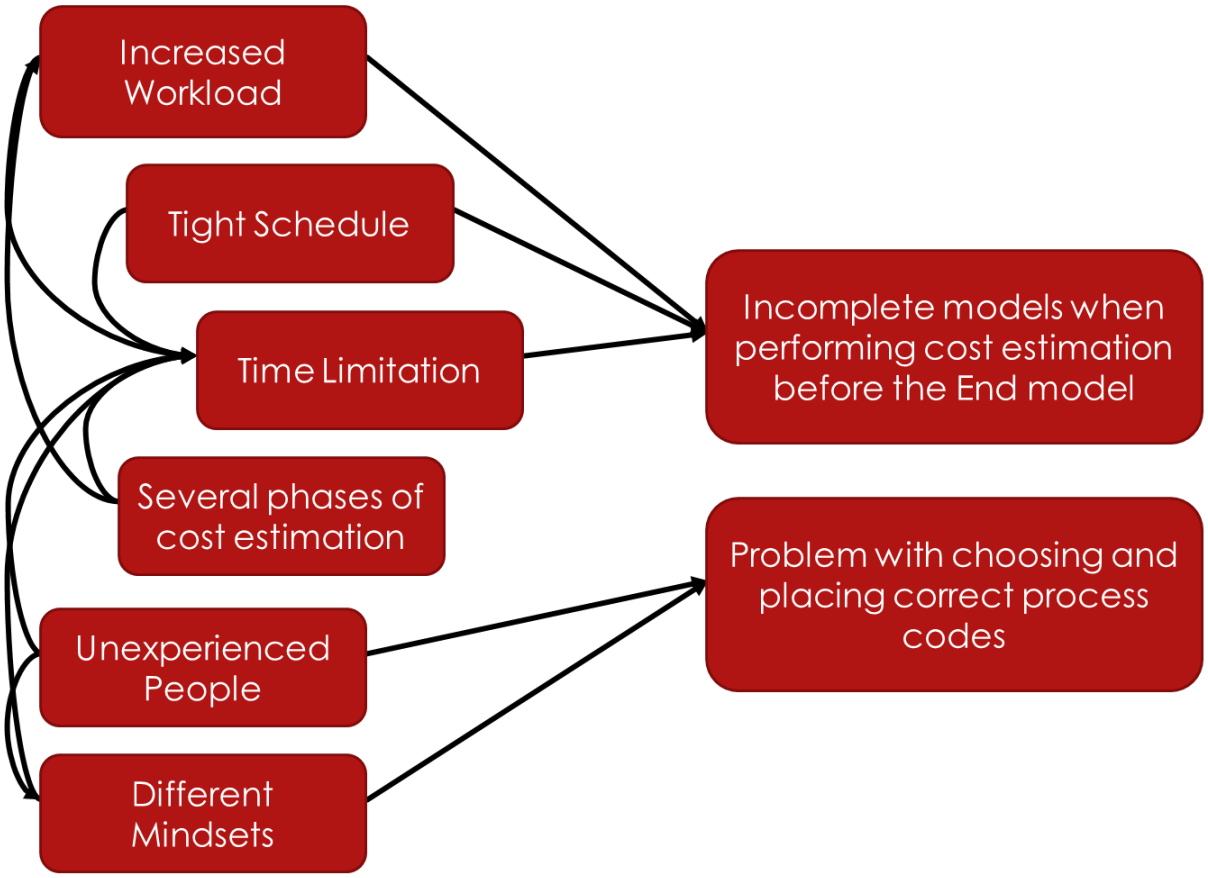


Figure 17, Challenges and limitations toward automated BIM-based Cost estimation

6 References

2020. Facts about E6 Kvål–Melhus. *NyeVeier.*

ALHASAN, S., KUMAR, B. & THANIKAL, J. V. 2017. Effectiveness of implementing 5D functions of building information modeling on professions of quantity surveying: a review. *International Journal of Civil Engineering and Technology,* 8**,** 783-800.

ALI, K. N., MUSTAFFA, N. E., KEAT, Q. J. & ENEGBUMA, W. I. 2016. Building information modelling (BIM) educational framework for quantity surveying students: The Malaysian perspective. *Journal of Information Technology in Construction (ITcon),* 21**,** 140-151.

ALUFOHAI, A. Adoption of building information modeling and Nigeria's quest for project cost management. FIG Working Week, 2012. 6-10.

AZHAR, S. 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering,* 11**,** 241-252.

BABATUNDE, S. O., EKUNDAYO, D., BABALOLA, O. & JIMOH, J. A. 2018. Analysis of the drivers and benefits of BIM incorporation into quantity surveying profession. *Journal of Engineering, Design and Technology*.

BABATUNDE, S. O., PERERA, S., EKUNDAYO, D. & ADELEYE, T. E. 2019. An investigation into BIM-based detailed cost estimating and drivers to the adoption of BIM in quantity surveying practices. *Journal of Financial Management of property and Construction*.

BOON, J. & PRIGG, C. Evolution of quantity surveying practice in the use of BIM–the New Zealand experience. Proceedings of the CIB International Conference on Management and Innovation for a Sustainable Built Environment, 2012. 84-98.

BORRMANN, A., KÖNIG, M., KOCH, C. & BEETZ, J. 2018. Building information modeling: why? What? How? *Building Information Modeling.* Springer.

BOUSQUET, O., BOUCHERON, S. & LUGOSI, G. Introduction to statistical learning theory. Summer School on Machine Learning, 2003. Springer, 169-207.

BOWEN, G. A. 2009. Document analysis as a qualitative research method. *Qualitative research journal,* 9**,** 27.

CHAN, I., LIU, A. & CHEN, B. Management strategies for 5D-BIM adoption in Hong Kong. Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate, 2018. Springer, 1023-1039.

CHOI, J., KIM, H. & KIM, I. 2015. Open BIM-based quantity take-off system for schematic estimation of building frame in early design stage. *Journal of Computational Design and Engineering,* 2**,** 16-25.

DE COUTO NASCIMENTO, V., DE CASTRO FERREIRA CONTI, A. C., DE ALMEIDA CARDOSO, M., VALARELLI, D. P. & DE ALMEIDA-PEDRIN, R. R. 2016. Impact of orthodontic treatment on self-esteem and quality of life of adult patients requiring oral rehabilitation. *The Angle Orthodontist,* 86**,** 839-845.

DEGRYSE, C. 2016. Digitalisation of the economy and its impact on labour markets. *ETUI Research Paper-Working Paper*.

DICICCO-BLOOM, B. & CRABTREE, B. F. 2006. The qualitative research interview. *Medical education,* 40**,** 314-321.

EASTMAN, C. M., EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*, John Wiley & Sons.

ELBELTAGI, E., HOSNY, O., DAWOOD, M. & ELHAKEEM, A. 2014. BIM-based cost estimation/monitoring for building construction. *International Journal of Engineering Research and Applications,* 4**,** 56-66.

FEAGIN, J. R., ORUM, A. M. & SJOBERG, G. 1991. *A case for the case study*, UNC Press Books.

FENG, C.-W., CHEN, Y.-J. & HUANG, J.-R. 2010. Using the MD CAD model to develop the time–cost integrated schedule for construction projects. *Automation in Construction,* 19**,** 347-356.

FIRAT, C. E., ARDITI, D., HAMALAINEN, J.-P., STENSTRAND, J. & KIIRAS, J. 2010. Quantity take-off in model-based systems.

FÜRSTENBERG, D. & LÆDRE, O. APPLICATION OF BIM DESIGN MANUALS: A CASE STUDY.

GASSMANN, O., FRANKENBERGER, K. & CSIK, M. 2013. The St. Gallen business model navigator.

GERRING, J. 2004. What is a case study and what is it good for? *American political science review***,** 341-354.

GHASSEMI, R. & BECERIK-GERBER, B. 2011. Transitioning to Integrated Project Delivery: Potential barriers and lessons learned. *Lean construction journal*.

HARTMANN, T., VAN MEERVELD, H., VOSSEBELD, N. & ADRIAANSE, A. 2012. Aligning building information model tools and construction management methods. *Automation in construction,* 22**,** 605-613.

HENRIETTE, E., FEKI, M. & BOUGHZALA, I. 2015. The shape of digital transformation: a systematic literature review. *MCIS 2015 proceedings***,** 431-443.

HWANG, Y.-S. 2004. Automatic quantity takeoff from drawing through IFC model. *Architectural Institute of Korea,* 20**,** 89-97.

ISMAIL, N. A. A., IDRIS, N. H., RAMLI, H., SAHAMIR, S. R. & ROOSHDI, R. R. R. M. 2018. Sustainable BIM-based cost estimating for quantity surveyors. *Chemical Engineering Transactions,* 63**,** 235-240.

JAN, S.-H., HO, S.-P. & TSERNG, H.-P. 2013. Applications of building information modeling (BIM) in knowledge sharing and management in construction. *International Journal of Civil, Structural, Construction and Architectural Engineering,* 7.

JRADE, A. & ALKASS, S. 2001. A conceptual cost estimating computer system for building projects. *AACE International Transactions***,** IT91.

KELLY, S. E., BOURGEAULT, I. & DINGWALL, R. 2010. Qualitative interviewing techniques and styles. *The SAGE handbook of qualitative methods in health research***,** 307-326.

KENT, D. C. & BECERIK-GERBER, B. 2010. Understanding construction industry experience and attitudes toward integrated project delivery. *Journal of construction engineering and management,* 136**,** 815-825.
KWON, O., JO, C.-W. & CHO, J.-W. 2011. Introduction of BIM quality standard for quantity take-off. *Journal of the Korea Institute of Building construction,* 11**,** 171-180.
LAHDENPERÄ, P. 2012. Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction management and economics,* 30**,** 57-79.
LEE, S.-K., KIM, K.-R. & YU, J.-H. 2014. BIM and ontology-based approach for building cost estimation. *Automation in construction,* 41**,** 96-105.
LEONARD-BARTON, D. 1990. A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites. *Organization science,* 1**,** 248-266.
LUTH, G. P., SCHORER, A. & TURKAN, Y. 2014. Lessons from using BIM to increase design-construction integration. *Practice periodical on structural design and construction,* 19**,** 103-110.
MA, Z., WEI, Z. & ZHANG, X. 2013. Semi-automatic and specification-compliant cost estimation for tendering of building projects based on IFC data of design model. *Automation in Construction,* 30**,** 126-135.
MA, Z., ZHANG, X., WU, S., WEI, Z. & LOU, Z. Framework design for BIM-based construction cost estimating software. Proceedings of the CIB W, 2010. 2010.
MATIPA, W. M., KELLIHER, D. & KEANE, M. 2009. A strategic view of ICT supported cost management for green buildings in the quantity surveying practice. *Journal of financial management of property and construction*.
MESSNER, J., ANUMBA, C., DUBLER, C., GOODMAN, S., KASPRZAK, C., KREIDER, R., LEICHT, R., SALUJA, C. & ZIKIC, N. 2019. BIM Project Execution Planning Guide (v. 2.2).
MONTEIRO, A. & MARTINS, J. P. 2013. A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. *Automation in construction,* 35**,** 238-253.
MOORE, S. 2015. Digitalization or Automation—Is There a Difference. *Haettu,* 7**,** 2017.
NANEVA, A., BONANOMI, M., HOLLBERG, A., HABERT, G. & HALL, D. 2020. Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context. *Sustainability,* 12**,** 3748.
PARVIAINEN, P., TIHINEN, M., KÄÄRIÄINEN, J. & TEPPOLA, S. 2017. Tackling the digitalization challenge: how to benefit from digitalization in practice. *International journal of information systems and project management,* 5**,** 63-77.
POLIT, D. F. & BECK, C. T. 2010. Generalization in quantitative and qualitative research: Myths and strategies. *International journal of nursing studies,* 47**,** 1451-1458.
SACKS, R., EASTMAN, C., LEE, G. & TEICHOLZ, P. 2018. *BIM handbook: a guide to building information modeling for owners, designers, engineers, contractors, and facility managers*, John Wiley & Sons.
SALMINEN, A., KAUPPINEN, K. & LEHTOVAARA, M. 1997. Towards a methodology for document analysis. *Journal of the American Society for Information Science,* 48**,** 644-655.
SATTINENI, A. & BRADFORD, R. H. 2011. Estimating with BIM: A survey of US construction companies. *Proceedings of the 28th ISARC, Seoul, Korea,* 564**,** 569.
SHOU, W., WANG, J., WANG, X. & CHONG, H. Y. 2015. A comparative review of building information modelling implementation in building and infrastructure industries. *Archives of computational methods in engineering,* 22**,** 291-308.
SPRAGUE JR, R. H. 1995. Electronic document management: Challenges and opportunities for information systems managers. *MIS quarterly***,** 29-49.
STOLTERMAN, E. & FORS, A. C. 2004. Information technology and the good life. *Information systems research.* Springer.
SUNIL, K., PATHIRAGE, C. & UNDERWOOD, J. The importance of integrating cost management with building information modeling (BIM). 2015. International Postgraduate Research Conference (IPGRC 2015).
SWITZER, C. 2008. Time for change: empowering organizations to succeed in the knowledge economy. *Journal of Knowledge Management*.
SYKES, W. 1990. Validity and reliability in qualitative market research: A review of the literature. *Journal of the Market Research Society*.
TIHINEN, M., KÄÄRIÄINEN, J., AILISTO, H., KOMI, M., PARVIAINEN, P., TANNER, H., TUIKKA, T. & VALTANEN, K. 2016. The Industrial Internet in Finland: on route to success?
TIWARI, S., ODELSON, J., WATT, A. & KHANZODE, A. 2009. Model based estimating to inform target value design. *AECBytes" Building the Future*.
TKÁČ, M. & MESÁROŠ, P. Potential of 3D laser scanning in construction in connection with Building Information Modelling. Increasing the efficiency of construction through modern methods of construction, Scientific paper proceedings, 2015. 103-110.
VAN NEDERVEEN, G. A. & TOLMAN, F. 1992. Modelling multiple views on buildings. *Automation in Construction,* 1**,** 215-224.
VITÁSEK, S. & MATĚJKA, P. Utilization of BIM for automation of quantity takeoffs and cost estimation in transport infrastructure construction projects in the Czech Republic. IOP Conference Series: Materials Science and Engineering, 2017.
WEBB, S. P. 2017. *Knowledge management: Linchpin of change*, Routledge.
WEE, B. V. & BANISTER, D. 2016. How to write a literature review paper? *Transport Reviews,* 36**,** 278-288.
WESTERMAN, G., BONNET, D. & MCAFEE, A. 2014. The nine elements of digital transformation. *MIT Sloan Management Review,* 55**,** 1-6.
WESTERMAN, G., CALMÉJANE, C., BONNET, D., FERRARIS, P. & MCAFEE, A. 2011. Digital Transformation: A roadmap for billion-dollar organizations. *MIT Center for Digital Business and Capgemini Consulting,* 1**,** 1-68.

WU, J. & ZHANG, J. Automated BIM Object Classification to Support BIM Interoperability. Construction Research Congress 2018: Sustainable Design and Construction and Education, 2018.

WU, S., WOOD, G., GINIGE, K. & JONG, S. W. 2014. A technical review of BIM based cost estimating in UK quantity surveying practice, standards and tools. *Journal of Information Technology in Construction (ITCon),* 19**,** 534-562.

7 Appendix.

8 Appendix A. Interview Guide

9 Introduction to interviewer

I am Saeid Morovvati, a current master student at NTNU, studying Project management in civil engineering specialization. As for my academic background, I have a bachelor's and a master's degree in Civil engineering (structural engineering). This interview is regarding my master thesis and specialization project at the Department of Civil and Transport Engineering. The study is supervised by Ola Lædre (Professor at the Department of Civil and Transport Engineering), and David Fürstenberg (Ph.D. candidate NTNU/COWI). I will review BIM-Based cost estimation, process, experiences, advantages, disadvantages, and the potential to implement and develop it for infrastructure projects. This topic has been chosen due to the research gap in this field and the potential for further digitalization improvements in the AEC industry.

10 General information

- This interview will be sent to the respondents before the interview to give them an insight into the questionnaire.
- This interview is meant to be audio recorded. In case of any conflict of interest in this regard, please notify the interviewer.
- A summarized report of the interview will be written and sent to the respondent to confirm and prevent any misunderstanding.
- Reported data from the respondents will be anonymous, and the interviewer will only mention their roles and positions in case of need.
- In case of need for further information or clarification, the interviewer will contact the respondent.

11 Introduction to respondent

- Please introduce yourself, and your organization including:
- The main activity area of organization
- Your position and role in the organization
- Your experiences in cost estimation and BIM-based Cost estimation
- Your experience regarding model-based design

12 Respondent’s contact information

- Full name:
- Position and organization:
- Preferred contact way in case of need:
- Email:
- Mobile:

13 Appendix B. Questionnaire

16. In your opinion, how does the project delivery method affect the cost estimation process?
17. Who is involved in the process of cost estimation?
18. How is cost estimation practiced in this project?
19. To which degree is the cost estimation process automated?
20. Which stakeholder is responsible for the different parts of the cost estimation (Quantity takeoff, bill of quantities, pricing)?
21. What kind of software is used in the process?
22. How did you assess the level of detail of the BIM model in this project?
23. In your opinion, how important are open file formats, e.g., IFC, for establishing an automated cost estimation?
24. How did you map cost items to the BIM entities?
25. How did you identify suitable cost items in the model?
26. How did you manage the dynamic changes in the project with regards to cost estimation?
27. How did you involve additional parameters in cost estimation (e.g. WBS, temporary structures, and unmodeled items and assumptions)?
28. Did you implement environmental costs in the BIM model?
29. How reliable do you consider the current cost estimation method?
30. How efficient is the current method used in this project compared to other cost estimation types (e.g. quantity take-off from 2D drawings or qualitative methods like m^2 bridge deck or meter road)?

14

2020. Facts about E6 Kvål–Melhus. *NyeVeier*.

ALHASAN, S., KUMAR, B. & THANIKAL, J. V. 2017. Effectiveness of implementing 5D functions of building information modeling on professions of quantity surveying: a review. *International Journal of Civil Engineering and Technology,* 8**,** 783-800.

ALI, K. N., MUSTAFFA, N. E., KEAT, Q. J. & ENEGBUMA, W. I. 2016. Building information modelling (BIM) educational framework for quantity surveying students: The Malaysian perspective. *Journal of Information Technology in Construction (ITcon),* 21**,** 140-151.

ALUFOHAI, A. Adoption of building information modeling and Nigeria's quest for project cost management. FIG Working Week, 2012. 6-10.

AZHAR, S. 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering,* 11**,** 241-252.

BABATUNDE, S. O., EKUNDAYO, D., BABALOLA, O. & JIMOH, J. A. 2018. Analysis of the drivers and benefits of BIM incorporation into quantity surveying profession. *Journal of Engineering, Design and Technology*.

BABATUNDE, S. O., PERERA, S., EKUNDAYO, D. & ADELEYE, T. E. 2019. An investigation into BIM-based detailed cost estimating and drivers to the adoption of BIM in quantity surveying practices. *Journal of Financial Management of property and Construction*.

BOON, J. & PRIGG, C. Evolution of quantity surveying practice in the use of BIM–the New Zealand experience. Proceedings of the CIB International Conference on Management and Innovation for a Sustainable Built Environment, 2012. 84-98.

BORRMANN, A., KÖNIG, M., KOCH, C. & BEETZ, J. 2018. Building information modeling: why? What? How? *Building Information Modeling.* Springer.

BOUSQUET, O., BOUCHERON, S. & LUGOSI, G. Introduction to statistical learning theory. Summer School on Machine Learning, 2003. Springer, 169-207.

BOWEN, G. A. 2009. Document analysis as a qualitative research method. *Qualitative research journal,* 9**,** 27.

CHAN, I., LIU, A. & CHEN, B. Management strategies for 5D-BIM adoption in Hong Kong. Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate, 2018. Springer, 1023-1039.

CHOI, J., KIM, H. & KIM, I. 2015. Open BIM-based quantity take-off system for schematic estimation of building frame in early design stage. *Journal of Computational Design and Engineering,* 2**,** 16-25.

DE COUTO NASCIMENTO, V., DE CASTRO FERREIRA CONTI, A. C., DE ALMEIDA CARDOSO, M., VALARELLI, D. P. & DE ALMEIDA-PEDRIN, R. R. 2016. Impact of orthodontic treatment on self-esteem and quality of life of adult patients requiring oral rehabilitation. *The Angle Orthodontist,* 86**,** 839-845.

DEGRYSE, C. 2016. Digitalisation of the economy and its impact on labour markets. *ETUI Research Paper-Working Paper*.

DICICCO-BLOOM, B. & CRABTREE, B. F. 2006. The qualitative research interview. *Medical education,* 40**,** 314-321.

EASTMAN, C. M., EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*, John Wiley & Sons.

ELBELTAGI, E., HOSNY, O., DAWOOD, M. & ELHAKEEM, A. 2014. BIM-based cost estimation/monitoring for building construction. *International Journal of Engineering Research and Applications,* 4**,** 56-66.

FEAGIN, J. R., ORUM, A. M. & SJOBERG, G. 1991. *A case for the case study*, UNC Press Books.

FENG, C.-W., CHEN, Y.-J. & HUANG, J.-R. 2010. Using the MD CAD model to develop the time–cost integrated schedule for construction projects. *Automation in Construction,* 19**,** 347-356.

FIRAT, C. E., ARDITI, D., HAMALAINEN, J.-P., STENSTRAND, J. & KIIRAS, J. 2010. Quantity take-off in model-based systems.

FÜRSTENBERG, D. & LÆDRE, O. APPLICATION OF BIM DESIGN MANUALS: A CASE STUDY.

GASSMANN, O., FRANKENBERGER, K. & CSIK, M. 2013. The St. Gallen business model navigator.

GERRING, J. 2004. What is a case study and what is it good for? *American political science review***,** 341-354.

GHASSEMI, R. & BECERIK-GERBER, B. 2011. Transitioning to Integrated Project Delivery: Potential barriers and lessons learned. *Lean construction journal*.

HARTMANN, T., VAN MEERVELD, H., VOSSEBELD, N. & ADRIAANSE, A. 2012. Aligning building information model tools and construction management methods. *Automation in construction,* 22**,** 605-613.

HENRIETTE, E., FEKI, M. & BOUGHZALA, I. 2015. The shape of digital transformation: a systematic literature review. *MCIS 2015 proceedings***,** 431-443.

HWANG, Y.-S. 2004. Automatic quantity takeoff from drawing through IFC model. *Architectural Institute of Korea,* 20**,** 89-97.

ISMAIL, N. A. A., IDRIS, N. H., RAMLI, H., SAHAMIR, S. R. & ROOSHDI, R. R. R. M. 2018. Sustainable BIM-based cost estimating for quantity surveyors. *Chemical Engineering Transactions,* 63**,** 235-240.

JAN, S.-H., HO, S.-P. & TSERNG, H.-P. 2013. Applications of building information modeling (BIM) in knowledge sharing and management in construction. *International Journal of Civil, Structural, Construction and Architectural Engineering,* 7.

JRADE, A. & ALKASS, S. 2001. A conceptual cost estimating computer system for building projects. *AACE International Transactions***,** IT91.

KELLY, S. E., BOURGEAULT, I. & DINGWALL, R. 2010. Qualitative interviewing techniques and styles. *The SAGE handbook of qualitative methods in health research***,** 307-326.

KENT, D. C. & BECERIK-GERBER, B. 2010. Understanding construction industry experience and attitudes toward integrated project delivery. *Journal of construction engineering and management,* 136**,** 815-825.

KWON, O., JO, C.-W. & CHO, J.-W. 2011. Introduction of BIM quality standard for quantity take-off. *Journal of the Korea Institute of Building construction,* 11**,** 171-180.

LAHDENPERÄ, P. 2012. Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction management and economics,* 30**,** 57-79.

LEE, S.-K., KIM, K.-R. & YU, J.-H. 2014. BIM and ontology-based approach for building cost estimation. *Automation in construction,* 41**,** 96-105.

LEONARD-BARTON, D. 1990. A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites. *Organization science,* 1**,** 248-266.

LUTH, G. P., SCHORER, A. & TURKAN, Y. 2014. Lessons from using BIM to increase design-construction integration. *Practice periodical on structural design and construction,* 19**,** 103-110.

MA, Z., WEI, Z. & ZHANG, X. 2013. Semi-automatic and specification-compliant cost estimation for tendering of building projects based on IFC data of design model. *Automation in Construction,* 30**,** 126-135.

MA, Z., ZHANG, X., WU, S., WEI, Z. & LOU, Z. Framework design for BIM-based construction cost estimating software. Proceedings of the CIB W, 2010. 2010.

MATIPA, W. M., KELLIHER, D. & KEANE, M. 2009. A strategic view of ICT supported cost management for green buildings in the quantity surveying practice. *Journal of financial management of property and construction*.

MESSNER, J., ANUMBA, C., DUBLER, C., GOODMAN, S., KASPRZAK, C., KREIDER, R., LEICHT, R., SALUJA, C. & ZIKIC, N. 2019. BIM Project Execution Planning Guide (v. 2.2).
MONTEIRO, A. & MARTINS, J. P. 2013. A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. *Automation in construction,* 35**,** 238-253.
MOORE, S. 2015. Digitalization or Automation—Is There a Difference. *Haettu,* 7**,** 2017.
NANEVA, A., BONANOMI, M., HOLLBERG, A., HABERT, G. & HALL, D. 2020. Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context. *Sustainability,* 12**,** 3748.
PARVIAINEN, P., TIHINEN, M., KÄÄRIÄINEN, J. & TEPPOLA, S. 2017. Tackling the digitalization challenge: how to benefit from digitalization in practice. *International journal of information systems and project management,* 5**,** 63-77.
POLIT, D. F. & BECK, C. T. 2010. Generalization in quantitative and qualitative research: Myths and strategies. *International journal of nursing studies,* 47**,** 1451-1458.
SACKS, R., EASTMAN, C., LEE, G. & TEICHOLZ, P. 2018. *BIM handbook: a guide to building information modeling for owners, designers, engineers, contractors, and facility managers*, John Wiley & Sons.
SALMINEN, A., KAUPPINEN, K. & LEHTOVAARA, M. 1997. Towards a methodology for document analysis. *Journal of the American Society for Information Science,* 48**,** 644-655.
SATTINENI, A. & BRADFORD, R. H. 2011. Estimating with BIM: A survey of US construction companies. *Proceedings of the 28th ISARC, Seoul, Korea,* 564**,** 569.
SHOU, W., WANG, J., WANG, X. & CHONG, H. Y. 2015. A comparative review of building information modelling implementation in building and infrastructure industries. *Archives of computational methods in engineering,* 22**,** 291-308.
SPRAGUE JR, R. H. 1995. Electronic document management: Challenges and opportunities for information systems managers. *MIS quarterly***,** 29-49.
STOLTERMAN, E. & FORS, A. C. 2004. Information technology and the good life. *Information systems research.* Springer.
SUNIL, K., PATHIRAGE, C. & UNDERWOOD, J. The importance of integrating cost management with building information modeling (BIM). 2015. International Postgraduate Research Conference (IPGRC 2015).
SWITZER, C. 2008. Time for change: empowering organizations to succeed in the knowledge economy. *Journal of Knowledge Management*.
SYKES, W. 1990. Validity and reliability in qualitative market research: A review of the literature. *Journal of the Market Research Society*.
TIHINEN, M., KÄÄRIÄINEN, J., AILISTO, H., KOMI, M., PARVIAINEN, P., TANNER, H., TUIKKA, T. & VALTANEN, K. 2016. The Industrial Internet in Finland: on route to success?
TIWARI, S., ODELSON, J., WATT, A. & KHANZODE, A. 2009. Model based estimating to inform target value design. *AECBytes" Building the Future*.
TKÁČ, M. & MESÁROŠ, P. Potential of 3D laser scanning in construction in connection with Building Information Modelling. Increasing the efficiency of construction through modern methods of construction, Scientific paper proceedings, 2015. 103-110.
VAN NEDERVEEN, G. A. & TOLMAN, F. 1992. Modelling multiple views on buildings. *Automation in Construction,* 1**,** 215-224.
VITÁSEK, S. & MATĚJKA, P. Utilization of BIM for automation of quantity takeoffs and cost estimation in transport infrastructure construction projects in the Czech Republic. IOP Conference Series: Materials Science and Engineering, 2017.
WEBB, S. P. 2017. *Knowledge management: Linchpin of change*, Routledge.
WEE, B. V. & BANISTER, D. 2016. How to write a literature review paper? *Transport Reviews,* 36**,** 278-288.
WESTERMAN, G., BONNET, D. & MCAFEE, A. 2014. The nine elements of digital transformation. *MIT Sloan Management Review,* 55**,** 1-6.
WESTERMAN, G., CALMÉJANE, C., BONNET, D., FERRARIS, P. & MCAFEE, A. 2011. Digital Transformation: A roadmap for billion-dollar organizations. *MIT Center for Digital Business and Capgemini Consulting,* 1**,** 1-68.
WU, J. & ZHANG, J. Automated BIM Object Classification to Support BIM Interoperability. Construction Research Congress 2018: Sustainable Design and Construction and Education, 2018.
WU, S., WOOD, G., GINIGE, K. & JONG, S. W. 2014. A technical review of BIM based cost estimating in UK quantity surveying practice, standards and tools. *Journal of Information Technology in Construction (ITCon),* 19**,** 534-562.