Interface of Building Information Modeling and Blueprints on Construction Sites

A qualitative study of on-site Building Information Modeling's impact on large-scale construction projects by implementing digital models as the foundation for blueprints and pursuing paperless construction sites.

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Master

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This master's thesis is submitted in partial fulfillment of the requirements for the degree Master of Science (norsk: sivilingeniør) in Industrial Economics & Technology Management. The master's thesis is conducted as a part of the education programme by the University of Agder and is approved as a part of this education. This approvement does not involve that the university warrants for any of the methods that have been utilized or the conclusions that have been drawn.

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Abstract

This Master's thesis discloses the impact of Building Information Modeling (BIM) during the delivery phase of large-scale construction projects. The Architecture, Engineering, and Construction (AEC) industry is gradually adopting more digital solutions in the pursuit of increasing operational efficiency and becoming more sustainable. In this regard, it is expedient to investigate whether the new tools and processes that BIM entails can provide the on-site delivery team with a better foundation of blueprints than traditional 2D paper-based drawings. The study was conducted through qualitative methods with an analytical generalization approach, including literature and case studies. Four different projects were examined through exploratory semi-structured interviews with key project representatives. The findings suggest that the implementation of on-site BIM through interfaces such as tablets and smartphones can enhance production activities and provide the delivery team with an improved and more comprehensive foundation of blueprints. However, several challenges must be considered. The projects investing in implementing digital solutions today are facilitating long-term value creation and are contributing to driving the industry forwards.

Keywords: Building Information Modeling; Blueprints; Interface; Digital transformation.

Sammendrag

Denne mastergradsavhandlingen omhandler virkningen av bygningsinformasjonsmodellering (BIM) i produksjonsfasen av byggeprosjekter i stor skala. Byggeindustrien innlemmer stadig flere digitale løsninger i jakten på å øke operasjonseffektiviteten og bli mer bærekraftig. I denne sammenheng er det hensiktsmessig å etterforske hvordan de nye verktøyene og prosessene som BIM medfører kan presentere fagarbeiderne på byggeplass med et bedre arbeidsgrunnlag enn de tradisjonelle papirbaserte 2D tegningene. Studien ble utført gjennom kvalitative metoder med en analytisk generaliserende tilnærming som inkluderte litteratur- og case-studier. Fire forskjellige prosjekter ble undersøkt gjennom utforskende semi-strukturerte intervjuer med nøkkelrepresentanter fra prosjektene. Funnene foreslår at implementering av BIM på byggeplass gjennom grensesnitt som nettbrett og smarttelefoner kan forbedre produksjonsaktiviteter og tilby leveransegruppen med et bedre og mer omfattende arbeidsgrunnlag. Likevel er det mange utfordringer som også må hensyntas. Prosjektene som investerer i å implementere digitale løsninger i dag tilrettelegger for langsiktig verdiskapning og bidrar til å utvikle bransjen videre.

Nøkkelord: Bygningsinformasjonsmodellering; Arbeidsgrunnlag; Grensesnitt; Digital omstilling.

Preface

This document contains the master's thesis that completes the education programme for the degree Master of Science in Industrial Economy & Technology Management at the University of Agder, School of Business and Law. The thesis constitutes 30 ETCS and was performed during the spring semester of 2021. The terminology used in the thesis is in parts based upon the terms defined by the International Organization for Standardization presented in the national standard for digitization of information about buildings and civil engineering works NS-EN ISO 19650. A basic understanding of common subjects of expression used in civil engineering is recommended for readers but is not an absolute necessity. The thesis is structured according to an extended version of the IMRaD-format with the reference style APA 6th.

Prior to starting the master's study programme, I had completed a bachelor's degree in civil engineering. When planning to write my master's thesis, it was of interest to study a subject that contains elements from both the construction industry and administrative processes, where I could combine the two engineering disciplines from my education. This became viable through the course IND419 Design & Engineering Management, where subjects such as BIM and VDC were central topics, in addition to project management. The problem statement and following research question were formed in close collaboration with the course lecturer, who has also been the supervisor of the thesis. As the AEC industry is currently undergoing a steady transformation towards digital solutions, this was identified as the main subject of the thesis – a subject that will presumably be of relevance in the industry for several years to come.

The COVID-19 pandemic has caused unprecedented difficulties for many activities worldwide during the early 2020s. The performance of this thesis was no exception to this, as strict national virus contamination regulations made certain tasks more challenging. However, it has uniquely promoted the use of digital solutions, and may also have contributed to expedite the digital transformation of many activities. There is no doubt that many of these digital solutions have come to stay for the foreseeable future, both within private and industrial use. As with BIM in the AEC industry, it is all about identifying the best way to apply them for most efficient use.

Lysekloster, May 28th, 2021.

Stian Johannessen

Stian Bråten Johannessen

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I would also like to acknowledge everyone who contributed to my research by being interviewed for the case studies. A study is only as good as its data, where – in this case – the informants have provided the utmost quality of feedback and insights on the subject. I am impressed and grateful for how I have been greeted by every project member I have contacted, the passion they exude for the subject, and the willingness to share their knowledge to provide my research with extensive first-rate data. Therefore, I would like to thank the key contributors to my research, namely Runar Nykvist, Mathias Engeset, and Pål Trollsås at Skanska, Tom Erik Strøm at Statsbygg, and Leif Rathe at Norconsult. Furthermore, I would like to acknowledge Lars Abrahamsen, Terje Kulien Lunde, Lars Kulien, Bent Trygve Hansen, Vegard Torkelsen, Inge Aarseth, and Agnar Johansen for their participation in the study.

Additionally, my appreciation goes to the University of Agder. My academic years at the institution have been inspired by the lecturers and personnel who facilitate the best conditions to learn and achieve an invaluable education, along with many of my fellow co-students whose drive and incredible talents have motivated me to keep working hard. I would especially like to thank Paul Ragnar Svennevig, who was the study coordinator during my bachelor’s degree in civil engineering and who also in parts has contributed to this thesis. Paul’s office door is always open, and I am grateful for his ever-present willingness to discuss BIM-related topics. I would also like to thank Torbjørn Bjorvatn, who has been the study coordinator for this master’s degree.

Finally, I would like to express my gratitude to my family and friends. I would especially like to thank my parents for their support during all my five years of studying at the university. This thesis and accompanying degree have only been made possible because of their countless contributions, encouragements, and unconditional support over a long period and could not have been achieved without them.

Table of contents

List of figures

List of tables

Abbreviations

2D	**Two-D**imensional
3D	**Three-D**imensional
4D	**Four-D**imensional
5D	**Five-D**imensional
5G	**Fifth G**eneration
AEC	**A**rchitecture, **E**ngineering, and **C**onstruction
BIM	**B**uilding **I**nformation **M**odeling
CAD	**C**omputer-**A**ided **D**esign
CM	**C**ontract **M**anagement
FBS	**F**unction-**B**ehaviour-**S**tructure
ICE	**I**ntegrated **C**oncurrent **E**ngineering
IFC	**I**ndustry **F**oundation **C**lasses
IPD	**I**ntegrated **P**roject **D**elivery
IT	**I**nformation **T**echnology
KPI	**K**ey **P**erformance **I**ndicator
LOD	**L**evel **O**f **D**evelopment
LPS	**L**ast **P**lanner **S**ystem
MMI	**M**odel **M**aturity **I**ndex
MNOK	**M**illion **No**rwegian **K**roner

NNM The **N**ew **N**ational **M**useum (norsk: Nye Nasjonalmuseet)

NPK New construction for psychiatric health Kristiansand (norsk: **N**ybygg **P**sykisk helse **K**ristiansand)

NS-EN ISO Norwegian Standard European Norm International Organization for Standardization (norsk: **N**orsk **S**tandard **E**uropeisk **N**orm den **I**nternasjonale **S**tandardiserings**o**rganisasjonen)

PDCA **P**lan-**D**o-**C**heck-**A**ct

R&D **R**esearch **&** **D**evelopment

RHO **R**adium **H**ospital in **O**slo (norsk: Radiumhospitalet i Oslo)

SiV The Hospital in Vestfold (norsk: **S**ykehuset **i** **V**estfold)

VDC **V**irtual **D**esign and **C**onstruction

1 | Introduction

This chapter introduces the purpose of the thesis, its background, and its relevance. Furthermore, it will describe the main topics and how the problem statement impacts both the industry and society at large, which culminates into the research question. Additionally, it addresses the scope and limitations of the study.

1.1 | Background

Over the last couple of decades, the Architecture, Engineering, and Construction (AEC) industry has – as most modern industries – undergone a steady evolution of digitalization and is gradually moving towards fully digital solutions (Bølviken, Kalsaas & Skaar, 2020). As a result, Building Information Modeling (BIM) has become a cornerstone in the adaptation of digital solutions in the industry, both as a tool and a process.

When defining BIM, it is of importance to differentiate between 'model', which indicates a digital building assembled by geometric objects visualized through software, and 'modeling', which refers to a broader and more comprehensive aspect of the term. Sacks, Eastman, Lee & Teicholz (2018a) regards BIM as a socio-technical system to describe the activity of changing processes in the design, construction, and facility management. The development, implementation, and appliance of BIM includes both improvements on existing methods, as well as introducing new possibilities, and has changed many of the ways construction projects are being conducted. According to Kensek (2014, p. 1), the concept of BIM discloses more than just software portraying three-dimensional (3D) models; it is an all-encompassing process, "*[…] involving a large group of stakeholders from design and construction to operations and maintenance. It is collaborative, encouraging the sharing of data, knowledge, responsibility, risk and reward.*" As a result, the implementation of BIM may facilitate increased communication among the interdependencies in complex construction projects.

The application of BIM has particularly appeared fruitful during the initiation, design, planning, and preconstruction phases of construction projects (Rowlinson, Collins, Tuuli & Jia, 2010; see also Arayici, Egbu & Coates, 2012). BIM technology introduces a dimension where data from the life cycle of an artefact can be accounted for in detail, from design to construction, operation, maintenance, and demolition. Yet, there are still questions to be answered regarding how to fully exploit the vast potential of BIM, especially during the performance and execution phase of projects – henceforth referred to as the delivery phase. An important question in the implementation of BIM during the delivery phase is 'how can the model drawings be transferred from the BIM engineers and accessed on the construction sites?' This can be described as the interface of the BIM blueprints and is key to the utilization of the digital model in practice. Traditionally, the main interfaces have been two-dimensional (2D) paper drawings, architectural renderings of viewpoints, and paper models, often because of the BIM software's inadequacies in providing realistic visualizations (Huang, Yien, Chen, Su & Lin, 2017). How to communicate the ideas efficiently and practically from the BIM engineers during design to the delivery team at the construction site and making them sufficiently understandable has been a limiting issue in many projects. However, technological advancements in recent years have negated these issues. Sacks, Korb & Barak (2018b, p. 34) states that "*Wherever BIM information can be carried through from design to fabrication directly, as is already the case for a variety of building components, drawings become superfluous.*" BIM models now offer a sufficient level of sophistication to replace 2D drawings, to serve as the foundation for blueprints in construction projects (Guy, 2021; see also Merschbrock & Nordahl-Rolfsen, 2016; Omholt-Jensen; 2018).

The ambition is to make the digital model accessible for the sub-contractors when it is needed. Here, it is crucial to make the interface as simple and efficient as practically possible, and ideally provide the sub-contractors with tailor-made blueprints that are relevant to their field, including sections of the details and viewpoints that are needed throughout their day-to-day operations. Is it sufficient to provide the delivery team with the full-scale model of the construction – provided that it contains a satisfactory level of detail – or is it necessary to facilitate a more customized interface approach between model and blueprints? With such issues in mind, this thesis aims to investigate the level of BIM interface facilitation is currently ongoing construction projects. This involves documenting the experiences on digital modeling from the various involved actors, their familiarity with BIM interfaces versus 2D paper blueprints, and whether the implementation of on-site BIM is appropriate during large-scale construction projects.

1.2 | Societal perspective

A report from Statistics Norway from 2018 reveals that productivity in the AEC industry has decreased by 10 percent nationally since the year 2000 (Todsen, 2018). It is envisioned that further implementation of BIM in construction projects can contribute to reversing the negative trend regarding productivity in addition to promoting sustainability. Sacks et al. (2018a, p. xxi) states that "*[…] BIM creates significant opportunities for society at large to achieve more sustainable building construction processes and higher performance facility with fewer resources and lower risk than can be achieved using traditional practices.*" This is substantiated by Tang, Chen, Tang Wu & Trofimova (2017) who state increased attention to sustainability as a major benefit of BIM, by facilitating more thorough sustainability analysis in early project stages. "*Compared with conventional 2D drawing method, BIM provides innovative simulation and visualization approaches for the entire lifecycle, which is from planning phase to final operation and management. Its effective and efficient performance not only means the decrease of project wastes and saving of energy during the construction phase, but also presents the possibility of long-term operation and management with high energy efficiency. With rapidly growing attentions, BIM is becoming the core of global AEC industrial revolution, which aims to realize low-energy consumed and sustainable development*" (Tang et al., 2017, p. 16). In summary, the utilization of BIM does not necessarily represent a sole solution to optimizing the AEC industry but can be a valuable contributing factor in improving overall construction processes, to enable the construction of greener and smarter buildings with fewer occurrences of waste and lowering of risks. This will in terms increase operational efficiency and enhance productivity.

The thesis focuses on the construction of public buildings, specifically hospital buildings, as these were among the most relevant cases accessible for the study at the time of writing. Hospital buildings are essential buildings for modern society, that provide indispensable services for the general public. They also offer the possibility of research and development (R&D) and science related to the field of medicine. It is therefore important that buildings associated with the health industry are constructed efficiently, with high standards and constructability. Digital solutions during the construction phase, such as the utilization of digital tools and paperless blueprints, may therefore benefit the government and the public society both in terms of economical savings, better access to public hospitals of high quality, and earlier availability as a result of shorter construction periods.

1.3 | Problem statement

As the AEC industry is increasingly adopting BIM during production, it is of relevance to acquire more knowledge related to how the implementation of digital solutions is being conducted in the delivery phase of large-scale construction projects. Here, it is of interest to gather more empirical data from recently completed or currently ongoing projects to assess how BIM impacts the work processes of the participating actors on construction sites, and whether fully digital solutions represent an advantage over traditional methods. Blueprints appear as the foundation for on-site construction activities, either as drawings prepared on paper-formats or digitally through the model and sectional drawings. The emphasis of the study is placed on whether the digital interfaces – such as BIM kiosks, tablets, and smartphones – offer a sufficient level of sophistication and convenience to replace traditional paper-based blueprints. By examining how project management, communication, and interfaces are facilitated digitally, the study intends to explore how to exploit the potential of BIM most efficiently, and whether its implementation can contribute to increasing operational efficiency in projects.

Based on this, the following research questions for the thesis were defined: **How does the utilization of BIM improve the foundation for blueprints in the delivery phase?**

The research question intends to investigate the implementation of on-site BIM in practice among national large-scale (100 MNOK or more) construction projects, to examine whether digital interfaces such as BIM kiosks, tablets, and smartphones provide a better foundation for blueprints than traditional 2D paper-based drawings.

1.4 | Scope and limitations

BIM is an extensive and wide-ranging topic with many areas of application. Therefore, it is necessary to adjust a narrow scope on a specific subject within the topic to make the thesis feasible. As a result, the scope was narrowed to focus on the interface aspect on construction sites during the delivery phase. Furthermore, the thesis mainly addresses the construction of public hospital buildings, although the construction of a public museum was included because of high relevance to the problem statement in terms of findings. The narrow scope limits the volume of representative projects applicable for investigation.

Gero & Kannengiesser (2014) discusses the phenomena of design as a profound human activity. Based on the design being a fundamental part of the way humans – e.g., engineers and architects

– intentionally reshape the world they inhabit, the Function-Behaviour-Structure (FBS) framework was defined as an ontology to describe all things designed, where function represents an artefact's purpose, behaviour represents an artefact's performance, and structure represents an artefact's infrastructural contents. When conducting large-scale construction projects, the interface represents a crucial aspect in the interdependence between design and the foundation of blueprints. The thesis aims to assess prerequisite conditions and cause and effect relations within the design and delivery processes of construction projects, to examine whether the implementation of digital interfaces enhances project efficiency. As a result, the study is located within the design description of the FBS framework, as illustrated in figure 1.4-1.

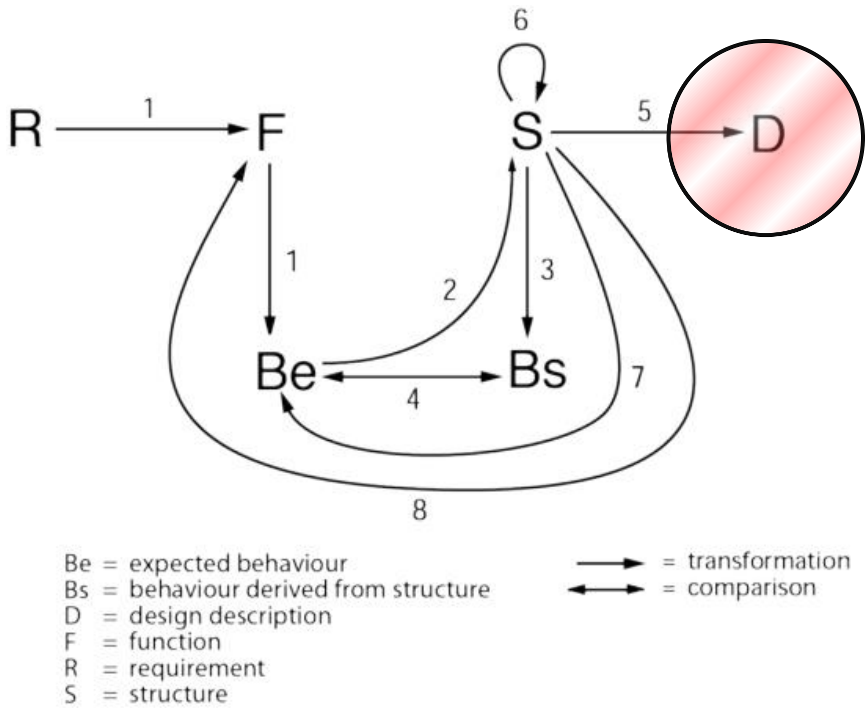

Figure 1.4-1: *The FBS framework (Gero & Kannengiesser, 2014, p. 268). The colored circle represents the scope of the thesis.*

The findings suggest that the choice of BIM software for a project represents an interesting aspect in terms of the interface. However, due to the magnitude of available software, it was not feasible to elaborate in detail on what the various programs have to offer in this thesis. Therefore, this topic is not defined within the thesis's scope.

The research for this thesis was conducted by the author during the spring semester of 2021. A Master's thesis consists of 30 ETCS which constitutes a workload of approximately 750 hours according to guidelines from the University of Agder. The thesis was performed during a single semester, and there existed no prior preparing assignments in advance to the start of the semester. This limited the level of pre-existing familiarity with the specifics of the subject. The author possesses pre-existing knowledge within certain aspects of the design and management of construction projects but has limited expertise in the technical day-to-day operations of the sub-contractors on the construction site during the delivery phase. Therefore, going into the research, it was unclear which tools and methods sub-contractors were familiar with, and the extensiveness of which digital solutions were utilized on-site. Physical on-site visitations of the construction sites have not been practically achievable due to COVID-19 virus contamination restrictions.

1.5 | Thesis outline

This Master's thesis contains seven chapters. Table 1.5-1 showcases the outline and structure of the thesis and describes the purpose of each respective chapter.

#	Headline	Contents
1	**Introduction**	Introduces the purpose of the thesis, its background, and relevance. Describes the main topics and how the problem statement impacts both the industry and society at large, which culminates into the research question. Addresses the scope and limitations of the study.
2	**Method**	Presents the research design and the methods that were utilized to resolve the research question.
3	**Framework**	Presents the general framework of information related to the subject to provide context to the findings.
4	**Theory**	Discloses theoretical research closely related to the research question and further presents relevant theory from the literature on to topics central to the study.
5	**Case**	Presents general information on each specific case study and key data related to their respective project.
6	**Results and discussion**	Presents the findings from empirical data and compares these to subjects from the theory through discussion.
7	**Conclusion**	Summarizes the thesis and offers inferences based on reflection around the findings.

Table 1.5-1: *Thesis outline.*

2 | Methods

This chapter presents the approach, research design, methods, and procedures that were applied during the study and writing of the thesis, to examine the subject matter and resolve the research question.

2.1 | Research design

The research design describes an overall plan for the scientific methods that were utilized when resolving the thesis' research question. The research question was founded on a theoretical framework surrounding topics related to BIM and digital transformation in the AEC industry, presented in Chapter 3 (Framework). Subsequently, four case studies – one in-depth and three to supplement the context – were examined based on the theoretical foundation, thus making the thesis a theoretically informed case study through analytical generalization. Three case studies – including the in-depth one – were related to the construction of public hospital buildings, while the last concerned the construction of a public museum. All cases are considered as relatively large-scale construction projects by Norwegian standards, based on parameters such as total costs, number of involved participants, dimensions of construction, etc., as presented in Chapter 5 (Case). The case studies provided the basis for the empirical data of the thesis. Additionally, theoretical literature was examined and explored simultaneously and throughout the gathering of empirical data, with parts of the elected theory being based on findings, presented in Chapter 4 (Theory). Inferences are composed of an abductive research approach including inductive reasoning methods. Abductive reasoning was utilized when defining the problem statement and researching existing theory on the subject, while an inductive approach was deployed during and after the gathering of empirical data to draw conclusions about the subject.

The research method is inspired by the concept of systematic combining, presented in Dubois & Gadde (2002, pp. 555–556), where it is argued that "*[…] theory cannot be understood without empirical observation and vice versa.*" Figure 2.1-1 displays the interlinks between theory and empiricism during systematic combining, where the case study is not regarded as a linear process, but as an integrated approach where the researcher is *"[…] constantly going 'back and forth' from one type of research activity to another and between empirical observations and theory […]*" with the "*[…] objective of matching theory and reality.*" The research design can therefore be summarized as theoretically grounded exploration through empirical case studies.

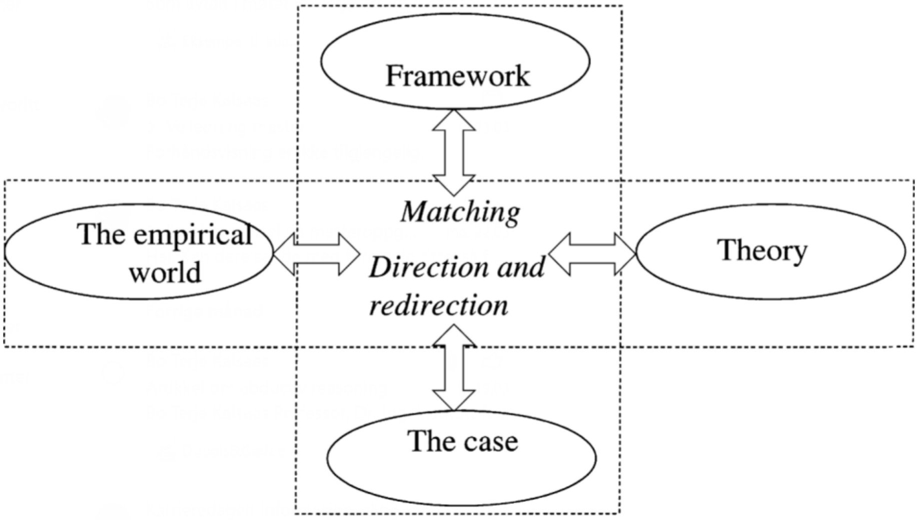

Figure 2.1-1: *Basic ingredients in systematic combining (Dubois & Gadde, 2002, p. 555).*

Inductive (theory building) reasoning involves understanding a topic based on patterns and developing explanations based on observations (Bernard, 2011, p. 7). Contrary to the deductive (theory testing) approach, induction starts with empirical research to develop a new theory as a result of the observations, rather than creating hypotheses from established theory (Goddard & Melville, 2004). Abductive reasoning expands on the inductive approach by enabling data-driven theory generation (Järvensivu & Törnroos, 2010). The combination of inductive and abductive reasoning was utilized in this thesis to cross-reference findings with existing theory, and thereby establish a higher degree of generalizability. Figure 2.1-2 displays the abductive reasoning model presented by Kovács & Spens (2005), which inspired the approach of researching this thesis.

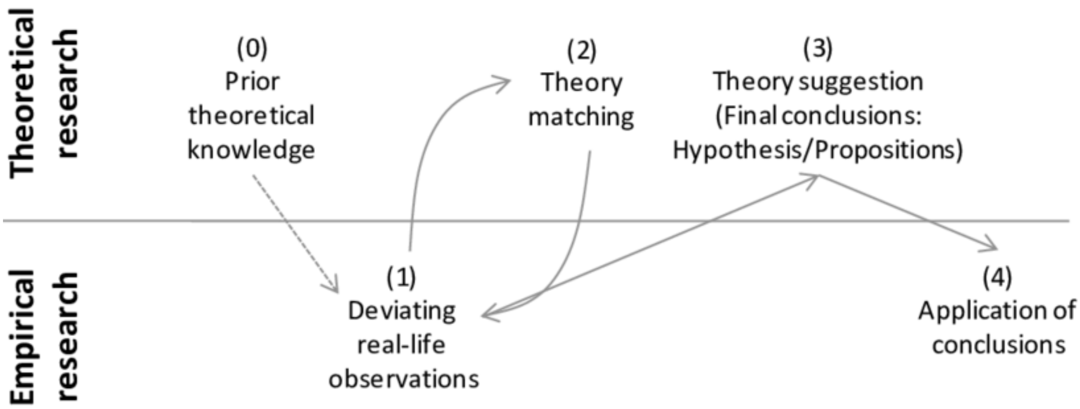

Figure 2.1-2: *Abductive research approach (Kovács & Spens, 2005).*

Responses from informants during the case studies are considered as the thesis' primary sources, where their feedback has provided the basis for the empirical data presented in Chapter 6 (Results and discussion). Supplementary data collected from literature studies are regarded as secondary sources, collectively used to establish a theoretical understanding of the subject matter, which are presented in Chapter 4 (Theory). The discussion and conclusions that were drawn consist of a combination between literature studies and case studies, where theory and empirical findings are compared and examined in relation to each other to provide the basis for inferences. However, during systematic combining, the researcher's main objective is to discover new perspectives within the theoretical framework (Dubois & Gadde, 2002). Systematic combining can therefore be regarded as a refinement of existing theories. Figure 2.1-3 showcases an outline illustration of the research design and presents the step-by-step scheme of how the research was conducted.

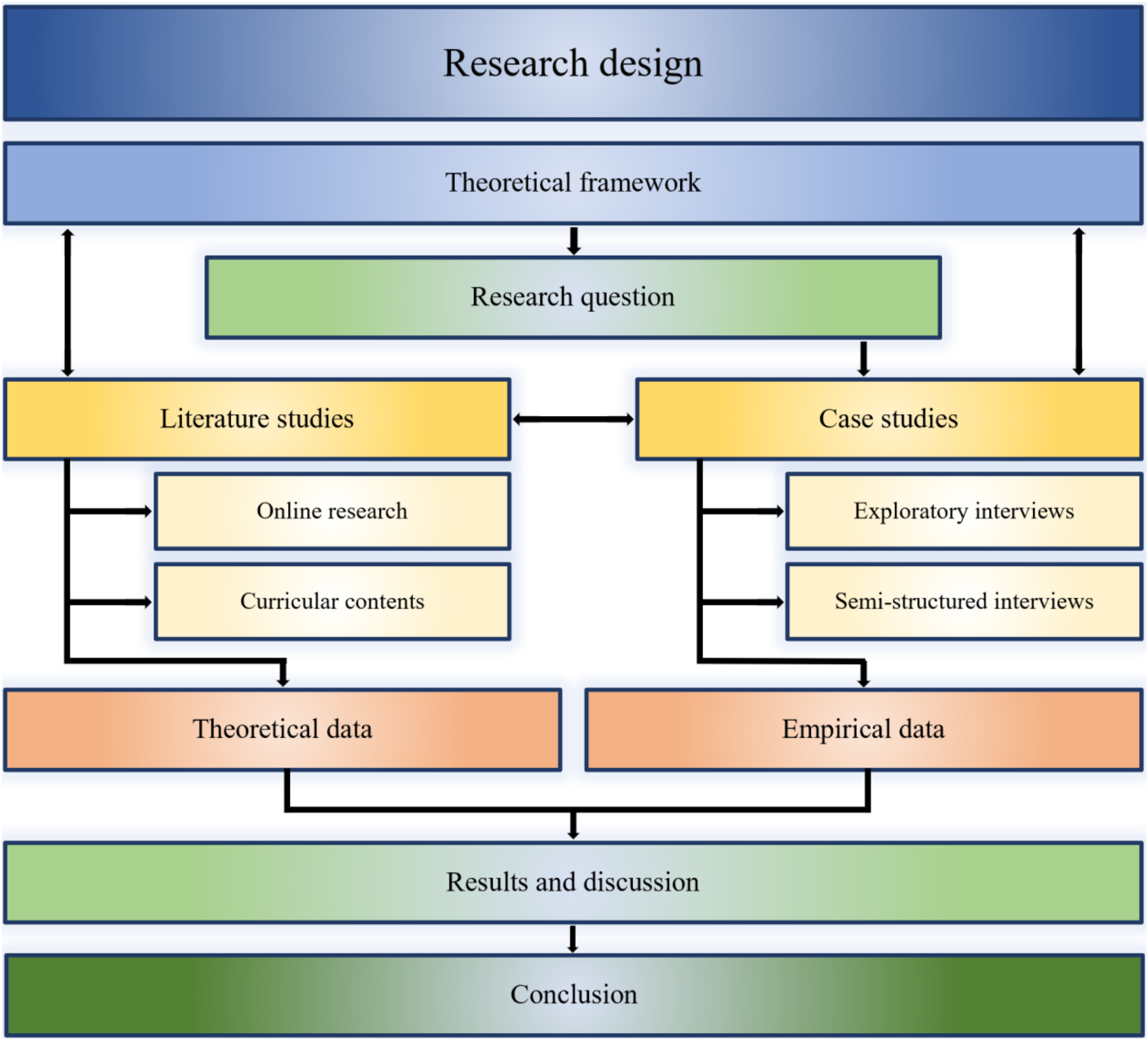

Figure 2.1-3: *Illustration of the thesis research design.*

2.2 | Literature studies

In recent years, BIM has been the center of attention in many studies of the AEC industry. Therefore, it has been of interest to supplement this thesis with a collection of existing data from the literature on relevant topics. This was accomplished through the method of literature studies. According to Balida (2020), the purpose of conducting a literature study in a thesis is: "*To enhance the understanding of the thesis; To prepare for the physical writing of the thesis; To ensure that the study is unique and not only repeating what others have done; To find gaps from previous studies and address those gaps.*" A review of existing literature creates a foundation for understanding a topic, which is essential when taking on a research project (Baker, 2000). This provides the basis for the thesis and serves as an argument for why the research question is stimulating for further examination. Findings from the literature studies have been assembled in Chapter 4 (Theory) and are furtherly addressed in discussion against the empirical findings.

The election of core subject matter for the literature studies was based around leading actors in the field of BIM. The works of renowned authors such as Charles Eastman, Rafael Sacks, and Karen Kensek were of special interest, who have all published important literature within the subject of BIM over several years. As a result, the main references for the literature studies include *BIM Handbook* (Sacks, Eastman, Lee & Teicholz, 2018a), *Building Lean, Building BIM* (Sacks, Korb & Barak, 2018b), and *Building Information Modeling* (Kensek, 2014).

Additionally, the literature studies have been supplemented with several published articles on the implementation of BIM in large-scale construction projects. These articles have been identified by formulating specific search terms to yield hits for desired contents. For this purpose, search engines such as Oria, Google Scholar, and ResearchGate have been utilized, in addition to databases of theses from both Norwegian and international universities.

Lastly, the literature studies also included a review of contents from the curriculum of courses from the Bachelor of Science Civil Engineering and Master of Science Industrial Economics & Technology Management education programmes at the University of Agder. Over five years of studying, many courses have contained highly relevant materials correlated to the thesis' problem statement. Especially contents presented in the course IND419 Design & Engineering Management has been applied to the literature studies, along with contents from BYG217 Project Management with Lean Construction, BYG211 Data Modeling & Surveying, and IND514 Project Business & Governance.

2.3 | Case studies

The main method for gathering empirical data has been through case studies. The case studies were performed through interviews with informants associated with each respective case study. A case study offers the possibility to examine and analyze specific real-world topics with a narrow scope. This is substantiated by Baxter & Jack (2008), who describes the case study as a qualitative method where the examination of a specific example is utilized to explain a theory or a phenomenon. Furthermore, Yin (2003) highlights the case study as an appropriate method when a study's purpose is to uncover problem statements on 'how' and 'why', when seeking an explanation to observations. The case study approach offers the possibility of investigating cause and effect relations from real-life settings, which provides the means for developing theory (Dubois & Gadde, 2002).

2.3.1 | Identifying appropriate cases

On account of the thesis's narrow scope, only a handful of relevant cases for the study exists on a national scale. When conducting case study research, it is essential to get in touch with the right sources, in terms of knowledge and experience related to both the project and the subject. Therefore, a thorough mapping of potential case studies and interview objects was necessary preliminary to initiating contact, to evaluate their relevance to the thesis problem statement. This was done in close collaboration with the thesis' supervisor, who holds an interest within all elected cases for the study. Projects deemed applicable to the research were also investigated prior to initiating contact.

2.3.2 | Interview process

Interviews were initiated by contacting a representative for each respective case. This was done by making informal phone calls to key actors related to the case, where an exploratory interview of the case commenced. Topics discussed during these interviews were mainly based on the project's ambitions in terms of the utilization of BIM and paperless blueprints. This created the foundation for general insights into the case and provided a further basis to whether the respective project was of relevance to the thesis problem statement. If determined that cases applied to the research, an appointment was scheduled for a more in-depth interview on the subject, where the informants ahead of time were notified of the line of questioning that was prepared through an interview guide. Interviews were performed digitally through Microsoft Teams. This was in part due to COVID-19 virus contamination restrictions that limited the opportunities for in-person interactions, but also because of the convenience that digital meetings entail.

The interview guide was constructed according to a semi-structured interview approach. Questions were defined based on central topics related to the project's experiences of BIM and digital blueprints during and throughout the project. Defining the questions as open-ended was a deliberate choice from a research perspective. Dubois & Gadde (2002) presents a distinction between 'active data' and 'passive data'. Passive data represents data directed by the line of questioning, while active data is associated with the explorative discovery of data, often difficult to uncover. In this context, a passive research approach, such as exploratory and semi-structured interviews, tends to yield the best chances for discovering active – or less predetermined – data, as it allows the informants to reflect loosely around the main bullet points, in addition to having a concrete line of topics. This approach is more fluid and 'adventurous' than a rigid interview guide with specific close-ended questions, as it lets respondents go on tangents about themes related to the project as a whole, in addition to having a particular topic as a reference point. This may provide a higher level of active data in findings – observations that could not have been found through active search (Dubois & Gadde, 2002). Findings from interviews were transcribed and documented locally in a case study database, in parts as a measure to protect privacy and confidentiality.

2.3.3 | Informants

A total number of twelve interviews were conducted in the study, whereas seven were exploratory and five were semi-structured. It has been of interest to gather data from different actors' perspectives on the subject. Therefore, informants hold various roles and responsibilities within each respective project. Table 2.3-1 presents the type of interview and number of interviews that were conducted, while table 2.3-2 presents an overview of which role the participating informants represent in their project within each respective case study.

Interviews conducted (12)		Case study			
		NPK[1]	SiV[2]	RHO[3]	NNM[4]
Type of interview	Exploratory	3	2	1	1
	Semi-structured	2	1	1	1
Number of interviews		5	3	2	2

Table 2.3-1: *Number and type of interview conducted.*

[1] New construction for psychiatric health Kristiansand (norsk: Nybygg Psykisk helse Kristiansand)
[2] The Hospital in Vestfold (norsk: Sykehuset i Vestfold)
[3] Radium Hospital in Oslo (norsk: Radiumhospitalet i Oslo)
[4] The New National Museum (norsk: Nye Nasjonalmuseet)

<table>
<tr><th colspan="2" rowspan="2">Overview of informants</th><th colspan="4">Case study</th></tr>
<tr><th>NPK</th><th>SiV</th><th>RHO</th><th>NNM</th></tr>
<tr><td rowspan="5">Roles represented</td><td>Project owner</td><td>X</td><td>X</td><td></td><td>X</td></tr>
<tr><td>General contractor project manager</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>BIM coordinator / manager</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>Sub-contractor(s)</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Consultant</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td colspan="2">Number of informants</td><td>6</td><td>2</td><td>1</td><td>1</td></tr>
</table>

Table 2.3-2: *Overview of informants and which roles were represented within their respective project.*

2.4 | Research quality

A master's thesis is a difficult basis for a study in many ways; resources are limited, and there is a scarcity of time to carry out the study. This limits the depth of which data can be collected and therefore necessitates a narrow scope. With these issues in mind, it was decided early in the study process to conduct the research using qualitative methods such as interviews and case studies. This is an appropriate approach when the objective is to study a specific problem that requires in-depth examination. Furthermore, it allows the gathering of empirical data around explicit and concrete subjects, with a high degree of precision. However, due to its structure, it is difficult to gather a vast amount of qualitative data – especially when limited time is a factor. Yin (2003) highlights validity, reliability, and generalizability as important aspects in achieving quality in empirical research.

Validity in qualitative research describes the legitimacy of findings through general trustworthiness and the credibility of sources (Sürücü & Maşlakçı, 2020). In order to achieve validity, the findings must be precisely related to the problem statement and reflect an accurate correlation with the research question. Validity was pursued through general methods for source criticism of both primary and secondary sources prior to and throughout the research period. Reliability in research describes the consistency of the results (Leung, 2015). A reliable study indicates a great likelihood of data replicability under similar research circumstances. It describes the extent of consistency within the results, and whether they are representable in other population samples (Joppe, 2000, as cited in Golafshani, 2003). However, it is debated whether reliability issue concerns have relevance in qualitative research. Lincoln & Guba (1985, p. 316, as cited in Golafshani, 2003, pp. 601–602) states that validity is dependent on reliability, and that "*[…] a demonstration of the former (validity) is sufficient to establish the latter (reliability).*" In summary, validity and reliability are closely associated with qualitative research. Securing research quality through validity and reliability was accounted for by conducting multiple case studies with a similar line of questioning. The interviews followed a semi-structured interview guide to provide consistency in the line of questioning for each respective case study.

From a scientific perspective, it is of importance to consider the validity and reliability from the early stages of conducting a study, and whether the findings have the potential to be considered generalizable. Due to the nature of subjectiveness when conducting qualitative research such as interviews, attention to validity and reliability is essential to achieve credible conclusions. When discussing the consequences of case studies, Dubois & Gadde (2002) states that the level of validity and reliability may decline if neglected, as findings are often situational specific to the case. This has been accounted for through triangulation of data by investigating more than one case study simultaneously; during the research period, a total of four independent cases were investigated. Baxter & Jack (2008) presents triangulation of data sources, data types, or researchers as the primary strategy to achieve credibility in case study research, by exploring the subject from multiple perspectives through replication logic. Conducting a multitude of case studies with different contextual conditions may enhance the level of statistical significance, which improves the generalizability and robustness of the results (Easton, 1995, as cited in Dubois & Gadde, 2002; see also Yin, 2003). Furthermore, combining the theoretical framework with theory from the literature studies and cross-referencing theory with the empirical data from case studies has elevated the degree of significance in findings.

3 | Framework

This chapter presents the general theoretical framework containing technological information, to provide a foundation of knowledge related to the subject and add context to the findings.

3.1 | Fundamentals of BIM

3.1.1 | Definition

While being a wide-ranging and complex subject, most actors in the AEC industry will generally agree upon the overall description of BIM. The main distinctions lie within separating the 'model' and the 'modeling' aspects; The 'model' appears as a visualization of the building by containing concrete and deliverable information, while 'modeling' encompasses the appliance of digitalized methods, tools, and processes throughout the entire life cycle of the building from design, construction, operation, to demolition (BibLus, 2021a). A few selected definitions of BIM are stated as follows:

> "*[…] We define BIM as a modeling technology and associated with set of processes to produce, communicate, and analyze building models*" (Sacks et al., 2018a, p. 14). BIM is characterized by features such as digital representations (objects) and components containing consistent and nonredundant data for specific analyses and work processes. Furthermore, *"[…] BIM is an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle.*" (NIBS, 2008, as cited in Sacks et al., 2018a, p. 14)

> "*[…] BIM is an integrated, structured digital database, informed by the architecture, engineering, construction, operations industry that consists of 3D parametric objects and allows for interoperability. BIM's fundamental characteristic is that it is a collection of parametric objects that contain data.*" (Kensek, 2014, p. 11)

> "*BIM is the process of building a virtual building through software. You assemble the building from objects that represent their real-life counterparts. It is not just 3D geometry; every object is a container of all the information of that component in the building in a digital format.*" (Montague, 2016)

3.1.2 | Historic development

According to Sacks et al. (2018a, p. 32), Computer-Aided Design (CAD) was developed as early as the 1970s and 1980s, where object-based parametric modeling was introduced. Subsequently, 3D modeling was initiated and developed during the 1980s, but have in the last 20 years grown exponentially along with the technological revolution (Wierzbicki, de Silva & Krug, 2011).

> "*Building Information Modelling as a term dates from around 2003. In this advice BIM refers to a wide and widening suite of working methods which become possible or necessary when the built environment industries move onto a digital basis and use artificial intelligence. In doing this the sector is only catching up with most modern industries which have been using parallel 'Product Lifecycle Management' technologies for two decades. As revealed in those other sectors, this is a 'Disruptive Technology'. It causes creative destruction of business models. Whilst 2D CAD allowed traditional practice to become more efficient, BIM suggests new practices altogether. Some will lose from this whilst others gain; the entire sector will be progressively reshaped.*" (Saxon, 2013, p. 7)

Consequently, Virtual Design and Construction (VDC) has been developed using techniques and methods within building information modeling, to conduct virtual first-run studies to test both the product and the construction process before the delivery phase (Sacks et al., 2018a, p. 16). This includes an in-depth assessment of the project performance regarding facilities, processes, supply chains, and project teams, providing a better understanding of how the project will operate in practice.

In recent years, BIM has been well established as a leading technology in the AEC industry. The focus going forwards is placed on advancing the efficiency of the various tools and methods. "*The strategy of BIM application in the AEC sector also requires that by 2016, government-invested projects over 20,000 square meters and 'green' building in the provincial level should adopt BIM in both design and construction stages, and by 2020, the industry guidelines for BIM application and government policy systems should be well-established*" (Tang et al., 2015, as cited in Tang et al., 2017, p. 2). This is achieved through maturity where projects familiarize themselves with the new methods of conducting construction processes, as well as the establishment of consistent formats and industry standards.

3.1.3 | Standards

Montague (2016) argues for the need for a universal standard in both the process and deliverable aspects of BIM. In the process aspect, contracts and protocols found the basis for establishing who will deliver what information, when it will be delivered, and what level of detail it should contain. In the deliverable aspect, the model represents the object for delivery. Here, interoperability between programs is essential, for different software to be able to communicate and transmit details regarding the model with each other. The format in which the models are developed represents the language of digital software. Based on the desire to establish a common language, i.e., an open and shared file format, the non-profit organization now known as buildingSMART introduced the Industry Foundation Classes (IFC) format, with the ambition of developing a neutral data model (Biblus, 2020). The IFC file provides BIM with a consistent format that promotes structure, predictability, and transparency within models.

Subsequently, the openBIM concept was defined, facilitating for "*[…] data exchange between all actors involved in the creation of a BIM model covering all possible fields of application: from design to construction, from building operations to its demolition and recycling of components and materials at the end of the building's life cycle. An essential requirement for the openBIM is the use of open and neutral data formats while the IFC format is the most common solution for the openBIM*" (BibLus, 2020). openBIM is defined as a vendor-neutral collaborative process that promotes the exchanging of files across the confinements of different software for seamless collaboration between every actor within a project, such as architects, consultants, engineers, contractors, and facility managers, through the life cycle of the artefact (buildingSMART, 2021). Figure 3.1-1 illustrates the interoperability between project participants in a closed versus an open system.

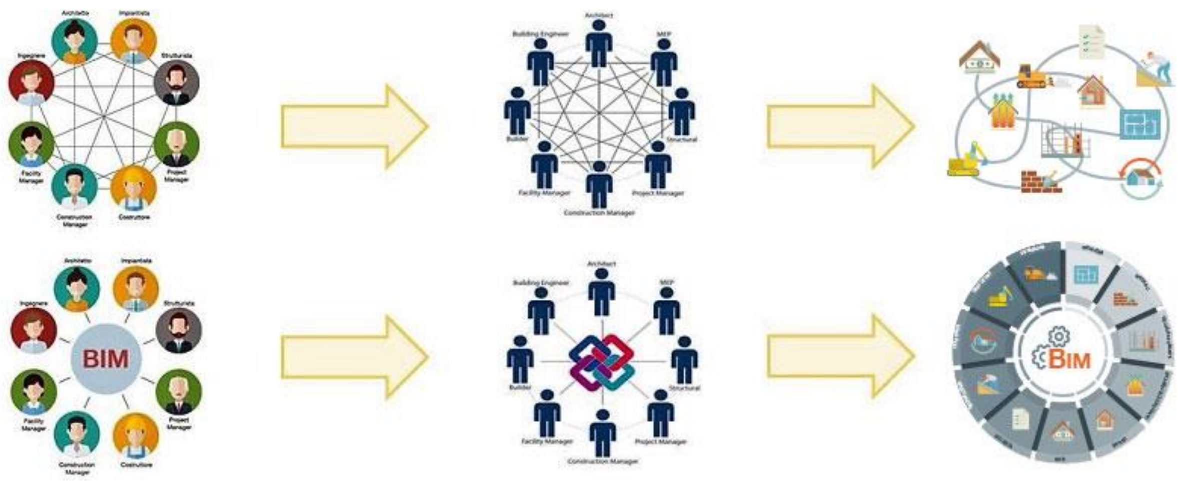

Figure 3.1-1: *Interoperability in a closed (upper) versus an open (lower) system (BibLus, 2021b).*

3.1.4 | Application

In essence, BIM is a term that discloses a digitalized model containing information on a building or a structure. However, considering recent developments in the AEC industry, the term has evolved into a much more complex concept than just a digital model; the appliance of BIM ranges from being a tool for visualizing an artefact to a principle for overall project management (Sacks et al., 2018a; see also Kensek, 2014, pp. 11–13). Montague (2016) states the importance of information in construction projects, where the quality of information affects the quality of the construction. In order to achieve quality in information, it must be (i) digital – that it can be used and reused by multiple actors simultaneously, (ii) searchable – that it can be found by search, (iii) accessible – that it is easy to locate and get to, (iv) accurate – that it is valid, current, and up-to-date, and (v) useful – that it is timely and ready to be used when accessed, as displayed in figure 3.1-2.

Figure 3.1-2: *Key elements of information quality in construction (Montague, 2016, p. 10).*

Yet, traditionally, building information in the AEC industry has been distributed in paper-formats on construction projects (Sacks et al., 2018a, p. 2). This limits the quality of information, in terms of paper-based information being more difficult to search, offers limited accessibility, and is not necessarily accurate, as the static format makes the information presented on paper susceptible to quickly being outdated when updates, adjustments, or correction occurs (Montague, 2016). Furthermore, it requires drafters that specialize in designing blueprints that fit this format, to develop comprehensive sets of print-out drawings. However – as comprehensive as the drawings may be – assembling 3D objects based on 2D instructions is not always a straightforward procedure. This is especially the case when the level of complexity increases. To develop an understanding of what the building will look like, it is necessary to translate symbols, lines, and shading patterns from the 2D drawings, to envision a picture of what the construction will look like in reality. Furthermore, Montague (2016) cites activities such as the labor-intensive task of multiple designers manually producing and coordinating 2D paper-based drawings, the excessive checking due to 'human error', and duplication of work as sources of waste in construction projects, in terms of added costs and time consumed. Figure 3.1-3 illustrates the fragmented layers of building information in a traditional paper-based construction project, which appears inefficient and tedious.

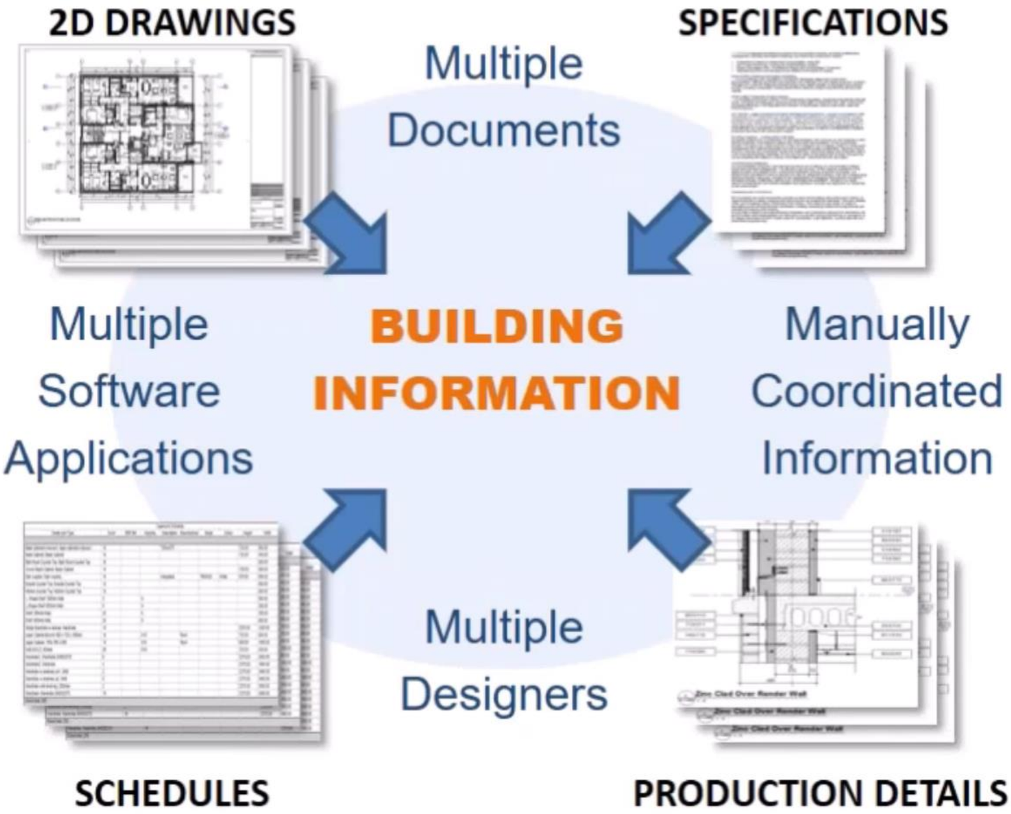

Figure 3.1-3: *Inefficiencies of fragmented traditional building information (Montague, 2016, p. 14).*

The implementation of BIM counteracts these issues by facilitating the integration of an all-encompassing universal framework of information on a single digital platform, where every project member has access to the same sets of information. The information added to the model, including prospective revisions, adjustments, or updates, is available for every project member simultaneously at all times. Additionally, a well-crafted BIM will provide the possibility of extracting geometric details of a building from the model to generate more traditional sectional viewpoints necessary for certain work assignments (Montague, 2016). The building model can be viewed in its entirety or be filtered by layers, e.g., floors, walls, or technical infrastructure, to provide a simplified and more concise viewpoint of sought details. This allows sub-contractors to view both the overall structure of the building and the isolated detailed viewpoints within their respective field from the same blueprint. This is expedient when coordinating the reciprocal interdisciplinary dependencies, as their models can be combined for interference checking (Kensek, 2014, p. 62).

3.1.5 | Dimensions

A 3D model encompasses the visual and structural elements of a building, through the parameters of width, height, and depth. This accounts for the infrastructural conditions of the building, such as the geotechnical foundation through a site/civil model, design through an architectural model, construction through a structure model, and the technical infrastructure through a services model, as showcased in figure 3.1-4 (Montague, 2016). However, as technological development ensues, the areas applicable for BIM in construction projects develop over time, as the modeling encompasses more information and expands multi-dimensionally. Currently, there is a general understanding that BIM includes seven dimensions (Kensek, 2014, pp. 19–29). Figure 3.1-4 also illustrates the layers on which 3D modeling builds and provides the basis for subsequent dimensions, while figure 3.1-5 summarizes the contents of each dimension.

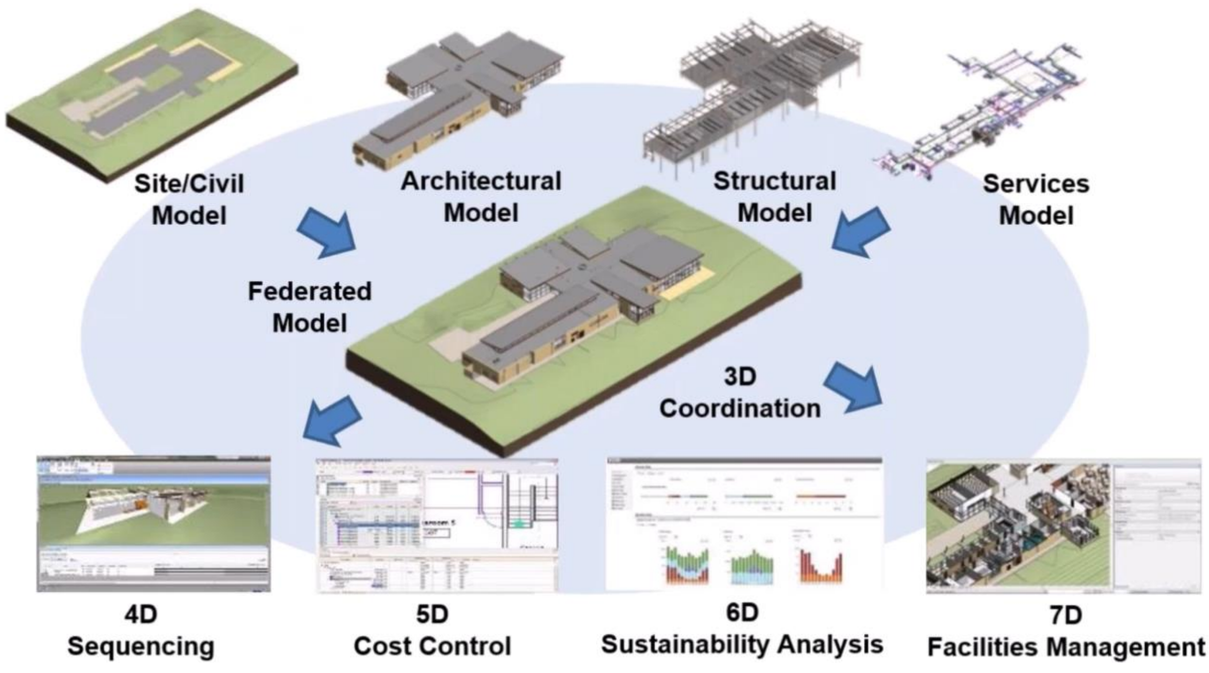

Figure 3.1-4: *Contents within 3D model and subsequent dimensions (Montague, 2016, p. 22).*

Four-dimensional (4D) modeling entails linking every object in the model to a construction program to perform planning, scheduling, visual sequencing, and general logistics in a virtual environment. This provides simplicity and allows certain administrative processes to be carried out earlier and more efficiently.

Five-dimensional (5D) modeling entails building cost estimation by linking every object to a cost database to calculate units and amounts faster and more accurately than traditional cost calculation. This presupposes the model containing every geometric object, and for them to be enriched with required cost data.

Six-dimensional (6D) modeling entails sustainability analysis, e.g., structural analysis, energy performance, environmental footprint, etc. This provides the possibility of an in-depth assessment of various building parameters, to re-iterate or optimize the performance of building components both individually and as a whole before construction.

Seven-dimensional (7D) modeling entails gathering all information the facility management requires to operate and manage the building, e.g., maintenance conditions, warranties, etc., to acquire and plan building life-cycle strategies through 'as built' models.

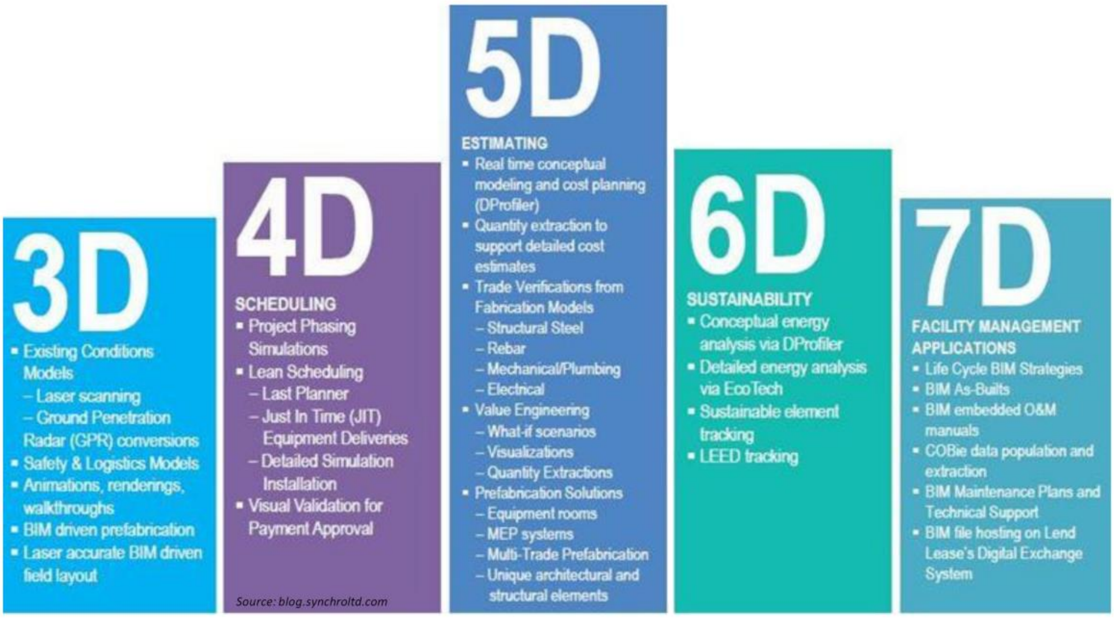

Figure 3.1-5: *Contents within the various dimensions of BIM (Aarseth, 2017, p. 17).*

Various projects set different targets to which degree of BIM utilization the project pursues. This is dependent on many factors, but the scale and complexity of the project play a large part in determining which degree of dimensions appears appropriate. Implementation of 3D BIM is currently becoming more customary in large-scale construction projects. Findings from Bjørnstad, Bjørhusdal & Westerlund (2019) argue that 4D tools can appear beneficial to the planning and governance aspects of construction projects but remains difficult to implement to the organizational culture on a national scale. Moses, Heesom & Oloke (2020) suggest that the threshold for implementing 5D BIM is higher in the industry as of today. As described by Sacks et al. (2018b, pp. 33–34), a paradigm shift within the way certain processes from design to fabrication are perceived might be necessary before managing to realize the full rewards of multi-dimensional BIM.

3.2 | Maturity

Maturity in construction represents the project development and achieving quality through learning and iterations. This thesis does not intend to explore the subject of maturity in detail but presents the key overall stages to add context to the findings.

3.2.1 | BIM levels

Sacks et al. (2018a, p. 15–16) characterize the progression of maturity of BIM information technology in four levels, from Level 0 to Level 3. The different levels express the degree of collaboration in the process and the sophistication of individual tools, which provides an understanding of the evolution of BIM over the last couple of decades. Level 0 is defined as unmanaged CAD, where information is presented and shared in 2D through paper-based formats. In Level 1, 3D CAD has been introduced, but 2D drawings are still the foremost foundation for blueprints. Although the information is stored and shared digitally in a common data environment, the model is not shared collaboratively among the project team members. In Level 2, every project team is working collaboratively on a 3D model, but with their own programs and not on a universal, singular platform. Subsequently, the information is shared in an assembly model through a common file format, where interference controls can be deployed. However, in Level 3, every discipline collaborates fully through a single, shared project model. The model is assembled in cloud-based storage where every project member can access and modify the same model. Implementation of openBIM in this stage eliminates the potential for conflicting information.

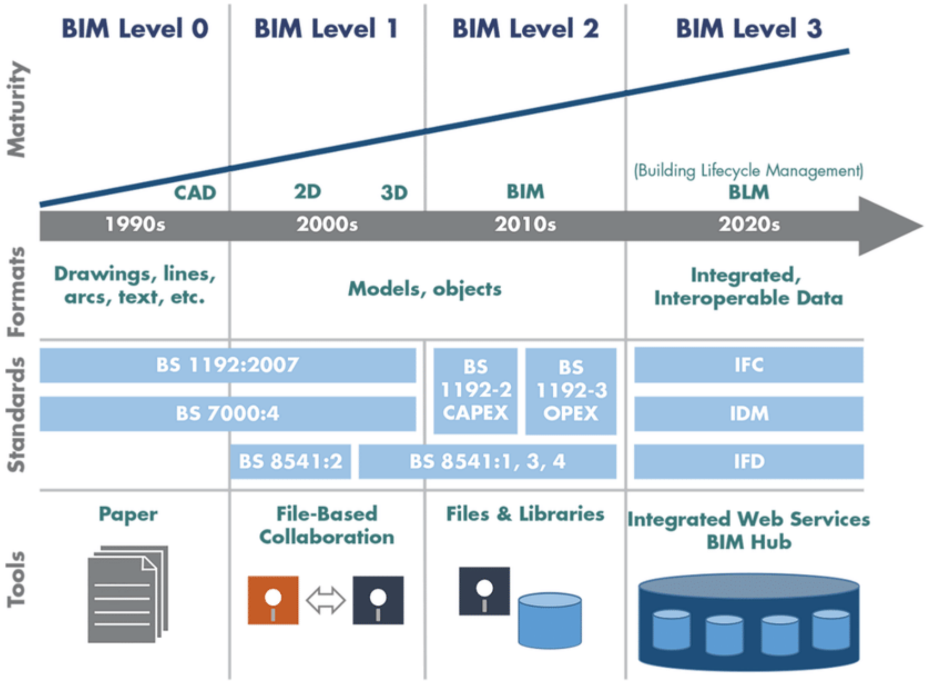

Figure 3.2-1: *The BIM maturity model (Sacks et al., 2018a, p. 15).*

3.2.2 | Model Maturity Index

When utilizing BIM in projects, the model may not be as complete as it appears due to its vast level of detail (Fløisbonn, Skeie, Uppstad, Markussen, Sunesen, 2018; see also Kensek, 2014, pp. 30–33). Therefore, a guideline was established to quantify the complexity and degree of completion of the model, universal for every project discipline, referred to as the Level Of Development (LOD). The term has subsequently been rebranded as Model Maturity Index (MMI) to provide more clarity of the concept's purpose as quantification of model maturity. MMI describes the maturity of model objects through a numerical code ranging from 100 to 500. Starting at MMI 100, the model is regarded as a proposal sketch, containing alternative solutions which are subject to adjustments and re-iterations. The process of achieving MMI 200 is based upon deciding upon a final conceptual design. At MMI 300, every technical enterprise has added their proposed technical solution to the model for interference and interdisciplinary control, where MMI 350 signifies control completion. At MMI 400, the completion of geometric modeling of all objects entails that the model is sophisticated enough to serve as the foundation for blueprints, provided that they are controlled and approved for construction. In the final stage, MMI 500, the model is fully complete and 'as built', containing continuous updates of project progress. The utilization of MMI is cited as an expedient tool for the planning of project deliveries and can also be used for planning and structuring collision controls (Fløisbonn et al., 2018).

3.3 | BIM devices

3.3.1 | Kiosk

A BIM kiosk – sometimes referred to as a BIM station – emerged as the most common digital hardware for interface in the early stages of BIM implementation on construction sites (Byggeindustrien, 2015). The BIM kiosks are a robust and durable device that can visualize building information models on construction sites. The kiosks are placed strategically on-site to provide project members with access to relevant viewpoints and details, as well as a database of all building information related to the project, such as all-encompassing blueprints and general overviews of the building, checklists, and meeting logs (Strand, 2017). Access to a multidimensional model through a BIM kiosk offers sub-contractors a more extensive quality of blueprints compared to the traditional 2D paper drawings, which ostensibly makes it easier to plan and execute tasks, with fewer occurrences of errors.

Many devices – such as the model developed by Rufo in collaboration with Veidekke, displayed in figure 3.3-1 – are built to withstand though weather conditions, dust, and contamination of small particles that can arise on construction sites (Rufo.no, 2019). This makes BIM kiosks more appropriate for use on construction sites than regular computers, which are likelier prone to immobilization during use under harsh conditions. However, traditionally, a BIM kiosk is only semi-mobile due to its size and weight. They are also in some cases reliant on electricity outtakes and network connections. Therefore, they must often be stationed at allocated areas. This makes it more difficult to access the digital building models and blueprints when they are needed at a specific workstation.

Figure 3.3-1: *Illustration of BIM kiosk developed by Rufo in collaboration with Veidekke (Rufo, 2019).*

3.3.2 | Tablet and smartphone

A tablet is a portable touch-based device that can store, transmit, and visualize BIM-related content (TechTerms, 2011). The interface of a tablet makes it more convenient on the go than a computer, as they offer graphical applications in a more compact and accessory-free device. Smartphones also offer similar functionalities but are smaller and more convenient to carry on-person. High-quality tablets and smartphones support wireless connectivity to mobile networks, which makes cloud-based and openBIM models accessible virtually everywhere. This makes both tablets and smartphones suitable devices for representing the interface between BIM and blueprints on-site.

Tablets and smartphones can offer access to both full-scale models and detailed viewpoints on-site from a single portable device, which represents an easier logistical interface compared to carrying a library of traditional paper-based blueprints (Heiskanen, 2014). It also enables instantaneous communication of e.g., progress or errors, which can be corresponded directly between sub-contractors, BIM coordinators, and project managers. Guy (2021) cites on-site tablets as "*[…] a complete game-changer for how people access information. With the right applications, everything that you need is available when you need it. Collaboration doesn't stop in the office; it is just as important out on site.*" This is especially expedient in large-scale construction projects that range over vast areas. Every actor having continuous access to the same set of contemporary information is regarded as a major benefit to using tablets and smartphones on construction sites (Construtech, 2013).

Figure 3.3-2: *Illustration of BIM interface through tablets and smartphones (vGIS, 2021).*

3.4 | BIM software

This section presents a few selected software programs that are central to the findings from the respective case studies. The thesis does not provide in-depth examinations of the various software because of scope limitations but presents relevant information of key programs appearing in the case studies at a surface level.

Software represents the generation of digital models and the visualization aspect of BIM. Currently, there is no single concurrence as to which software program is more efficient, and different projects with different actors may opt for different programs. For the various disciplines involved in a project, e.g., architects, consultants, or contractors, some programs may appear more expedient for their respective fields. Programs such as Graphisoft ArchiCAD and Autodesk Revit were early adopted during the implementation of BIM and were consequently embraced in numerous construction projects (Sacks et al., 2018a). However, in recent years, several new BIM software programs have been developed and released, such as: Solibri, a model viewer and checker program that displays BIM through the IFC format; VisiLean, a Lean-based planning tool for communication and visualization of progress; StreamBIM, a cloud-based collaboration platform, facilitated for displaying BIM through tablet and smartphone interfaces; and dRofus, an openBIM based planning tool for coordinating BIM.

4 | Theory

This chapter discloses theoretical research closely related to the research question. Furthermore, it presents relevant theories from the literature on topics central to the study. The theory introduced in this chapter is subsequently evaluated in light of the empirical findings from the case studies, presented in Chapter 6 (Results and discussion).

4.1 | Interface of BIM versus traditional blueprints

Facility delivery processes have traditionally been dependent on using 2D drawings (Sacks, et al. 2018a, pp. 2–3). Waste in the form of unanticipated costs and delays caused by errors and omission of information is cited as a drawback of a paper-based interface. The generation, manufacturing, and administration of large numbers of paper-based documents entail a considerable undertaking in terms of time consumption and expenses. Andreassen & Beste (2020) elaborates that paper blueprints are prone to being promptly outdated upon changes, inconsistencies, or adjustments during the construction phase. BIM solves many of these issues purely by being a digital interface but also facilitates more sophisticated displays of information and related processes (Sacks et al., 2018a, p. 12). This includes updates being published continuously within the blueprint interface to ensure that every project participant always possesses the correct foundation of work.

As of 2017, Statsbygg, the Norwegian state-owned project owner, has focused on conducting projects defined as paperless (Andreassen & Beste, 2020). This encompasses the use of tablets for purposes such as blueprint interface, being the platform for communication on construction sites. Based on empirical data, generated project rewards included reduced time spent on non-value adding activities, better workflow through faster reporting and correction of errors, reduced costs of manufacturing and administrating paper-based drawings and continuous access to up-to-date and accurate blueprints. As a result of increased efficiency within both coordination, logistics, and quality, paperless blueprints are now considered ‘Best Practice’ for every new Statsbygg project. The implementation of BIM is considered to be an important part of furthering innovation and sustainability within the industry, where Statsbygg identifies with being an early adopter of digital tools and methods. Emphasis is placed on the project owner’s responsibility in transforming innovative digital concepts into tangible value, by establishing and governing concrete requirements to contractors within the utilization of digital tools.

The device quality in terms of software and hardware technology represents an important part of the digital blueprint interface. A study by Vik (2012) suggests that inadequate operative systems and robustness in devices embody a challenge for on-site use of tablets, where their use often was dependent on appropriate weather conditions. However, this technology has improved greatly during the years after the study was conducted, which suggests current tablets being more suited for use on construction sites. Additionally, findings from Merschbrock & Nordahl-Rolfsen (2016) presents that BIM must be carefully prepared to facilitate its usage in on-site operations. Often, the Information Technology (IT) capabilities of sub-contractor craftsmen on-site are limited, where the BIM model must be modified before it can be used. Therefore, considerable engineering resources are required in preparing blueprints of a suitable layer of intricacy. The industry at large must further increase its IT capabilities in addition to define appropriate contracts for BIM use, to solve practical prerequisites on-site. Lin (2015) cites interface management as an important aspect for the successful implementation of BIM during the construction phase of projects. Facilitating a system where participating actors are assisted with the transmittance of information by a BIM-related engineer who is familiar with how the models are structured may prove beneficial in minimizing ineffective communication.

Harstad, Lædre, Svalestuen & Skhmot (2015) and Murvold, Vestermo, Svalestuen, Lohne & Lædre (2016) discuss the utilization of BIM devices such as kiosks and tablets on construction sites. Here, findings suggest that having information available on BIM devices at all times may enhance productivity on construction sites, by reducing the risk of errors due to outdated drawings, less time consumed to obtain necessary information, more streamlined communication, and easier processes for reporting and documenting of progress. Kiosks and tablets hold large amounts of information in a compact format and display it in a manner that is more convenient and accessible than a library of paper-based drawings. These devices also provide digital sectional viewpoints if desired, through minor processing of the model. However, certain prerequisites are required for the effective use of BIM devices. Facilitating suitable network structures along with guidance and training of craftsmen in IT processes are key actions when implementing on-site BIM. Furthermore, devices must be waterproof and robust enough to be able to withstand moisture, sand, vibrations, and concrete dust that may appear on construction sites. Additionally, having ambassadors to promote success stories may encourage other project members to comprehend the value and benefits digital solutions can provide. Eriksen (2018) cites fewer errors in production as a benefit of on-site BIM. Inconsistencies and oversights can be detected more fluently, which benefits the project in many areas. However, the aforementioned literature also presents challenging aspects of BIM implementation, citing high initial costs of equipment and training, lack of IT proficiency among the delivery team, and willingness to adapt to new methods as key matters. This is substantiated by Fuglesang (2017), who elaborates technical terminology barriers, cybersecurity, and limited experience as areas that must be carefully considered when implementing on-site BIM. For BIM to be effective, information must be accessible through open formats. The data must also be properly maintained through the construction process, to reflect an accurate and up-to-date representation of the artefact and its progress.

4.2 | BIM in design and delivery

Literature suggests that the implementation of BIM applies to many areas in both design and delivery of construction projects. The effects of BIM during design have been well-documented over recent years (Sacks et al., 2018a, pp. 21–23; see also Bolpagni, 2013; Saxon, 2013; Svalestuen, Knotten, Lædre, Drevland & Lohne, 2017), e.g., BIM appears beneficial to improve interdisciplinary collaboration, where interferences can be solved through clash detections (Kensek, 2014, p. 62; see also Andreassen & Beste, 2020), and can successfully be combined with processes such as VDC, the Last Planner System (LPS), and Integrated Concurrent Engineering (ICE) sessions (Fosse, Ballard & Fischer, 2017). Additionally, Sacks et al. (2018a, pp. 23–24) cite several benefits of BIM during the delivery phase:

> "*Use of design model as basis for fabricated components,*" where objects inducted to the model display an accurate representation of the building objects for fabrication and construction.
>
> "*Quick reaction to changes,*" where the model can display and communicate changes and updates to the building design continuously as they appear. This provides a far more seamless and efficient solution compared to the time-consuming and error-prone paper-based systems.
>
> "*Discovery of design errors and omissions before construction,*" where errors and inconsistencies can be eliminated through the combination of technical models into an assembly model, enabling collision controls and better interdisciplinary coordination between the various technical enterprises. This inhibits conflicts and constructability issues by identifying problem areas before they are detected in the field.

"*Synchronization of design and construction planning,*" where 4D modeling and VDC enable the simulation of construction processes. "*This provides considerable insights into how the building will be constructed day by day and reveals sources of potential problems and opportunities for possible improvements (site, crew and equipment, space conflicts, safety problems, and so forth).*"

"*Better implementation of Lean Construction techniques,*" where the BIM model provides the basis for better planning and scheduling of sub-contractors to ensure just-in-time arrival of people, equipment, and materials. Lean principles involve facilitating for better workflow and reduction of waste, which can be easier be conducted when design and material requirements are accounted for by an underlying BIM.

"*Synchronization of procurement with design and construction,*", where the model can be utilized to acquire accurate quantities for materials and building objects. "*These quantities, specifications, and properties can be used to procure materials form product vendors and sub-contractors.*"

The aforementioned benefits are supported by Tang et al. (2017, p. 3), who states that implementation of BIM can (i) enrich and optimize planning, (ii) enhance the creativity of design, (iii) reduce rework and improve quality, (iv) shorten the construction period, (v) reduce overall cost, (vi) improve collaboration among multi-disciplines, and (vii) achieve multi-dimensional visualization and full life-cycle management. However, several barriers that may hinder the implementation of BIM are also cited, including: (i) the technological barrier, where the threshold for utilizing various digital software and tools may appear too complex for certain project members; (ii) the economical barrier, where high initial costs of investing in BIM may impede organizations – especially small and mid-sized businesses – in accessing them; (iii) the normative problem, where a lack of unified industry standards and market regulations – both nationally and internationally – may impair the development of a universal BIM 'language'; and (iv) the educational aspect, where proper training of current and future actors in the industry are required to fully exploit the BIM potential. Sacks et al. (2018a, pp. 28–30) also discusses the challenges of replacing 2D environments with building modeling, which encompasses "*[...] far more than acquiring software, training, and upgrading hardware.*" It requires a fundamental understanding of the technology and how to utilize it. Facilitating for good collaboration – for example through Integrated Project Delivery (IPD) contract arrangements –

of the shared digital information platform and the development of efficient project teams are emphasized as important considerations.

> "*BIMs can result in a leaner construction process with a greater degree of utilisation of prefabrication, improved workflow stability, reduced inventories and enhanced teamwork (Alarcon et al., 2013). When BIMs are implemented in the design phase, there could be some challenges to carry it forward to the construction phase. Some of the most common barriers are: software and hardware issues, cultural barriers, contractual and legal aspects, lack of commitment, lack of training and lack of a client request for it (Alarcon et al., 2013). Compared to the positive aspects of implementing BIMs in the construction phase, however, the challenges must be said to be of a relatively limited nature*." (Svalestuen et al., 2017, pp. 209–210)

4.3 | BIM after delivery

The development of an all-encompassing model representing the building structure during project design and delivery may prove a useful tool for the project owner beyond construction completion. The model can be handed over as part of the delivery, facilitating its use during the operation and maintenance phase. In this context, the concept of 'digital twins' has been introduced. Lu, Xie, Heaton & Parlikad (2019) states that artificial intelligence, machine learning, and data analytics, combined with the modeled structural geometric objects, can be used to "*[…] create dynamic digital models that are able to learn and update the status of the physical counterpart from multiple sources.*" This is substantiated by Sacks et al. (2018a, p. 25), who cite better management and operation of facilities as a valuable benefit. "*Previous analyses used to determine mechanical equipment, control systems, and other purchases can be provided to the owner, as a means for verifying the design decisions once the building is in use. This information can be used to check that all systems work properly after the building is completed.*" Hence, an 'as-built' model, where all the building's components and functions are included, may provide an accurate foundation for monitoring of real-time control systems and performance of building maintenance assessments and facility operation.

5 | Case[5]

This chapter presents general information on each specific case study, overall statistics, and key data related to the BIM ambitions for each respective project. The case of NPK is considered as the thesis' main case for most in-depth study, while the other three cases are included for supplementary context and comparable findings. The cases are portrayed from the perspective of the informants within each respective case and their role in the project.

5.1 | Sykehusbygg & Skanska: Psychiatric hospital in Kristiansand (NPK)

This case regards the construction of the new psychiatric hospital (norsk: Nybygg Psykisk helse Kristiansand) at Eg in Kristiansand, Norway. Figure 5.1-1 illustrates the final design of the hospital. The project encompasses the construction of a large-scale psychiatric hospital, containing seven units from the current psychiatric hospital in Kristiansand, in addition to a psychiatric clinic department for children and youth previously situated in Arendal. The hospital will contain four bedroom wings, each accommodating 20 bedrooms. It will also be facilitated for several emergency rooms, tailored to the patients' age range and condition. In consideration of being a psychiatric hospital, the building is designed to span over one floor, covering a building footprint of 7 700 m^2 over a gross area of 10 759 m^2.

Figure 5.1-1: *Digital illustration of the building design of NPK (Sykehusbygg, 2020).*

[5] Information presented in this chapter was gathered from primary sources during the interview processes, unless cited otherwise.

The construction period is scheduled from early 2020 to early 2023 and will be available to patients by April 2023. The key involved actors include Sykehusbygg acting on behalf of Helse Sør-Øst as the project owner, with Skanska engaged as the main contractor through an IPD form of contract. The total cost of the project is estimated to 927 MNOK, with Skanska's contract being worth around 700 MNOK.

The project group has stated the ambition of constructing "*the best psychiatric hospital in the world.*" The construction of this type of hospital is not a common occurrence on a national scale, where both the overall design and details require a high degree of unique considerations and customizations. It is of essence to design the functionalities of the building in close collaboration with the end client and target users. Therefore, emphasis has been placed upon understanding the requirements and necessities of the clients during the early stages of design. Experiences have also been gathered from other large-scale psychiatric buildings, such as the hospital in Tønsberg, the prison in Agder, and Alrek health Centre in Bergen, to establish an understanding of who the building is for, how it must be structured, and why it must be carefully designed. Certain infrastructure in psychiatric hospitals must be built more durable compared to other hospitals, because of the wear and tear they may be exposed to. These concerns represent an important element in the design and digital modeling of the building, where samples were tested in practice by modeling and constructing a replica of the bedrooms on a 1:1 scale, to assess the functions and uncover potential errors or deficiencies before the construction phase commenced.

The project owner has issued grand ambitions for the utilization of BIM in the project. This is supported by the general contractor's aspiration of being a leading actor within the digital transformation in the AEC industry. In close collaboration with the project owner, the general contractor has formulated the project ambition as being "*a digital snowplow*", by establishing a digital construction site that endeavors and utilizes digital tools. This involves conducting pilot projects on various BIM elements such as methods and software. The NPK project aims to utilize BIM to achieve a paperless construction site with models serving as digital blueprints. It is also desired to perform planning, monitoring, and reporting through digital solutions. Additionally, the digital model is being considered to be delivered and continued from the construction to the operational phase of the building. Here, it will function as a 'digital twin' where for example maintenance requirements can be identified and reported in real-time, as well as being a live representation of the building's structure, details, and conditions.

5.2 | Sykehuset i Vestfold & Skanska: Hospital in Tønsberg (SiV)

This case regards the construction of two new hospital buildings at the Hospital in Vestfold (norsk: Sykehuset i Vestfold) in Tønsberg, Norway, commonly referred to as the Tønsberg project. Figure 5.2-1 illustrates the final design of the hospital. The project contains the development of a psychiatric building and a somatic building. Similar to the NPK case, the key actors involved in the Tønsberg project include Sykehuset i Vestfold acting on behalf of Helse Sør-Øst as the project owner, with Skanska engaged as the main contractor through an IPD form of contract (Skanska, 2017). This entails the involved project actors working as a cohesive unit where the roles are dynamic, whereas the individual best suited to the respective role performs it. The total gross area for the project stretches over around 44 000 m^2, where the psychiatric building covers 12 000 m^2 and the somatic building covers 32 000 m^2 (Aarseth, 2017). The construction period started in 2017 where the psychiatric building was completed in 2019, while the somatic building is scheduled for completion in mid-2021. The total cost of the project is estimated to 2 700 MNOK.

Figure 5.2-1: *Digital illustration of the building design of the two new buildings at SiV (Sykehuset i Vestfold, 2021). The pictures showcase the psychiatric building to the left and the somatic building to the right.*

The project ambition regarding BIM revolves around the model being governing on-site. Inherently, the project pursued a construction site completely free of drawings, with the model acting as the sole foundation for blueprints. This ambition turned unfeasible in the long run – however, the project generally succeeded in being paperless. The flow of information was run digitally, through both BIM kiosks, tablets, and smartphones. For this project, the project owner has requested the development of the digital model, not sets of drawings. Subsequently, after completion of the construction project, the model will be delivered and used during the operational phase as a 'digital twin'. Thus, the model is required to be developed 'as built', which entails specific requirements for elements included in the model, how it is structured and assembled, and how it shall be used going forward.

5.3 | Norconsult: Radium Hospital in Oslo (RHO)

This case regards the construction of four newbuilding wings at the Radium Hospital (norsk: Radiumhospitalet) at Montebello in Oslo, Norway. Figure 5.3-1 illustrates the final design of the hospital. The project contains the development of a clinic building and a proton therapy building, where the construction period is scheduled from early 2019 to early 2024 (Oslo universitetssykehus, 2021). The clinic building will function as an expansion to daily activities at the hospital, while the proton therapy building will house advanced equipment that can offer essential examinations and treatments for – among others – cancer patients, currently not available in the country. The buildings will contain both patient rooms and bedrooms, operating rooms, monitoring rooms, and three proton treatment rooms including one for R&D. As the project commences adjacent to and simultaneously as daily hospital operations, the construction processes require large considerations and adjustments of technical infrastructure. The project owner is Helse Sør-Øst, who is conducting the work process in close collaboration with Oslo University Hospital (Helse Sør-Øst, 2021). The design and architecture were performed by Henning Larsen Architects, AART Architects, and Momentum Arkitekter, with actors such as Norconsult functioning as key consultants throughout the project. The total gross area for the project stretches over 44 259 m^2, with a total cost of 5 083 MNOK.

Figure 5.3-1: *Digital illustration of the building design of the four new building wings at the Radium Hospital (Helse Sør-Øst, 2021).*

The project aspires to be paperless and free of drawings within blueprints. The ambitions are founded on a comprehensive BIM manual explaining the frameworks of how the various parts should be connected. The blueprints are fully digital, where the model is a live representation of the construction status. Both consultants, surveyors, contractors, and the project owner participates in the design and delivery of the model. The various actors deliver different parts of the model containing separate elements. The parts are subsequently compiled into an assembly model, encompassing every geometric detail and section of the building (Helse Sør-Øst, 2018). A considerable emphasis has been placed on keeping the "*craftsmen in the center*", where the model and sectional viewpoints are adapted to making the best work foundation for the sub-contractors. The interaction between the design team and the delivery team entails providing the craftsmen with the best possible resources and adjusting the digital viewpoints thereafter to fulfill their requirements.

5.4 | Statsbygg: The New National Museum in Oslo (NNM)

This case regards the construction of the New National Museum (norsk: Nye Nasjonalmuseet) at Vika in Oslo, Norway. Figure 5.4-1 illustrates the final design of the museum. The project involves the construction of a museum building containing an assembly of national art. The collection of art will range from older and modern art, contemporary art, architecture, and design, previously located in several different museums in Oslo, where the building will house around 5 000 pieces of artwork in 89 showrooms (Statsbygg, 2021).

Figure 5.4-1: *Digital illustration of the building design of the National Museum (Statsbygg, 2021).*

The building structure is mainly supported by concrete, covering a gross area of 54 600 m^2. The construction project commenced in 2014, where the museum is scheduled to open for visitors in 2022. Statsbygg acts as the project owner with a Contract Management (CM) form of contract, which entails the project owner conducting the building design in detail before employing contractors who produce according to blueprints with technical directions. The total cost of the project is estimated to 6 050 MNOK.

The project had ambitions of being a pioneering project of BIM at an early stage nationally. At the time the project started, there was a scarcity of knowledge in the market regarding the level of detail, the value of the model, and how to use it in practice. Therefore, the project owner began by formulating a BIM strategy to establish targets for the application of BIM. The project was deemed not sufficiently matured to start with a universal BIM server, as too many risks were involved. Therefore, each sub-contractor modeled in their own software and exported files in the IFC format to be assembled into a comprehensive model through Solibiri. Digital modeling within a building of this scale – which is a single structure volume where everything is connected – is complicated to operate when several model pieces are present, which became the basis for preparing a single model that is enriched with information throughout the development of the project.

BIM was not utilized for the 'sake of being digital', but to support the realization of general project objectives; overall, the BIM makes it easier for the project to manage costs and building geometry. Additionally, the model was used for planning and progress reports, visualizing the building, create sectional viewpoints, and identifying challenging areas of coordination. For the project owner, the digital model has been an expedient tool in providing an overview of project status. Thus, outside stakeholders, with varying degrees of in-depth project knowledge, may be provided with the opportunity to familiarize themselves with the building through the model and obtain an impression of how things look and work.

6 | Results and discussion

This chapter presents the empirical data from the case studies, where the findings are presented and discussed critically. Subsequently, empirical data are assessed in relation to the theory introduced in Chapter 4 (Theory). The accumulation of theoretical and empirical findings provides the basis for inferences, presented in Chapter 7 (Conclusion).

6.1 | Projects with BIM versus traditional construction projects

A common denominator between all investigated cases in the study is that the main underlying cause for the implementation of on-site BIM in projects is based on increasing operational efficiency on construction sites. Focus on first and foremost paperless construction sites, but also BIM-based blueprints where the multi-dimensional model replaces the conventional 2D drawings were highlighted as the core difference between current and traditional projects in the industry. The consensus among the key actors from the case studies concerning paperless construction sites is that the transformation from paper formats to digital solutions is regarded as more or less imminent in large-scale projects. In terms of blueprints, there are still some doubts on whether the AEC industry as a whole has reached a satisfactory level of maturity within BIM for models to fully overtake and replace conventional drawings as the main foundation of blueprints in the immediate future.

Empirical data from the NPK case study suggests that the BIM initiative must originate from future-minded and assertive decisions from the project owner and the general contractor from a superior position. It is essential for them to act as the key drivers in the implementation of digital solutions and prepare appropriate requirements for the sub-contractors. This is supported by findings from the NNM project, where the project owner plays a major part in defining the framework for BIM usage in both this and other projects in their portfolio. Statsbygg has set requirements for BIM in every project since 2011 and has established a manual of delivery requirements, referred to as 'SIMBA'. The project owners leading the line and enforcing requirements contribute to driving the BIM initiative in the industry and encouraging other stakeholders to invest in digital solutions. This is substantiated by findings from SiV, where the project owner's role, within forming dialogues and ensuring requirements for BIM delivery is met by the contractors, is highlighted as key to be able to push the digital transformation further.

The role of the BIM coordinator represents an important aspect throughout the implementation of on-site BIM. At NPK, the BIM coordinator performs consolidation and quality assurance of models from the design team and executes collision controls to eliminate potential inaccuracies. The outcome is a unified and comprehensive model that – through processes of gradual maturity – is more or less free of errors. This model represents the basis for blueprints and can be used for displaying viewpoints or taking measures of details. The application of BIM thereby replaces the traditional drawings as the foundation for blueprints. A comparison between a traditional 2D drawing – displayed in figure 6.1-1 – and the model – displayed in figure 6.1-2 – showcases the detail measures of a transformer room at NPK. Whereas the drawing is limited to the information and measures presented, the model allows the extraction of measures for every length or angle, as well as a virtual visualization of the overall situation.

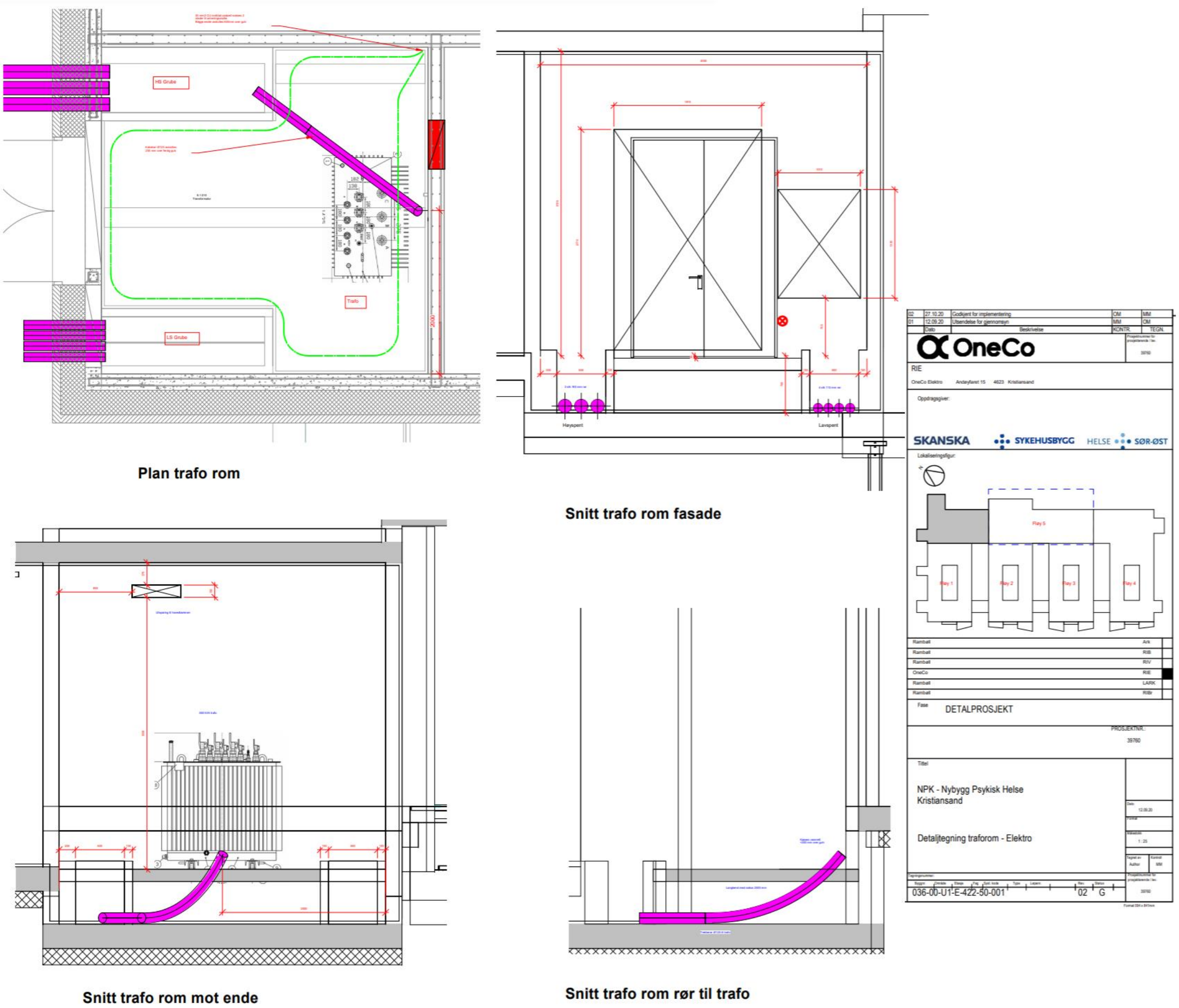

Figure 6.1-1: *2D drawing with measures of transformer room at NPK (image courtesy of Skanska).*

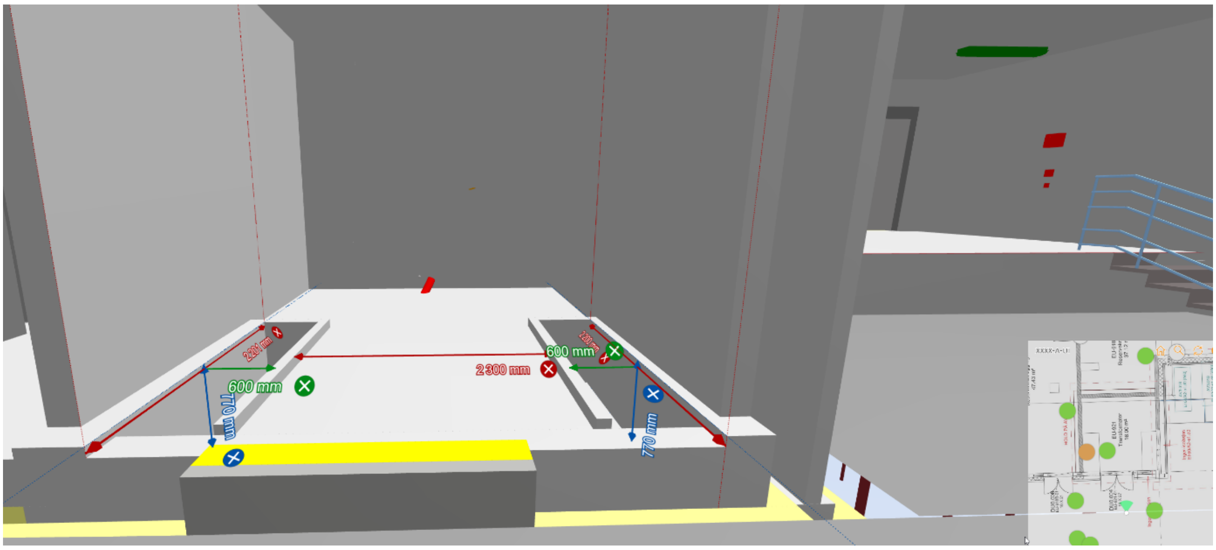

Figure 6.1-2: *Measures of transformer room at NPK integrated in the model (image courtesy of Skanska).*

However, the model must be available on an appropriate platform and easily accessible for the delivery team at the construction site. At the NPK project, this has been accounted for by implementing a new role in the project team, titled interface manager. This role requires competence and experience from both design and production and functions like a translator between the fields, by conducting interface processes. The interface manager works in close collaboration with both the BIM coordinator and the delivery team, to ensure a smooth and seamless flow of information between the parties. The implementation of a dedicated interface manager supports the claims of Lin (2015) in facilitating for appropriate usage of BIM by participating actors on-site.

6.2 | Interface between BIM and construction site

The interface of BIM represents the transmission of model information between the design team and the sub-contractors. Findings from the various cases suggest that mobile handheld devices will be more prevalent in future construction projects. In terms of hardware interface, the empirical data supports a shift from BIM kiosks to tablets and smartphones. The findings from this study further strengthen the theories presented by Harstad et al. (2015) and Murvold et al. (2016), discussed in Chapter 4 (Theory), in that the usage of tablets on construction sites may enhance communication between design and construction practitioners, as well as reducing waste and errors related to the limitations of paper-based blueprints.

BIM kiosks were widely utilized in early BIM-adopting projects but are currently being phased out and replaced by the more mobile interfaces of tablets and smartphones. This is the case at the NPK project, which has abandoned the usage of BIM kiosks in its entirety. The main arguments against the BIM kiosks include that they are impracticably stationary, which entails too many time-consuming back-and-forth visits. Facilitating their required technical infrastructure is also cited as a major drawback of the BIM kiosk. However, at RHO, BIM kiosks are still utilized in certain capacities, along with tablets and smartphones. At NNM, BIM kiosks were available at select locations but were limited in use due to issues related to the technical infrastructure. At the time of this project, being paperless was still a foreign concept, as the usage of tablets and smartphones had not yet become customary in construction projects on-site. At SiV, both BIM kiosks and handheld devices were utilized. Discussions were made regarding abolishing the BIM kiosks, but they were ultimately kept as they still proved useful in certain situations. Nevertheless, facilitating the utilization of handheld devices is the main focus point going forward. Additionally, larger screens may be placed on strategic locations, facilitated for that the tablets and smartphones can connect and share their screens for a more sizeable display of certain blueprint elements. This is expedient for providing a broader overview of the overall conditions, which can be lost on a small screen. Furthermore, task groups can view the model together and see the same sections at the same time, which will promote better collaboration between interdisciplinary fields.

In terms of the software interface, various programs are deployed within the respective cases. As of today, the findings do not suggest the presence of an industry-standard within a singular software being used – although some programs, e.g., StreamBIM and Solibri, are being mentioned in several cases. The key is the interoperability of model parts through a consistent format. Here, the industry standard is the IFC format, which communicates with numerous other software for easier assembly of models.

At NPK, the model is available through the program StreamBIM on tablets and smartphones. Purchasing licenses to products such as StreamBIM is costly but is cited as a necessary investment to ensure the appropriate performance of the digital processes. Through StreamBIM, the devices always provide the delivery team with complete access to the 3D digital building in its entirety, which can be navigated and used as needed. This software also supports filtration of floors and the components of various technical sub-contractors, to make the viewpoints clearer and more simplified. Adjusting the model to support efficient filtration of floors and technical components and making them easily accessible represents an important assignment for the project BIM coordinator. The interface manager also contributes to facilitating the delivery team's usage of BIM on-site. Every object inside the model – e.g., walls, ceilings, or doors – contains geometric details such as dimensions, materialistic composition, and structure, which are available upon selection. An example of this is illustrated in figure 6.2-1, where lighting details are displayed through the StreamBIM interface at NPK.

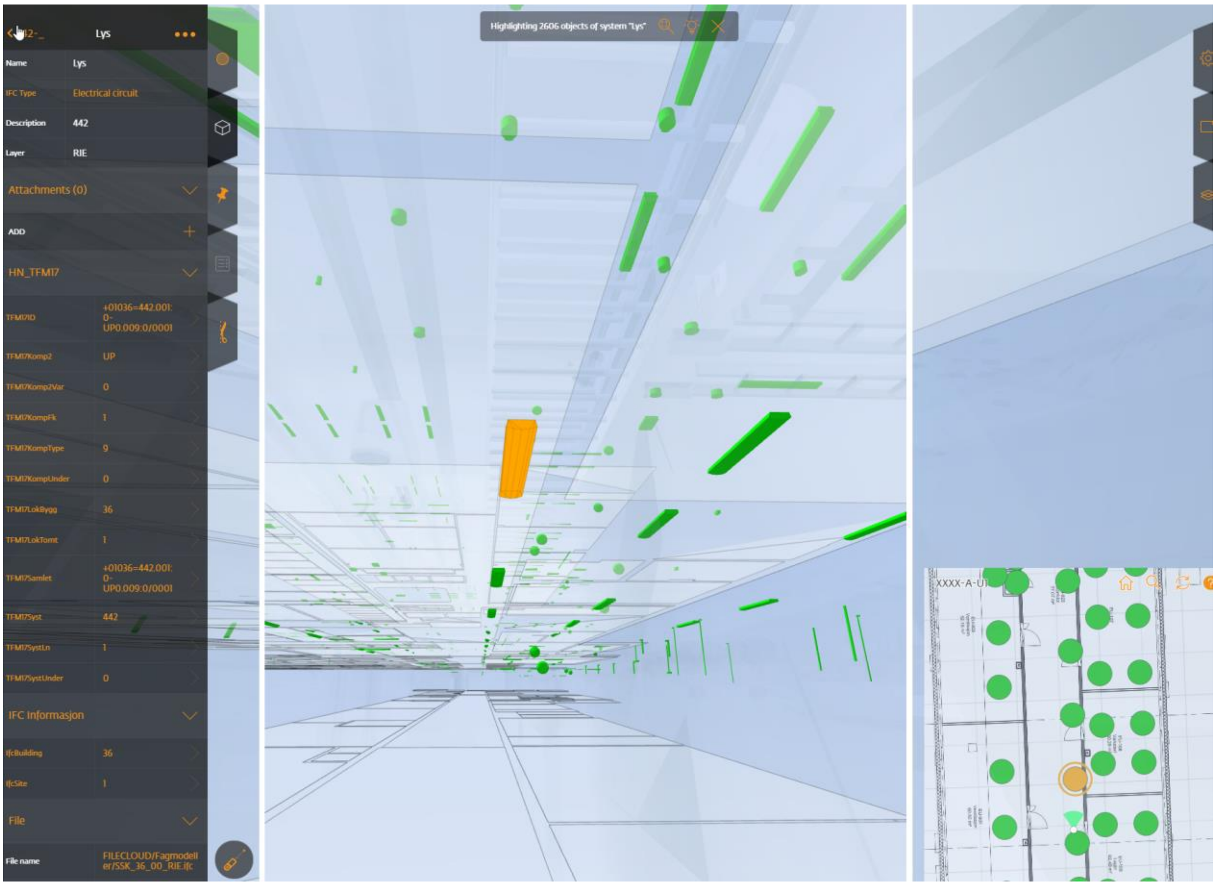

Figure 6.2-1: *Digital illustration of lighting details displayed through the StreamBIM interface at NPK. The object selected is a type of lamp, highlighted in orange (image courtesy of Skanska).*

At the NPK project, it is required that each sub-contractor possesses a sufficient level of digital competence to be able to navigate and use the model as needed. Collision controls are executed by the general contractor, but the sub-contractors are expected to operate the model themselves, to extract e.g., viewpoints, details, and measurements. The general contractor facilitates for the model to be available and up to date, where errors and inaccuracies can be reported and updated continuously. The key is cited as making the model appear as simple and efficient as practicably attainable, for the delivery team to be able to access the information they require at the right time. Furthermore, every sub-contractor possesses the same model, making the reciprocal interdependencies less complex.

At SiV, an all-encompassing assembly model are available through the Solibri interface on both BIM kiosks and handheld devices. The various sub-contractors were trained to navigate and make their own excerption from the model in its entirety, to access the information relevant for their respective assignment. The instruction within utilizing digital tools was an extensive process to undertake, which required some time to properly implement. However, they proved to be a convenient tool that performed excellently in practice as the craftsmen became familiar with using them – especially within the technical fields. Utilization of the model as the foundation for blueprints lead to fewer drawings being necessary – however, some were still requested if the model provided an insufficient level of detail.

The RHO project has adopted a different approach to interface management, focusing on the requisites of the craftsmen on-site. The model is utilized as the foundation for blueprints, but a larger emphasis is placed on the BIM coordinators 'replicating' traditional drawings within the digital interface. The argument for this is making the model more accessible and easily available when it is needed, by making sectional viewpoints of geometric details beforehand. Additionally, the model is available in its entirety – for purposes such as for visualizing the full-scale of the building – but preparing sectional segments will make the model and supplied details more concise where less time is consumed by navigating the model manually. These sectional viewpoints are available through BIM kiosks, tablets, and smartphones on-site. Furthermore, the interface is cloud-based where the model is available at all times through streaming. This ensures the model always being up to date with the latest revisions and progress, accessible for every project member continuously. This approach is supported by the general contractor representative at SiV, who highlights the process of making details and measures more accessible within the model as an important area of focus. However, it is emphasized that current interfaces appear limited within an automated generation of sectional viewpoints and detailed measurements, which entails a time-consuming task for the design team, BIM coordinators, or consultants in producing the work basis. A development within automated processes for the generation of these sections within the model is sought after to increase its efficiency on-site.

Interoperability between both software and hardware is being highlighted as an important aspect within the digital platforms utilized. At NPK, the sub-contractors have been equipped with Apple products to ensure that the various devices are compatible; the craftsmen carry each their own iPhone, while the foremen additionally have access to iPads. The sub-contractors also cite access to expediently state-of-the-art technology as an important element in fulfilling the digital processes. The devices must retain hardware of a sufficient level of quality for efficient usage, e.g., ample screen size, powerful processors and internal memory, strong backlight, and access to high-speed internet. The craftsmen at NPK stated the difference between newer smartphones and older models as 'day and night', in terms of the aforementioned qualities. The quality of the equipment impacts the quality of the digital blueprints greatly. This is substantiated by findings from NNM, where the BIM kiosk did not represent a sufficient device for providing access to the model, in parts due to technological limitations.

6.3 | Additional benefits of on-site BIM

6.3.1 | Reducing errors

The empirical data reveals several advantages of utilizing BIM-based blueprints compared to traditional methods, which creates positive ripple effects through the project. At NPK, the BIM model helps to uncover and correct errors at an early stage, which might not have been noticed until construction has commenced. This decreases the potential of waste occurring at the construction site, as errors are corrected before they may appear on-site. A paperless construction site means every member of the project always possesses an up-to-date and full-scale model of the building, with the latest progress and revisions at hand. A paper blueprint is limited to the information printed, whereas the model contains accessibility to the construction in full. Furthermore, this eliminates the possibility of tangible drawings getting lost or compromised by tough conditions on-site. These perspectives are shared by both the SiV and the RHO project, who further highlights the benefits of eliminating the administration of drawings on-site. Additionally, the cost of errors is a large expense in construction projects. Increasing the efficiency of constructive labor while reducing the occurrence of errors and waste encompasses significant overall cost savings. In this sense, it is advantageous that the model can be updated continuously and that you can enter progress, errors, and deviations directly in the model provided that you get the latest version delivered to the construction site. The new apps and tools make this easier.

6.3.2 | Planning and reporting progress

Digital solutions may provide benefits beyond being the foundation for blueprints and visualization of models. At NPK, software such as VisiLean is utilized for gathering information related to the project on a universal platform where all members have access to the same sets of data, where progress and deviations can be reported continuously. VisiLean is an entirely new system the general contractor has applied to this project, which functions as a tool for planning and follow-up of the development at the construction site. Lean principles, such as pull planning and Plan-Do-Check-Act (PDCA), are practiced when appropriate, in terms of visualization and efficiency. Progress for every activity, including the seven prerequisites (norsk: de syv forutsetninger) from the LPS, are available on tablets and smartphones, where the foremen transmit the information in detail on weekly meetings. Increased operational efficiency on-site is stated as the major benefit of implementing this software. The tool permits the delivery team to conduct internal controls and report work progress from their location on-site, which greatly reduces the time consumed on reporting. This facilitates more efficient workflows and shorter meetings, which in turn translates to swifter progress, deliveries of increased quality, and lower costs. This is supported by the sub-contractors, who state that the continuous update of the work foundation makes the assignments more accessible and precise. This substantiates the argument that on-site BIM facilitates better communication and flow of information compared to traditional blueprints.

6.3.3 | Interdisciplinary understanding

At SiV, the grouping of all information on a single and universally accessible platform is cited as a benefit of BIM in the delivery phase, as this enables easier access to the required information. Furthermore, it facilitates for better understanding between interdisciplinary fields, where every sub-contractor can view each other’s drawings and adapt accordingly. Drawings have traditionally been distributed singularly per field, where the sub-contractors cannot view each other’s plans. The accessibility and interdisciplinarity that BIM provides are major benefits in both design and production, where it promotes communication and understanding between the various technical enterprises. Going forward, the craftsmen can refine the model to show only their respective infrastructure. This makes the blueprints clearer and more concise, where unnecessary information is filtered away. An example of this is illustrated in figure 6.3-1, where the technical electricity details at NPK are easily accessible as other ‘irrelevant’ details are filtered away.

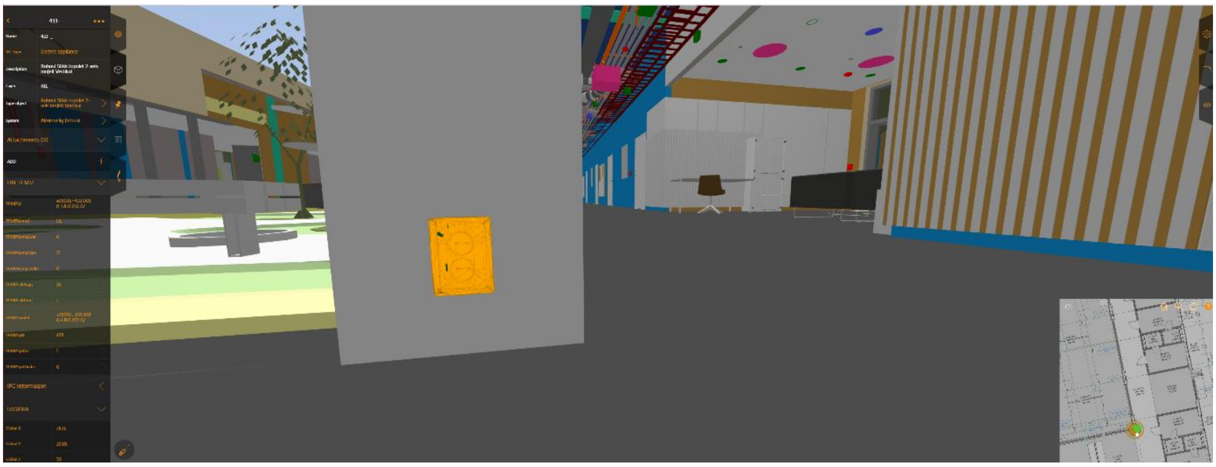

Figure 6.3-1: *Digital illustration of electricity details at NPK where other 'irrelevant' technical installations have been filtered away. An outlet is highlighted in orange, with all accompanying information displayed to the left (image courtesy of Skanska).*

6.3.4 | Visualizing the project

At NNM, the project owner representative highlights the aspect of utilizing the model for visualizations as a major benefit of BIM both on and off-site. An all-encompassing model allows for efficient presentation of overall status, structural compositions, progress reports, and sectional viewpoints, both when communicating with contractors, customers, or general stakeholders, where details are governing. This is also the case at NPK, where the model provides the possibility of visualizing the building design virtually, both inside the building and from an overall perspective. Figure 6.3-2 illustrates the building from inside the basement hallways, while figure 6.3-3 illustrates the overall design of the building.

Figure 6.3-2: *Digital illustration of indoor building design from the hallways of the basement at NPK (image courtesy of Skanska).*

Figure 6.3-3: *Digital visualization of the overall building design at NPK (image courtesy of Skanska).*

However, in the case of the NNM project, the model has not possessed enough information in all areas to be able to show this in full. Here, a combination of drawings has been used in addition to the model – although the advantage lies in being able to visualize and understand fundamental conditions. For displaying all overall technical details, such as ventilation, electricity, pipes, etc., viewing how they are connected, and running collision controls, the model appears significantly beneficial both in design and delivery phases. As a result, the technical sub-contractors have been successful in attaining required details directly from the model. This has been achieved by each technical enterprise employing a dedicated BIM engineer who assists the craftsmen on-site, by navigating the model and generating the required foundation for blueprints. In future projects, it is desired that these processes become more automated and streamlined, where the craftsmen can obtain their blueprints individually.

6.4 | Challenges of on-site BIM

6.4.1 | Adapting to new methods

The 'human' aspect is being highlighted as an important consideration when implementing on-site BIM solutions. This is supported by Sacks et al. (2018a, p. 365) who states that "*The lack of appropriately trained professional staff, rather than the technology itself, is still the current bottleneck for most companies.*" Various digital tools and accompanying methods require maturity between the involved actors individually, as well as in the industry at large. At the NPK project, the physical transformation of work methods between the paper format and digital models represents one of the main challenges of on-site BIM implementation. The sub-contractors at the construction site have varying degrees of experience using digital solutions such as tablets and smartphones in work contexts and require thorough training guidance to be able to exploit their potential efficiently. In some cases, reaching a stage where the potential of BIM can be fully exploited on-site necessitates instruction, guidance, and adaptation within the new tools and methods. These experiences are substantiated at RHO, where efforts are placed upon making the model as effortlessly understandable as possible. Certain craftsmen may approach the new methods with some skepticism and uncertainty – often due to a lack of IT proficiency or having familiarized themselves with working in 2D over several years – and it is important for them to firsthand generate positive experiences with the new tools and methods, to motivate them to embrace the digital solutions.

6.4.2 | Quality of devices

On-site devices may be exposed to rough weather conditions and dust, which requires hardware of a certain quality. The sub-contractors at NPK expresses that in some cases, a laminated sheet of paper may provide an easier interface for blueprints in snow and rain than operating a smartphone. Furthermore, the model contains large quantities of data, which requires devices of appropriate hardware quality to be able to process the information efficiently. Generally, informants believe that this can be solved through maturity, along with further development of the interface and device technology. This is closely interlinked with the technological development of hardware at large. Today, devices are more tailored for on-site usage on construction sites than merely a few years ago, and it is expected that the development of more robust and applicable devices will continue in the imminent foreseeable future.

6.4.3 | Low tolerance of modeling errors

Findings suggest that utilizing a digital model as the sole foundation for blueprints in large-scale construction projects presents the design team with a critical assignment. As the model represents the building's blueprints in their entirety, every structure and detail must be modeled preliminary to the construction phase. Every piece of an assembly model must be cohesive and consistent. This requires a model of high quality, with a basically 'perfect' degree of accuracy within the geometric objects displayed in the model; if the model is flawed, the construction will be built as such. This entails a comprehensive digital competence within the design team and the actors that produce and develops the model. A larger emphasis must therefore be placed upon digital modeling during the design phase, to ensure that the model has the best prerequisites to achieve the desired quality. This includes oversight and supervision of the various sub-contractors involved in the design.

6.4.4 | Level of detail in models

The level of detail included in the model within complex geometric objects and structures is cited as an important aspect in making the model sufficiently sophisticated. Limitations within the object details of the model are mentioned by several informants as one of the most critical challenges of on-site BIM. The architectural field and designers have – for various reasons – had difficulties in including detailed geometry in the model. Traditionally, these have been displayed through sectional drawings and 2D viewpoints. The level of detail in the model is often not at the level needed to build properly – e.g., in a special type of wall – compared to detail drawings or sectional viewpoints. Modeling with a higher degree of detail and making them more visible is highlighted as an area for improvement by the general contractor representative at SiV. If everything is not detailed, some sectional drawings may be necessary, with details where the structure is different from 'normal'. Making these details visible has been a shortcoming in the model – the architect has worked on creating 3D details and linking them to the geometric objects but has not implemented them in blueprints used on-site yet. The NPK project aims to overcome this challenge and further the level of detail in modeling, by modeling the geometry of certain elements in full, including the climate shell and supporting structures. Access to these details directly in the model reduces the necessity for sectional viewpoints, often visualized through paper drawings. However, the technological framework may again appear as a constraining factor. The technical infrastructure, in terms of network access and hardware power, may enforce limitations related to the size and depth that a single model can contain, for the digital devices to be able to process them on-site.

6.4.5 | Technical infrastructure

The SiV project encountered difficulties within the technical infrastructure, where placements of BIM kiosks were dependent on network access. These concerns were shared by NNM, who cites investments in technology and digital competence as key for being able to utilize BIM on-site efficiently. The network capacity appeared as a bottleneck, both in terms of accessibility and download speed. On a construction site stretching more than hundreds of meters, continuous access to network routers represents an infrastructural challenge. The solid concrete building structure of the NNM project furthered these issues, where several strategically placed wired hubs were required. Therefore, a thorough plan for technical infrastructure is necessary to provide the digital devices on-site whit sufficient access to a stable and reliable internet connection. Today, software that operates both online and offline are more prevalent, which was not available at the time of the project. Additionally, the development of the 5G mobile network may provide better conditions for network accessibility and high-speed data transmission on construction sites.

6.4.6 | Managing the interface of digital devices

Data from the general contractors emphasize that the projects do not pursue being paperless for the sake of it if recognizing that the paper-based format could still provide value in some contexts. At NPK, paper drawings were drawn up from the model to provide a general overview of the building, upon the request of certain sub-contractors. The argument for this is that a full-scale view of the building may be difficult to envision through the narrow-sized screen of a tablet or a smartphone and that a paper-based print-out provides a broader overview of the scale of the building and the construction as a whole. Particular paper-based drawings also provide the possibility to scribble notes or measurements easily by hand – a feature that may not be fully integrated into some of the digital interfaces as of yet. For these functions, the tangible paper format arguably still holds an advantage over digital tools. This is substantiated by findings from SiV, who suggests that integrated features for carrying over relevant information must be further developed within the software interfaces. Currently, some digital proficiency may be required to create notes and remarks, take measures, or add comments in the model. These issues can be counteracted through more streamlined functions within the programs, along with the craftsmen expanding their familiarity with the new tools and methods.

Navigating the model on-site is highlighted as an issue by several of the informants. The devices contain large amounts of data, where finding the right information at the right time may not always appear straightforward. The focus must be placed around developing viewpoints of the blueprints that are easy to locate and access, and that get updated in accordance with the project progress. However, this is also linked to how the actors are familiar with utilizing digital solutions individually; it is generally accepted that people having ‘grown up’ with utilizing digital tools in everyday settings have a more natural ability to operate and understand them. At SiV, the BIM manager draws a parallel to navigating by roadmaps; those inexperienced with digital solutions may require large-scale folding paper-based viewpoints to fathom the details and comprehend the whole picture, whereas navigating a digital map on a smartphone may remain sufficient for others. Therefore, a natural generational shift in the industry may ease the pressure related to the capacity and tolerance of understanding and operating digital devices.

Making sub-contractors – especially the smaller or inexperienced ones – delivering their blueprints digitally with all required information modeled is also mentioned as a challenge at SiV. This is cited as a development that is necessary within the industry on a general basis.

Requirements and demands for the sub-contractors utilizing digital modeling must be set and followed up by the project owner and the general contractor, but one must at the same time provide training and guidance along the way. The sub-contractors must possess a level of competence that enables them to deliver in accordance with what is requested – which was a larger challenge in earlier projects but is more common today. As the contractors carry out more projects that demand similar requirements – often by employing the same contractors for several projects – one can contribute to their growing and maturing, as well as developing the industry.

6.5 | Fulfilment of project targets through BIM

Some of the case studies have concrete targets specified for the utilization of BIM. Others have more general Key Performance Indicators (KPIs) where the utilization of BIM presents an element in achieving overall targets. At RHO, the project owner has an overall BIM strategy that must be followed. The usage of certain digital tools and methods supports this strategy. This is also the case for NNM, where the usage of BIM supports overall processes, such as governing economics, geometries, and quantities and structure volumes in precise detail. In achieving KPIs related to the area, BIM has provided an appropriate solution in measuring and controlling the fulfillment of specific targets. This is also the case for economic aspects, where the model can be used to calculate various unit amounts and costs. At SiV, the model represented parts of the delivery requirements from the general contractor to project owner, in the place of traditional sets of drawings.

At NPK, the general contractor's ambition to explore and utilize various BIM-based solutions was an important aspect in winning the tender, as it aligned with the prerequisites aspired by the project owner. The project owner develops strategies for processes and performance of digital solutions that must be satisfied. The general contractor pursues being "*a digital snowplow*" in the AEC industry, where the processes and solutions presented in the tender are essential to winning the contract. However, performing the solutions in practice is a demanding task; in some areas, it involves conducting pilot projects within certain software or methods that are yet to be tested. Here, it is important that the gap between theory and empiricism is balanced, where the elected solutions must present a quantifiable effect. The incentive for utilizing digital modeling is not being digital in itself but facilitating for added project value in terms of increased operational efficiency and fewer occurrences of waste. Consequently, the NPK project is necessary to further the digital transformation in practice, where the experiences will generate increased value in construction projects long-term.

The project owner acting as a key driver for the digital transformation is recognized as a crucial factor by several of the case studies. At NPK, the BIM ambitions materialize in the project proposal stage, where concrete requirements of utilizing specific tools and methods provide the basis for which contractors may apply in the project. In this case, the project owner has stated: "*What is to be built must be modeled, and what is modeled are to be built.*" Therefore, it is essential that the modeling is done thoroughly and correct – otherwise, what is built will be flawed. This entails a comprehensive and demanding task for the design team, as the model representing the foundation for blueprints must be 'perfect'. Maturity is an essential element to achieving a model of this state. The surrounding system of controls, involving internal control, interdisciplinary control, collision control, etc., is quantified by MMI, where errors and inaccuracies in the model are to be identified and solved. Documentation is also an important part of this process. When running MMI 400, the model performs at a capacity where it is sophisticated enough to be used as the foundation for blueprints. Preliminary to this, the model must be 'approved by production', which entails the delivery team participating in securing constructability before the model is distributed. The project manager emphasizes the importance of "*building correctly and building correctly on the first try.*" Therefore, it is crucial that the model representing the foundation of blueprints being correct. Adjustments may occur between MMI 400 and 500, but the target is as few corrections as possible. Figure 6.5-1 and figure 6.5-2 illustrate an example of the design difference in the model between MMI 200 and MMI 400 at the NPK project.

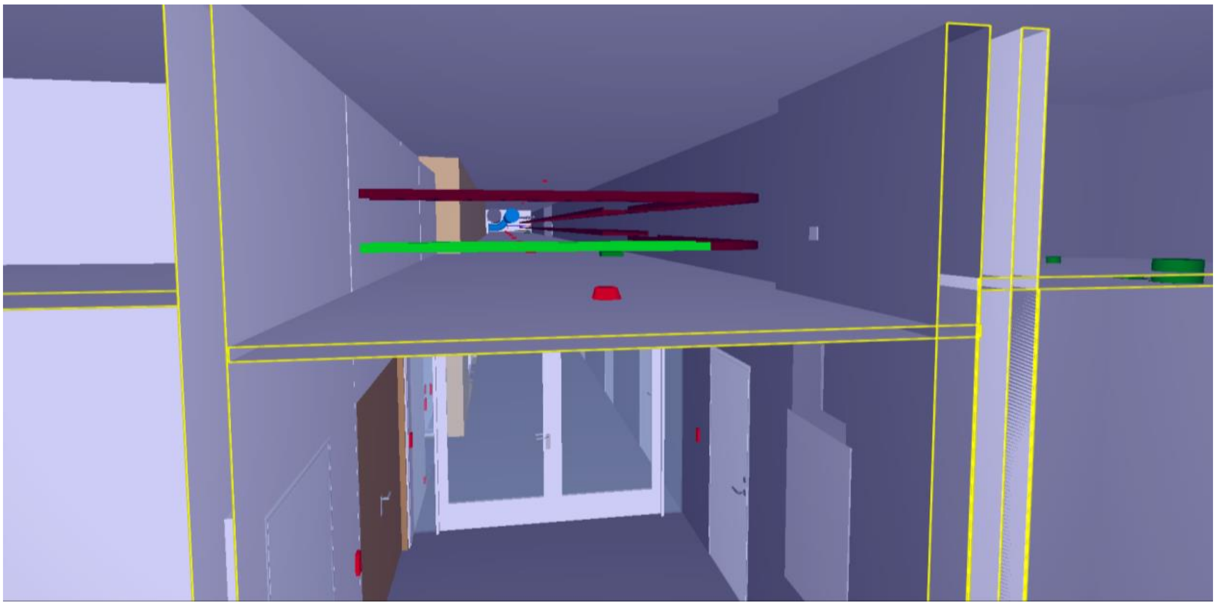

Figure 6.5-1: *Model section of ceiling details at NPK in MMI 200 (image courtesy of Skanska).*

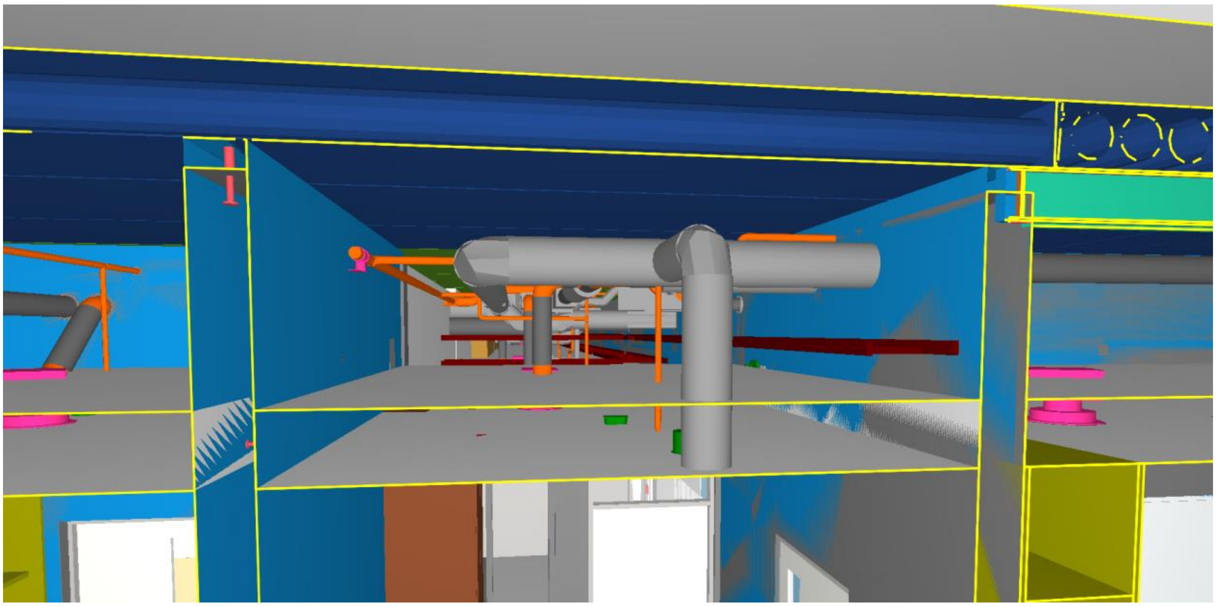

Figure 6.5-2: *Model section of ceiling details at NPK in MMI 400 (image courtesy of Skanska).*

6.6 | Critical reflections

The construction manager at NPK states that digital transformation entails a completely different way of working. The in-depth visualization BIM generates of the building works well from the design team's perspective. This is supported by the general contractor representative at SiV, who states that BIM provides great value 'in the office', but the 'real value' lies in utilizing it on-site. However, for the craftsmen at the construction sites, there is a long process in being able to exploit the full potential efficiently, as many are not used to operating digital devices. This requires gradual maturity and experience over time. Projects such as the NPK and SiV contribute to furthering the development in the industry. This is supported by the sub-contractors, who also appreciate the technological aspect within the devices evolving over time. The consensus is BIM being a productive aid when understanding the tools in detail and accumulating competence within new methods through experience.

The BIM coordinator at NPK expresses that it is a difficult task to conduct the digital transformation, but each project with targeted ambitions for BIM – such as the NPK project – contributes to pushing the shift further by going step-by-step in the 'right' direction. Certain parts of the industry might not be completely ready for the changing of work methods from what they have been familiar with over a large period. Therefore, it is necessary to witness the benefits of digital tools firsthand and forming positive experiences before realizing the advantages of digital modeling and being able to utilize them efficiently and successfully. This is substantiated by the project owner representative at NNM, citing that implementing BIM in projects today takes time and effort, but will expectedly induce savings in the long run. Thus, the projects of today can be regarded as an investment in future projects.

A relevant question for examination is what incentivizes the various actor to utilize BIM in the execution of construction projects. The project owner's incentive for utilizing digital solutions lies in increased operational efficiency and economical savings; they do not want to implement digital solutions for the sake of 'just being digital' but seeks a quantifiable effect. At NNM, the project owner representative expresses belief in BIM being the present and the future within the delivery phase of large-scale construction projects, but that both contractors, consultants, design, and engineering actors must implement it further in their operations for it to evolve into the powerful tool it has the potential to be. If being reasonably forward-looking and assertive within its use proves a quantifiable value, it is easier to get every project member on board. It is challenging to start with 3D modeling when has not been done before – and contemplating which information is appropriate to include in the model. BIM is not a new subject today, but the matter at hand is how to enhance its effects further.

Experiences from RHO showcases that implementation of on-site BIM contributes to reducing the percentage of error. Earlier projects have demonstrated the challenges of transmitting information from the model of an appropriate degree of sophistication for the sub-contractors to be able to utilize them efficiently. If the threshold for using the model is too high, it is easy to regress back to what feels safe and familiar in paper-based drawings. At RHO, this has been attempted to counteract by placing the "*craftsmen in the center*" and adjusting the interface of information to their needs. The main obstacle is getting acquainted with the new methods of working. This has been attempted to solve by collaborating closely with every contractor, instructing and provide guidance within how to utilize the model most efficiently, and attaining the information that is required for their respective assignment.

The NNM project commenced at a time where more uncertainty was related to the utilization of BIM in large-scale construction projects. Therefore, it was decided that traditional 2D drawings, both digital and printed, would apply ahead of the model. However, all drawings were produced upon exact geometric excerptions from the model, that subsequently were enriched with further details not included in the model. The drawings were considered as the governing tool, but the model provided the basis for blueprints. Therefore, the model determined the geometric input from design, while the drawings represented the interface on-site. Consequently, one can argue that the experiences from this project contributed to paving the way for other projects with similar ambitions of furthering the development of BIM today.

A properly matured all-encompassing digital model of a large-scale construction project may appear useful beyond the design and delivery phase. In many projects, the models are being prepared for a life after the structural construction is completed, where the project owner or general contractor develops the model as a part of the project delivery. The model can be delivered for use during the operational phase of the building as a digital twin, where elements such as maintenance requirements can be managed digitally throughout the life cycle of the building. This may streamline communication barriers within the personnel that operates the building, to make reporting of wear and tear and following upkeep more efficient. At NNM, BIM during the delivery phase has been utilized to enrich the continuous project model alongside the progress in the construction. Thereby, the model will encompass detailed information of every component, which provides the possibility of being able to efficiently map and navigate the building or troubleshoot and correct errors – elements that are cumbersome or impossible by looking through a library of drawings – especially when in paper-format. This presupposes the model being maintained during the operational phase, but as long as it is 'kept alive', it can be considered a digital twin of the building. Additionally, findings from both NPK and SiV disclose the models being prepared for having similar purposes after the delivery phase.

While many of the advantages within digital solutions appears undeniable, the accumulation of data suggests that implementing BIM in the delivery phase of large-scale construction projects is a complex process with many considerations to acknowledge. Therefore, it is necessary to approach the transformation procedures with caution. Gradually adapting to the new tools and methods, and carefully assessing how they impact the work processes both positively and negatively, is key to be able to exploit the full potential of BIM long-term. However, recognizing both one's own and the various tool's limitations and not overreaching is equally important. In some circumstances, the implementation of digital tools may not have the desired effect in terms of exceeding traditional methods. Certain situations call for some additional information or tacit knowledge that may be needed to deliver optimally – not because of difficulties to adapt, or the continuation of traditional methods – where the paper format still represents an expedient solution for select work processes on-site.

7 | Conclusion

This chapter summarizes the thesis and offers inferences based on reflection around the findings. The chapter is introduced with a synopsis of the thesis that recaps the thesis' contents. Subsequently, the conclusive remarks that provide the basis for inferences are presented, followed by recommendations for further examination of the subject.

7.1 | Synopsis

This thesis has presented a qualitative case study within the usage of on-site BIM in construction projects by performing both literature studies and case studies. Four case studies were conducted where the informants represented various roles – including representatives from the project owner, general contractor, sub-contractor, and consultant – within their respective projects. The study set out to investigate the research question 'How does the utilization of BIM improve the foundation for blueprints in the delivery phase?' through exploratory interviews and analytical generalization. The findings do not suggest a singular answer to how the implementation of BIM should be conducted on construction sites; instead, it provides multiple critical considerations when facilitating for efficient use of the model on-site, based on the perceptions and experiences of the case study project members within the digital solutions.

7.2 | Conclusive remarks

The study has uncovered several aspects where the utilization of on-site BIM improves the foundation for blueprints in large-scale construction projects. The model provides the project member with a shared platform across their respective discipline. This increases interdisciplinary understanding and eliminates errors in the form of interferences. Having access to the model through handheld devices on-site promotes better communication in the form of more streamlined reporting and documenting of both progress and inaccuracies, which also entails more efficient time consumption. Drawings traditionally displayed on resource expensive paper-formats are now available through BIM kiosks, tablets, and smartphones, where all-encompassing blueprints are accessible continuously. The digital interfaces present a more practical foundation for blueprints than paper drawings, as they are more convenient to administer and can access all required information through a singular device.

In terms of challenging aspects, findings suggest that technological development and adapting to the new methods the technology brings are the foremost limiting factors. Sometimes, the ambitions exceed the technology currently available. Other times, the technology can be regarded as too intricate for efficient deployment. Facilitating proper on-site technical infrastructure and investing in appropriate software and hardware is key. As for exploiting the full potential of BIM on-site, much relies on the project actors familiarizing themselves with the digital solutions, combined with the technological development at large. It is undeniable that utilizing digital blueprints entails a major transformation of the work methods many craftsmen have been used to for several years. For them to be able to utilize the digital devices efficiently, it is necessary with proper training and guidance combined with a willingness to adapt. Here, it is important for the project owner and the general contractor to act as the key drivers, by motivating and incentivizing the use of digital solutions. Additionally, interface devices must present data of such quality that it becomes more convenient to use them before they can be regarded as value-adding factors to construction projects. Today, such devices have a level of sophistication that they tolerate the display of vastly comprehensive models and details. They are also available in a convenient size for being carried around and are build robust enough to withstand being used under tough conditions on the construction site without compromising the quality of information they hold.

Facets of the digital transformation in the delivery phase of construction projects involve implementing tools and methods that increase productivity, efficiency, and quality on-site. In this regard, it is important to recognize when BIM solutions are appropriate and when traditional methods still may perform equally as well. The empirical data implies that the 2D format is not completely dead – it may still have an expedient area of usage within certain circumstances. Empirical data indicates that both digital and paper drawings were utilized in current projects – however, the paper format in a lesser degree than digital drawings. Situations where drawings are preferred to the model include providing sectional viewpoints of details where the models lack geometric depth, or when harsh weather or on-site conditions obstructs the digital interfaces. Interestingly, the paper format is also subject to usage in some contexts, such as providing an appropriate visualization of the overall picture of the large-scale building or scribbling marks and comments more effortlessly. At this time, the perception is that 2D formats still may be applicable in certain circumstances of current projects – however, as the digital solutions become more widespread and the industry matures collectively, the experiences may shift to a point where the model as the sole foundation for blueprints becomes the best solution of all involved parties.

The findings suggest that most large-scale projects performed today facilitate utilizing 3D and 4D BIM, while subsequent dimensions are less common as they are still just being released in the industry. Appropriate access to both software and hardware is required to be able to utilize 5D, 6D, and 7D. As technological development ensues, more projects are implementing higher dimensions of BIM as the project members become more familiar with working digitally and the technology of both software and hardware enables it. However, the constraint of utilizing multi-dimensional BIM is not purely technological, it also requires higher implementation capabilities and BIM maturity from early design stages through delivery.

Problems discovered in construction projects today play a part in forming the development of solutions for future projects. Software interfaces are in constant development, where the next iteration of programs may take action within issues identified by the projects piloting BIM on construction sites today. Therefore, the experiences from these projects are important to identify which elements of BIM are ready to be continued and which require further adaptations and iterations. This can be regarded as an investment for better operational efficiency in future projects and represents an important part in driving the AEC industry forwards long-term.

7.3 | Recommendations

The thesis was prepared, planned, and executed over a 20-week period during a single semester which provides a limited extent of time for research. This restricts both the amount and depth of case studies, which can limit the degree of validity and reliability in findings. The time limitation also imposes simplifications of the interview process and line of questioning. Because of the restricted timeframe of a master's thesis, there was a limited amount of case studies that could be conducted. It was also unfeasible to examine 'all' existing research and relevant theory on the subject, which therefore increases the possibility of knowledge gaps and oversights in this study. For further research, it is recommended to build a broader theoretical foundation on the topic, to ensure a better starting point for research. This would also enable future studies to go more in-depth on the subject matter, such as specifications, pros and cons of various BIM software, and the process of implementing BIM on-site.

The study has uncovered some of the sub-contractors' perspectives on utilizing BIM on-site. However, a more in-depth examination of the prerequisite conditions of the craftsmen's day-to-day operations might have yielded more concrete results regarding how digital solutions can be implemented most effectively. Grand ambitions, statements, and assumptions on digital tools from an overall level add little value to a project if the craftsmen on-site are not able to utilize them properly.

Focus on furthering the implementation of on-site BIM in forthcoming large-scale construction projects, along with the technological development in the industry, may provide more empirical experiences for future studies of the subject. Some of the cases investigated in this thesis are still in the early stages of production, where the date of delivery is still a few years ahead. Revisiting these cases in a few years might provide additional interesting findings on their experiences of on-site BIM – including which solutions have worked and which have appeared challenging.

Interoperability is an important subject in terms of BIM development. The work that is being performed by buildingSMART to provide the industry with standardized formats and open software could be studied further, along with the implementation of standards for terminology and processes within the digital solutions.

The study uncovered interesting findings on the topic of utilizing BIM beyond project delivery, as a digital twin in the maintenance and operational phase. This is a topic that – to the author's knowledge – is yet to be examined in-depth, as there is still a scarcity of empirical data available. Further studies should focus on the areas of application and impacts of digital twins in practice, by gathering data from projects with ambitions of piloting these state-of-the-art methods.

References

Aarseth, I. (2017). Tønsbergprojektet. Retrieved from https://docplayer.me/47722187-Inge-aarseth-prosjektleder-digital-samhandling-og-tekniske-grensesnitt-sykehuset-i-vestfold-hf-del-av-helse-sor-ost-konsernet.html

Andreassen, A. & Beste, T. (2020). Innovasjon i praksis: Hvordan kan en offentlig byggherre være driver av innovasjon? *Praktisk økonomi & finans, 36*(3), pp. 190–199. https://doi.org/10.18261/issn.1504-2871-2020-03-03

Arayici, Y., Egbu, C. & Coates, P. (2012). Building information modelling (BIM) implementation and remote construction projects: Issues, Challenges and Critiques. *Electronic Journal of Information Technology in Construction 17*(1), pp. 75–92. https://www.itcon.org/2012/5

Baker, M.J. (2000). Writing a literature review. *The Marketing Review*, *1*(2), pp. 219–247. https://doi.org/10.1362/1469347002529189

Balida, D.A. (2020). Dissertation Writing: The Literature Review. *ResearchGate*. https://doi.org/10.13140/RG.2.2.22016.15360

Baxter, P. & Jack, S. (2008). Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report, 13*(4), pp. 544–559. https://doi.org/10.46743/2160-3715/2008.1573

Bernard, H.R. (2011). *Research Methods in Anthropology* (5th ed.). AltaMira Press.

BibLus. (2020, October 2nd). IFC format and Open BIM, all you need to know [Blog post]. Retrieved from https://biblus.accasoftware.com/en/ifc-format-and-open-bim-all-you-need-to-know/

BibLus. (2021a, April 1st). Modeling, Model and Management: the three M's of BIM and the right BIM tools [Blog post]. Retrieved from https://biblus.accasoftware.com/en/modeling-model-and-management-the-three-ms-of-bim-and-the-right-bim-tools/

BibLus. (2021b, April 12th). IFC file: all you need to know [Blog post]. Retrieved from https://biblus.accasoftware.com/en/ifc-file-all-you-need-to-know/

Bjørnstad, J.E., Bjørhusdal, L.J. & Westerlund, V.L. (2019). *4D Software in the Norwegian Construction Industry* (Bachelor's thesis). Norwegian University of Science and Technology, Trondheim.

Bolpagni, M. (2013). *The implementation of BIM within the public procurement* (Master's thesis). Technical Research Centre of Finland, Helsinki.

Bølviken, T., Kalsaas, B.T. & Skaar, J. (2020). *Call for a Common System for Lean Design Management*. Unpublished manuscript.

buildingSMART. (2021). What is openBIM? Retrieved from https://www.buildingsmart.org/about/openbim/openbim-definition/

Byggeindustrien. (2015). BIM-kiosker beste idé på den kloke tegning. Retrieved from http://www.bygg.no/article/1252390

Constructech. (2013, May 12th). BIM for Tablets in the Field [Blog post]. Retrieved from https://constructech.com/bim-for-tablets-in-the-field/

Dubois, A. & Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Elsevier Journal of Business Research 55*(7), pp. 553–560. https://doi.org/10.1016/S0148-2963(00)00195-8

Eriksen, C. (2018). Digitalisering av byggeprosessen – Bruk av BIM i produksjon (Master's thesis). Norwegian University of Science and Technology, Trondheim.

Fløisbonn, H.W., Skeie, G., Uppstad, B., Markussen, B & Sunesen, S. (2018). MMI – Modell Modenhets Indeks. Retrieved from https://www.eba.no/siteassets/bilder/rapporter-og-publikasjoner/mmi-modell-modenhets-indeks.pdf

Fosse, R., Ballard, G. & Fischer, M. (2017). Virtual Design and Construction: Aligning Bim and Lean in Practice. In *25th Annual Conference of the International Group for Lean Construction*. Heraklion, Greece, 9-12 Jul 2017, pp. 499–506. https://doi.org/10.24928/2017/0159

Fuglesang, A. (2017). BIM i bruksfase – en kvalitativ kartleggingsstudie av status ved bruk av BIM i bruksfase (Master's thesis). Norwegian University of Science and Technology, Trondheim.

Gero, J. & Kannengiesser, U. (2014). The Function-Behaviour-Structure Ontology of Design. In Chakrabarti, A. & Blessing, L.T.M. (Ed.), *An Anthology of Theories and Models of Design* (pp. 263–283). London: Springer. https://doi.org/10.1007/978-1-4471-6338-1_13

Goddard, W. & Melville, S. (2004). *Research Methodology: An Introduction* (2nd ed.). Blackwell Publishing.

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report, 8*(4), pp. 597–606. https://doi.org/10.46743/2160-3715/2003.1870

Guy, L. (2021, April 14th). How tablets transform construction sites [Blog post]. Retrieved from https://www.pbctoday.co.uk/news/bim-news/tablet-construction-sites/91924/

Harstad, E.B., Lædre, O., Svalestuen, F. & Skhmot, N. (2015). *How Tablets Can Improve Communication in Construction Projects*. Paper presented at the Proc. 23rd Annual Conference of the International Group for Lean Construction, Perth, Australia.

Heiskanen, A. (2014). BIM and Tablets on a Construction Site – Video. Retrieved from https://aec-business.com/bim-tablets-construction-site-video/

Helse Sør-Øst. (2018). Protonsenter ved Radiumhospitalet, Helse Sør-Øst. Retrieved from https://www.helse-sorost.no/Documents/Store%20utviklingsprosjekter/OUS/Radiumhospitalet/Skisseprosjekt%20proton.pdf

Helse Sør-Øst. (2021). Fakta om nytt klinikkbygg og protonsenter på Radiumhospitalet. Retrieved from https://www.helse-sorost.no/om-oss/vart-oppdrag/hva-gjor-vi/utviklingsplaner-og-store-utviklings-og-byggeprosjekter/nytt-klinikkbygg-og-protonsenter-pa-radiumhospitalet/fakta-om-nytt-klinikkbygg-og-protonsenter-pa-radiumhospitalet

Huang, C.-Y., Yien, H.-W., Chen, Y.-P., Su, Y.-C. & Lin, Y.-C. (2017). *Developing a BIM-based Visualization and Interactive System for Healthcare Design*. Paper presented at the 34th International Symposium on Automation and Robotics in Construction, Taipei, Taiwan, pp. 372–379. https://doi.org/10.22260/ISARC2017/0051

Järvensivu, T. & Törnroos, J.-Å. (2010). Case study research with moderate constructionism: Conceptualization and practical illustration. *Industrial Marketing Management, (39)*1, pp. 100–108. https://doi.org/10.1016/j.indmarman.2008.05.005

Kensek, K.M. (2014). *Building Information Modeling* (1st ed.). Oxfordshire: Routledge.

Kovács, G. & Spens, K.M. (2005). Abductive reasoning in logistics research. *International Journal of Physical Distribution & Logistics Management, 35*(2), pp. 132–144. https://doi.org/10.1108/09600030510590318

Leung, L. (2015). Validity, reliability, and generalizability in qualitative research. *Journal of Family Med Prim Care, 4*(3), pp. 324–327. https://doi.org/10.4103/2249-4863.161306

Lin, Y.-C. (2015). Use of BIM approach to enhance construction interface management: A case study. *Journal of Civil Engineering and Management, 21*(2), pp. 201–217. https://doi.org/10.3846/13923730.2013.802730

Lu, Q., Xie, X., Heaton, J., Parlikad, A.K. & Schooling, J. (2020). From BIM Towards Digital Twin: Strategy and Future Development for Smart Asset Management. In Borangiu, T., Trentesaux, D., Leitão, P., Giret Boggino, A. & Botti Navarro, V. (Eds.), *Service Oriented, Holonic and Multi-agent Manufacturing Systems for Industry of the Future* (pp. 392–404). Universitat Politècnica de València, Spain. https://doi.org/10.1007/978-3-030-27477-1_30

Merschbrock, C. & Nordahl-Rolfsen, C. (2016). BIM Technology acceptance among reinforcement workers – The case of Oslo Airport’s terminal 2. *Journal of Information Technology in Construction (ITcon), 21*(1), pp. 1–12. http://www.itcon.org/2016/1

Montague, R. (2016, July 27th). *30-minute Introduction to BIM* [Video file]. Retrieved from https://www.youtube.com/watch?v=bJTNhbVcBFk

Moses, T., Heesom, D. & Oloke, D. (2020). Implementing 5D BIM on construction projects: Contractor perspectives from the UK construction sector. *Journal of Engineering Design and Technology*. Advanced online publication. https://doi.org/10.1108/JEDT-01-2020-0007

Murvold, V., Vestermo, A., Svalestuen, F., Lohne, J. & Lædre, O. (2016). *Experience from the use of BIM-stations*. Paper presented at the Proc. 24th Annual Conference of the International Group for Lean Construction, Boston, MA, USA.

Omholt-Jensen, K. (2018, January 28th). Flere papirløse prosjekter hos Norconsult [Blog post]. Retrieved from https://streambim.com/no/flere-papirlose-prosjekter-hos-norconsult/

Oslo universitetssykehus. (2021). Nye Radiumhospitalet. Retrieved from https://oslo-universitetssykehus.no/om-oss/nye-oslo-universitetssykehus/nye-radiumhospitalet

Rowlinson, S., Collins, R., Tuuli, M.M. & Jia, A.Y. (2010). Implementation of Building Information Modeling (BIM) in Construction: A Comparative Case Study. *Proceedings of the 2nd International Symposium on Computational Mechanics and the 12th International Conference on the Enhancement and Promotion of Computational Methods in Engineering and Science*, pp. 572–577. https://doi.org/10.1063/1.3452236

Rufo. (2019, March 11th). Veidekke utviklet BIM-kiosk med Rufo [Blog post]. Retrieved from https://blogg.rufo.no/veidekke-utviklet-transportkasse-til-bim-kiosk-med-rufo/b/7126/?utm_source=Gammelblogg&utm_medium=Artikkel&utm_content=Bimkiosk&utm_campaign=Videresending

Sacks, R., Eastman, C., Lee, G. & Teicholz, P. (2018a). *BIM Handbook: A guide to Building Information Modeling for Owners, Designers, Engineers, Contractors and Facility Managers* (3rd ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.

Sacks, R., Korb, S. & Barak, R. (2018b). *Building Lean, Building BIM: Improving Construction the Tidhar Way*. New York: Routledge.

Saxon, R.G. (2013). *Growth through BIM*. London: Construction Industry Council.

Skanska. (2017). Skanska og CURA-gruppen inngår kontrakt om sykehusutbygging i Vestfold. Retrieved from https://www.skanska.no/hvem-vi-er/media/pressemeldinger/201690/Skanska-og-CURAgruppen-inngar-kontrakt-om-sykehusutbygging-i-Vestfold

Statsbygg. (2021a). BIM. Retrieved from https://www.statsbygg.no/bim

Statsbygg. (2021b). Nytt Nasjonalmuseum. Retrieved from https://www.statsbygg.no/prosjekter-og-eiendommer/nytt-nasjonalmuseum

Strand, S.S. (2017). Veidekke lanserer fleksibel BIM-kiosk. Retrieved from https://www.bygg.no/article/1326096

Sürücü, L. & Maşlakçı, A. (2020). Validity and Reliability in Quantitative Research. *Business And Management Studies An International Journal 8*(3), pp. 2694–2726. https://doi.org/10.15295/bmij.v8i3.1540

Svalestuen, F., Knotten, V., Lædre, O., Drevland, F. & Lohne, J. (2017). Using building information model (BIM) devices to improve information flow and collaboration on construction sites. *Journal of Information Technology in Construction (ITcon), 22*(1), pp. 204–219. http://www.itcon.org/2017/11

Sykehusbygg. (2020). Nybygg psykisk helse, Kristiansand (NPK). Retrieved from https://sykehusbygg.no/byggeprosjekt/prosjekter-i-sor-ost/nybygg-psykisk-helse-kristiansand-npk

Sykehuset i Vestfold. (2021). Sykehusutbygging – Tønsbergprosjektet. Retrieved from https://www.siv.no/om-oss/sykehusutbygging-tonsbergprosjektet

Tang, L., Chen, C., Tang, S., Wu, Z. & Trofimova, P. (2017). Building Information Modeling and Building Performance Optimization. Encyclopedia of Sustainable Technologies, pp. 311–320. https://doi.org/10.1016/B978-0-12-409548-9.10200-3

TechTerms. (2011). Tablet. Retrieved from https://techterms.com/definition/tablet

Todsen, S. (2018). Produktivitetsfall i bygg og anlegg. In *Statistics Norway*. Retrieved from https://www.ssb.no/bygg-bolig-og-eiendom/artikler-og-publikasjoner/produktivitsfall-i-bygg-og-anlegg

vGIS. (2021). Collaborate and Detect Covert Design Errors. Retrieved from https://www.vgis.io/augmented-reality-esri-gis-ar-for-construction-bentley-microstation-autodesk-cad/

Vik, V. (2012). Implementering av BIM i bærekraftig oppgradering av bygninger (Master's thesis). Norwegian University of Science and Technology, Trondheim.

Wierzbicki, M., de Silva, C.W. & Krug, D.H. (2011). BIM – History and Trends. International Conference on Construction Applications of Virtual Reality: Weimar.

Yin, R.K. (2003). *Case Study Research: Design and Methods* (3rd ed.). Sage.

Appendix

A.1 | Interview guide

IND590 Masteroppgave: Industriell økonomi & teknologiledelse.

Tittel: ***Interface of Building Information Modeling and Blueprints on Construction Sites*.**

Intervjuguide: [Person] v/[Selskap], [Prosjekt] case-studie.

1. *Generelt om prosjektet: utbyggelse av [Prosjekt].*
2. *Hvilken rolle har du og selskapet [Selskap] i prosjektet?*
3. *Hva er prosjektets ambisjoner med tanke på utnyttelse av digitale verktøy?*
4. *Hva gjøres annerledes i forhold til "tradisjonelle" prosjekter?*
5. *Hva er fordelene med å benytte digitale arbeidstegninger/tegningsfri arbeidsplass? Hva er utfordringene? Finnes det noen ulemper?*
6. *Hva er grensesnittet mellom modeller og byggeplass? Hvordan fremstilles modellene på arbeidsplass? Hva har utførende tilgang til?*
7. *Hvordan relaterer bruken av digitale verktøy til prosjektets overordnede mål og KPI'er?*
8. *Hvilke erfaringer har dere gjort så langt med tanke på tegningsfri byggeplass i dette prosjektet (eventuelt i tidligere prosjekter)?*
9. *(Annet).*

Master