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Increasing Utility Value of BIM in All Project Phases

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Abstract:
Many BIM applications have been developed since the concept of BIM was first published. Increased use of BIM has been most noticeable from 2000 until today in Norway. BIM has most commonly been used in the initial and closing phases of a project. The researcher partnered with Rambøll Norge AS for this research work. They have so far not fully implemented BIM in the construction phase of their projects, but have expressed that they wish to change this. Their desire was the triggering factor for this research work, which attempted to answer the following research questions:

- *What are the benefits and challenges with using BIM in the construction phase?*
- *What actions are necessary to increase the utility value of BIM in all project phases?*
- *Who should be responsible for implementing the actions?*

An extensive literature search, a brief document study and twelve semi-structured open-ended interviews were conducted to collect data for this research. Many of the benefits disclosed are made possible due to the greatly enhanced visualization digital BIM models offer: Error detection, higher quality project products, increased predictability, and a more efficient construction process, etc. The interviewees pointed out the AEC industry's lack of BIM interest, willingness, and skills to be incredibly damaging to the implementation of BIM. The interviews uncovered some more comprehensive challenges, including the missing standardization of BIM tools and processes, and how BIM should be implemented and included in contract agreements. The interviewees would like to see the Norwegian government, buildingSMART or Standard Norge step in and assist the AEC industry in their attempt to implement BIM to its full extent.

Keywords:

1. Building Information Modeling
2. Benefits and challenges
3. Actions
4. Responsible party

PREFACE

This Master Thesis was prepared at the Department of Civil and Transport Engineering at the Norwegian University of Science and Technology spring 2015. The Master Thesis equates to 30 credits and is the final assignment of my master's degree in Civil Engineering and Project Management.

This research studies the benefits and challenges with using BIM in the construction phase, as well as the necessary actions to increase the utility value of BIM, and the parties responsible for implementing the actions. The choice of topic was initially based on my own interests. I felt I could benefit from increasing my own knowledge about Building Information Modeling. The research approach and purpose were shaped by inputs from my supervisor at Rambøll Norge AS and in dialogue with my supervisor at the Department of Civil and Transport Engineering. I think the chosen topic is very interesting because I predict that BIM tools and BIM processes are here to stay, and that the perceived challenges will diminish with time. The research methodology mainly consisted of a wide and thorough literature study and twelve semi-structured open-ended interviews of people from two case study projects. The interviews were made possible in collaboration with Rambøll Norge AS.

This research has been extensive, time consuming and challenging at times. I feel as though I have learned a lot about BIM processes through this work, but that I still have a lot to learn about BIM tools and practical approaches to BIM. This report was written in English because Ramboll AS is an international company. It is my hope that as many as possible will benefit from its contents.

I want to thank Truls Løver Arnesen for his time and help, as well as my case informants Torstein Lillebakk, Frederick Heidahl and Magne Johansen for their case material input and contributions. Truls has throughout the last two semesters assisted as external supervisor and been available for discussions. He also made a superb effort in getting case projects. Additionally, I wish to thank those who allowed me to interview them.

I would like to thank my supervisor Associate Professor Ola Lædre who has been of great help during this work and who has contributed with good dialogues and great advice. Thanks to Jardar Lohne for his academic input. Their contributions have been most helpful, and are very much appreciated.

Norwegian University of Science and Technology
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Maria Eriksen Hellum

ABSTRACT

Many BIM applications have been developed since the concept of BIM was first published decades ago. Increased use of BIM has been most noticeable from 2000 until today in Norway, but the use and the achieved utility value vary greatly, partly depending on the company size. BIM is most commonly used in the initial and closing phases of a project, while many choose to go back to traditional 2D methods during the construction phase, creating a black hole in the BIM implementation process. This can cause duplication of work, which can reduce the potential time, cost and quality benefits BIM offers. Is it true that the benefits from implementing BIM in the construction phase doesn't make up for the efforts it requires?
This master thesis attempts to convince the AEC industry that utilizing BIM in all project phases can contribute to optimize planning, communication and analyzing in ways that exceed the abilities of traditional implementation methods.

The researcher partnered with Rambøll Norge AS for this research work. They have so far not fully implemented BIM in the construction phase of their projects, but have expressed that they wish to change this. Their desire was the triggering factor for this research work. The researcher did a pilot study in fall 2014. Knowledge gained during the pilot study helped shape the research topic and the research questions, which read as follows:

- *What are the benefits and challenges with using BIM in the construction phase?*
- *What actions are necessary to increase the utility value of BIM in all project phases?*
- *Who should be responsible for implementing the actions?*

Currently experienced benefits and challenges with using BIM in all project phases must be identified as well as actions necessary to increase the benefits and reduce the challenges, in order to fulfill this research's purpose: Finding arguments in favor of using BIM in all project phases, and attempt to diminish the above-mentioned black hole.

A construction project has a limited duration and is the sum of a unique product, the project organization and the construction processes necessary to achieve completion. Projects' supereminent objective is to satisfy the clients' needs within the constraints of cost, duration, and quality objectives. Client acceptance of the final product is the key variable, as it clarifies if a project fulfilled its intended purpose. This thesis focused on the construction phase, but the transitions from preceding and to proceeding phases were still of some interest.

A Building Information Model can briefly be defined as an intelligent, digital 3D model incorporated with the building component information necessary to build the building. Building Information Modeling is the processes involving the generation and management of Building Information Models. The 3D model provides for enhanced visualization, model walkthroughs, and collision detection. A 4D model provides for the ability to plan, schedule, monitor, and manage a project. A 5D model provides for quantity take-outs, and 'real-time' and life cycle cost estimation. The 6D model provides for energy calculations and analyses, and addresses environmental strain. A 7D model provides for facility management, operation and maintenance, and life-cycle analysis.

This research work was carried out using an inductive research approach and qualitative research methods to collect data. An extensive literature search, a brief document study, and twelve semi-structured open-ended interviews of experienced BIM users involved in one of

the two case projects were conducted to collect data for this research. The group of interviewees consisted of: Four people with roles in the client's project administration, three discipline consulting engineers, one architect, two people with roles in the contractor's project management, one BIM technician and one BIM technician professor.

The interviewees were asked to elaborate on the benefit and challenges they have experienced concerning these aspects in BIM projects: Phase transitions, responsibility distribution, analytical features, information sharing, communication, visualization, collaboration and cooperation, lean construction, waste reduction, and schedule and budget planning and monitoring. They were also asked to recommend necessary actions to increase the utility value of BIM, and to name the parties they see as responsible for implementing the actions.

Many of the benefits the interviewees claimed to have experienced are made possible due to the greatly enhanced visualization digital BIM models offer: Performance analyses, error detection, quantity summation, work activity identification, verification of constructability, increased predictability, waste reduction, higher quality project products, and a more efficient construction process through free flow of information, constant model access and improved communication. Their claims are supported by literature reviewed in the literature study.

The interviewees each mentioned, on several occasions, that the AEC industry's lack of BIM interest, lack of willingness to adopt new tools and processes, and low level of BIM skills are incredibly damaging to the implementation of BIM. Proposed actions to reduce these challenges included increasing people's BIM interest and level of BIM skills, which may be solved locally. Individual companies could arrange training seminars for their employees, but employees have to be willing to adopt BIM. Research on the overall utility value of BIM or the expected savings of cost and time from implementing the construction phase utilizing BIM tools and BIM processes may contribute to convince AEC industry participants nation-wide. The latter is also one of the researcher's recommended future research topics.

Some more comprehensive challenges were also uncovered during the interviews. BIM tools and BIM processes have in many cases simply been applied to traditional project implementation methods and contract strategies. Appropriate levels of detail in BIM models and intended use of models are seldom specified in contract agreements. The interviewees would like to see the government, buildingSMART or Standard Norge step in and announce standard BIM applications and information exchange systems, and establish standards for how BIM should be implemented and how BIM should be included in contract agreements.

One of the interview questions dealt with combining BIM and budget planning and monitoring. None of the interviewees were able to give well-justified answers, as none of them have had any previous success actually combining the two.

SAMMENDRAG

Mange BIM-applikasjoner har blitt utviklet siden begrepet BIM først ble publisert. Bruken av BIM har i Norge hatt en merkbar økning fra 2000 til i dag, men bruksområdene og den oppnådde nytteverdien varierer i stor grad, delvis avhengig av bedriftenes størrelse. BIM er mest brukt i de innledende og avsluttende prosjektfasene. Mange velger å gå tilbake til tradisjonelle prosesser og 2D-verktøy i byggefasen, noe som skaper et sort hull i BIM prosjektenes gjennomføringsmetode. Dette kan føre til dobbeltarbeid og en reduksjon av de potensielle fordelene BIM tilbyr i forbindelse med tid, kostnad og kvalitet. Er det virkelig slik at fordelene med å implementere BIM i byggefasen ikke overgår den innsatsen som kreves? Undertegnede vil med denne masteroppgaven forsøke å overbevise byggebransjen om at det å benytte BIM som gjennomføringsmetode i alle prosjektfaser kan bidra til å optimalisere planlegging, kommunikasjon og analysering på måter som overgår evnene til tradisjonelle metoder.

Undertegnede har samarbeidet med Rambøll Norge AS i dette forskningsarbeidet. De har så langt ikke implementert BIM i byggefasen av sine prosjekter fullt ut, men har uttrykt at de ønsker å endre dette. Dette ønsket var den utløsende faktoren for forskningsarbeidet. Undertegnede gjorde et pilotstudium høsten 2014, som bidro til å forme masteroppgavens forskningstema og forskningsspørsmål, som lyder som følger:

- *Hvilke fordeler og ulemper finnes ved bruk av BIM i gjennomføringsfasen?*
- *Hvilke tiltak må iverksettes for å øke nytteverdien av BIM i alle prosjektfaser?*
- *Hvem bør være ansvarlig for implementeringen av tiltakene?*

Opplevde fordeler og ulemper med å bruke BIM i alle prosjektfaser må identifiseres. Videre må tiltak som er nødvendige for å øke nytteverdien og redusere ulempene identifiseres. Sammen skal dette oppfylle forskningens formål: Å finne argumenter i favør av å bruke BIM i alle prosjektfaser, og å forsøke å redusere det tidligere nevnte sorte hullet.

Et byggeprosjekt har en begrenset varighet og er summen av et unikt produkt, prosjektorganisasjonen og byggeprosessene som må til for å oppnå ferdigstillelse. Prosjektets overordnede mål er å tilfredsstille kundens behov innenfor de avtalte tid- og kostnadsrammene, til den avtalte kvaliteten. Kundeaksept av sluttproduktet er viktig, da dette avgjør om prosjektet kan betraktes som en suksess. Denne masteroppgaven har hatt fokus på gjennomføringsfasen, men overgangen fra prosjekteringsfasen til byggefasen, samt overgangen fra gjennomføringsfasen til driftsfasen har likevel vært av interesse.

En bygningsinformasjonsmodell kan kortfattet defineres som en intelligent, digital 3D-modell beriket med komponentinformasjon som er nødvendig for utførelsen. Bygningsinformasjonsmodellering innebærer de prosessene som involverer produksjon og forvaltning av bygningsinformasjonsmodeller. 3D-modellen gir forbedret visualisering som tilrettelegger for tidlig modellgjennomgang ("walkthrough") og kollisjonsoppdagelse. En 4D-modell tilrettelegger for planlegging, fremdriftsplanlegging, oppfølging og ledelse av et prosjekt. 5D-modellen muliggjør mengdeuttak, og sanntids- og livssykluskostnadsestimering. En 6D-modell tilrettelegger for energiberegninger og miljøbelastningsanalyser. En 7D-modell tilrettelegger for forvaltning, drift, vedlikehold og utvikling (FDVU), og livsløpsanalyser.

Forskningsdesignet til denne masteroppgaven består av en induktiv forskningstilnærming og bruk av kvalitative forskningsmetoder for datainnsamling. Et omfattende litteraturstudium, et

kortfattet dokumentstudium og tolv semistrukturerte intervjuer av erfarne BIM-brukere ble gjennomført for å samle inn data. Informantgruppen bestod av: fire personer med roller i byggherrevirksomhet, tre rådgivende ingeniører, en arkitekt, to personer med roller i entreprenørvirksomheter, en BIM-tekniker og en BIM-tekniker professor.

Informantene ble bedt om å utdype hvilke fordeler og ulemper de har opplevd i BIM-prosjekter med hensyn til disse aspektene: faseoverganger, ansvarfordelingen, analytiske funksjoner, informasjonsdeling, kommunikasjon, visualisering, samarbeid, trimmet bygging, sløsing, og fremdrifts- og budsjettplanlegging og oppfølging. De ble også bedt om å anbefale tiltak de anser som nødvendige for å øke nytteverdien av BIM, samt å utnevne hvilke parter de anser som ansvarlige for implementeringen av disse tiltakene.

Mange av fordelene informantene hevdet å ha opplevd kommer som følger av den forbedrede visualisering digitale BIM modeller tilbyr: ytelsesanalyser, feiloppdagelse, mengdeuttak, identifisering av arbeidspakker, verifisering av gjennomførbarhet (”constructability”), økt forutsigbarhet, sløsingsreduksjon, økt produktkvalitet og en mer effektiv byggeprosess pga. fri informasjonsflyt, konstant modelltilgang og bedre kommunikasjon. Deres utsagn støttes av litteraturen som ble gjennomgått i litteraturstudiet.

Informantene nevnte ved flere anledninger at byggebransjens mangel på interesse for BIM, manglende vilje til å ta i bruk nye verktøy og prosesser, og lave nivå av BIM ferdigheter oppleves som utrolig ødeleggende for implementeringen av BIM. Forslag til tiltak for å redusere disse ulempene inkluderte å øke bransjens interesse og BIM ferdigheter, noe som kan løses lokalt. Bedrifter kan enkeltvis arrangere opplæringsseminarer for sine ansatte, men ansatte må samtidig selv være villige til å ta i bruk BIM. Videre forskning på den samlede nytteverdien av BIM og de forventede tids- og kostnadsbesparelser fra å benytte BIM som gjennomføringsmetode i byggefasen ble etterspurt og ansett som virkemidler som kan bidra til å overbevise den norske byggebransjen. Det sistnevnte er også én av undertegnedes anbefalinger for fremtidige forskning.

Noen mer omfattende ulemper ble også avdekket under intervjuene. BIM-verktøy og BIM-prosesser har i mange tilfeller kun blitt tilføyet tradisjonelle gjennomføringsmetoder og kontraktstrategier. Tilfredsstillende detaljeringsnivåer for BIM-modellene og tiltenkt bruk av modellene er sjelden spesifisert i kontraktene. Informantene ønsker å se regjeringen, buildingSMART eller Standard Norge tre inn for å utnevne standard BIM-programmer og informasjonsutvekslingssystemer, og for å etablere standarder for hvordan BIM bør implementeres og hvordan BIM bør inkluderes i prosjektkontrakter.

Et av intervjuspørsmålene omhandlet det å kombinere BIM, budsjettplanlegging og budsjettoppfølging. Ingen av informantene var i stand til å gi godt begrunnede svar, da ingen av dem så langt har klart å kombinere disse med suksess.

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ABBREVIATIONS AND TERMS

English Term	Explanation	Norwegian Term
2D Drawings	Shop drawings, working drawings, paper drawings	Arbeidstegninger
Autodesk Navisworks	A 3D design review package for Microsoft Windows	Autodesk Navisworks
Autodesk Revit	Modeling software program	Autodesk Revit
BIM	Building Information Modeling or Building Information Model	Bygningsinformasjonsmodellering
BIM kiosk	A ruggedized computer system built for the construction personnel on site	BIM kiosk
Change Order	Changes in the scope of work agreed to by the owner, contractor and architect/engineer	Endringsmelding
Construction Manager	A building technology expert consultant for the builder/client	Byggeleder
Construction Scheduler	A person engaged by the builder as a resource for the contractor that prepares the construction schedule	Fremdriftsplanlegger
Construction Site Manager	Responsible for planning, coordinating, and controlling a project throughout the construction phase	Anleggsleder
Consulting Engineer	Persons responsible for pure consulting, design and engineering, and preparation of tender documentation	Rådgivende ingeniør (RIB/RIV/RIE/RIG)
Contractor	Performs construction work for a client within the agreed cost and time frames	Total-, hoved- og generalentreprenør
Crew supervisor	Leader of a small work team	Bas
Engineering Group Coordinator	The engineering group's daily representative toward the client	Prosjekteringsgruppekoordinator (PGK)
Engineering Manager	The engineers' administrative manager	Prosjekteringsleder
Foremen	Leader of a group of construction crews	Formann
Graphisoft ArchiCAD	Modeling software program	Graphisoft ArchiCAD
ICE meetings	A work methodology based on the parallelization of tasks	Samlokalisert arbeidsmøte
Industry Foundation Classes (IFC)	A format for the exchange of BIM	IFC
ISY G-prog	Software for construction project descriptions	ISY G-prog
LKE	Larvik city council, real estate division	Larvik Kommune Eiendom

Microsoft Project	Project management software used to organize activities and resources	Microsoft Project
Oracle Primavera P6	Project management software used to organize activities and resources	Oracle Primavera P6
PMF	Project Mesterfjellet	Prosjekt Mesterfjellet skole
PNN	Project New National Museum	Prosjekt Nytt Nasjonalmuseum
Project Manager	Person performing the ongoing daily management of a project on behalf of the project owner	Prosjektleder
Property Developer	A contractor responsible for both engineering and construction execution	Totalentreprenør
Request For Information (RFI)	Used to gather information to help make a decision on what steps to take next	Informasjonsforespørsel
Solibri Model Checker	Free software for viewing Solibri Model Checker files and standard IFC files	Solibri Model Checker
Solibri Model Viewer	The Quality Assurance solution for BIM validation and analysis	Solibri Model Viewer
Subcontractor	A company hired by the general contractor to perform a specific task as part of the overall project	Underentreprenør (UE)

1 INTRODUCTION

Chapter 1 Introduction gives an introduction to this report's topic and purpose. It gives insight to the motivation for the research, and an introduction of the collaboration partner. The presentation of the research questions is followed by the demarcations. A brief introduction of the case projects is provided, and the last subchapter explains this report's structure.

1.1 Motivation for Research

The construction industry includes construction, renovation, repair, maintenance, demolition and completion of buildings and construction work. The industry is called the Architecture, Engineering and Construction industry and will therefore be denoted the AEC industry in this master thesis. The AEC industry is the largest industry in Norway in terms of the number of companies connected to the industry.

Thirty-three percent of all businesses in Norway are AEC businesses (Regjeringa, 2012), as these businesses range from tile vendors to contractors. The AEC industry is also the second largest industry in terms of value added and in number of employment, and the industry has had a strong growth since the early 2000s. Construction projects have evolved to become larger in size and more complex parallel to this growth. The government has imposed stringent environment restrictions and construction requirements, and project complexity has increased in the sense of complex building elements as well as complex project organizations. Traditional 2D based project methods have as a result proven less and less suitable. The AEC industry also encounters great challenges in environmental context. It is called the 40 %-industry because it accounts for 40 % of energy usage, 40 % of material consumption, 40 % of greenhouse gases production, and 40 % of waste disposal (Miljødepartementet, 2000). The design, the construction and the maintenance of buildings must be carried out in a leaner way, and communication, information sharing and project management need to be more efficient.

BIM is a visualization tool and a management process. A Building Information Model is an intelligent, digital 3D model of the project, capable of containing building component information. A Building Information Model is a database that provides digital information about the design fabrication, construction, project management, logistics, and the building's material and energy consumption. Building Information Modeling is utilizing this model to communicate and manage the project through, and with the help of, the model. Building Information Modeling involves information sharing, taking advantage of its interoperability, and analyzing the project's buildability and constructability in early project phases. Such a model can support processes like project management, cost management, construction management, and facility operation management.

The concept of BIM was first published decades ago (Eastman et al., 2011), and several software programs and BIM applications have been developed since. Despite the decent quality of today's BIM applications, the AEC industry is an industry reluctant to drastic change, and to implement BIM. Increased use of BIM has been most noticeable from 2000 until today in Norway, but the usage and the achieved utility value vary greatly, partly depending on the size of the company. BIM is most commonly used in the initial phases of a project for designing and planning, and the Building Information Model is handed over to the project owner by project completion. BIM is however, only modestly utilized during the actual construction, creating a black hole in the project's implementation process. Many BIM project participants go back to traditional 2D methods during the execution of the construction phase. This can cause duplication of work, which can reduce the potential time and cost benefits BIM offers. Why is it that project organizations choose to go back to traditional methods in the construction phase of so-called BIM projects? Is it true that the benefits of implementing BIM in the construction phase does not make up for the efforts it requires? What actions are necessary to make the implementation worth the costs, time and efforts? This master thesis attempts to convince the AEC industry that utilizing BIM in all project phases can contribute to optimize planning, communication and analyzing in ways that exceed the abilities of traditional methods.

1.2 Collaboration Partner

The researcher partnered with Rambøll Norge AS for the master thesis. Rambøll Norge AS is a consultancy company within construction and architecture, engineering, transport, energy and environment in northern Europe, and is very familiar with using BIM. Rambøll Norge AS is currently using various BIM applications in the initial and closing project phases. Rambøll Norge AS has so far not fully implemented BIM in the construction phase of their projects, but has expressed that they want to change this. This desire was the triggering factor for this research work. A pilot study was conducted by the researcher fall 2014 (Hellum, 2014). Knowledge gained during the pilot study helped shape the research topic and the research questions for this master thesis.

1.3 Purpose

This master thesis deals with the above-mentioned black hole by finding arguments in favor of utilizing BIM in all project phases. Currently experienced benefits and challenges of using BIM in all project phases must be identified as well as actions necessary to increase the benefits and reduce the challenges. The main purpose of this research is therefore to answer the following research questions:

- *What are the benefits and challenges with using BIM in the construction phase?*
- *What actions are necessary to increase the utility value of BIM in all project phases?*
- *Who should be responsible for implementing the actions?*

To find the true benefits and challenges, both potential and actual benefits and challenges must be reviewed, included and evaluated. A person's role, position and education are considered influential factors to a person's opinion and perception. The BIM world includes many different parties: Software producers and developers, partly impartial researcher, current users, and potential users that are not yet convinced. It is to be expected that these parties' perceived benefits and challenges might differ from another.

1.4 Demarcations

This research will neither focus on the benefits and challenges of using BIM in the initial phases nor in the operating phases. Most current users are already using BIM applications in these phases, suggesting that they are confident that the benefits exceed the challenges and disadvantages for such work. The transition from the design phase to the construction phase as well as the transition from the construction phase to the operation phase will however be of some interest. Including these transitional phases will help the researcher and readers gain a more comprehensive overview and understanding.

1.5 Reasons for choosing Case Projects

The purpose of this research is to identify the challenges that exist and that prevent people from utilizing BIM in the construction phase. The intention is to find actions that are important and necessary in order to reduce the challenges or to increase the benefits. It is considered essential that potential interviewees have experience with BIM. The researcher was granted access to two case projects to establish contact with their project participants, and to find potential interviewees. Case Project 1, the New National Museum project, has a goal to become a reference project in BIM. BIM was in case project 2, Mesterfjellet skole in Larvik, used for coordination, collision control and production planning, and had intention of being use for the owner's future operation and maintenance. Detailed information about the case projects and their BIM goals can be reviewed in Appendix B and C.

1.6 Report Structure

The purpose of and the motivation for this research are defined and explained in Chapter 1 Introduction along with its demarcations. The research questions are answered based on theory and recent research. The theoretical part of the report is given in Chapter 2 Theory, which reviews the definition of a project and of project success, explains a typical project model and project organization, explains the scope of construction site management, and discloses researched and documented benefits and challenges of BIM, as well as BIM actions. The research methods used to answer the research questions are described in Chapter 3 Methodology. The empirical part of the report involves semi-structured interviews of project participants from two case studies. The case study projects were assigned to the researcher to establish contact with potential interviewees with previous experience with BIM. The purpose of the interviews was to uncover benefits and challenges with using BIM in the construction phase, as well as necessary actions and parties responsible for their implementation. Chapter 4 Results and Discussion constitutes the analytical part of this report. The conclusion and a brief discussion of possible future work are given in Chapter 5 Conclusion. An illustration of the report structure is given in Figure 1.

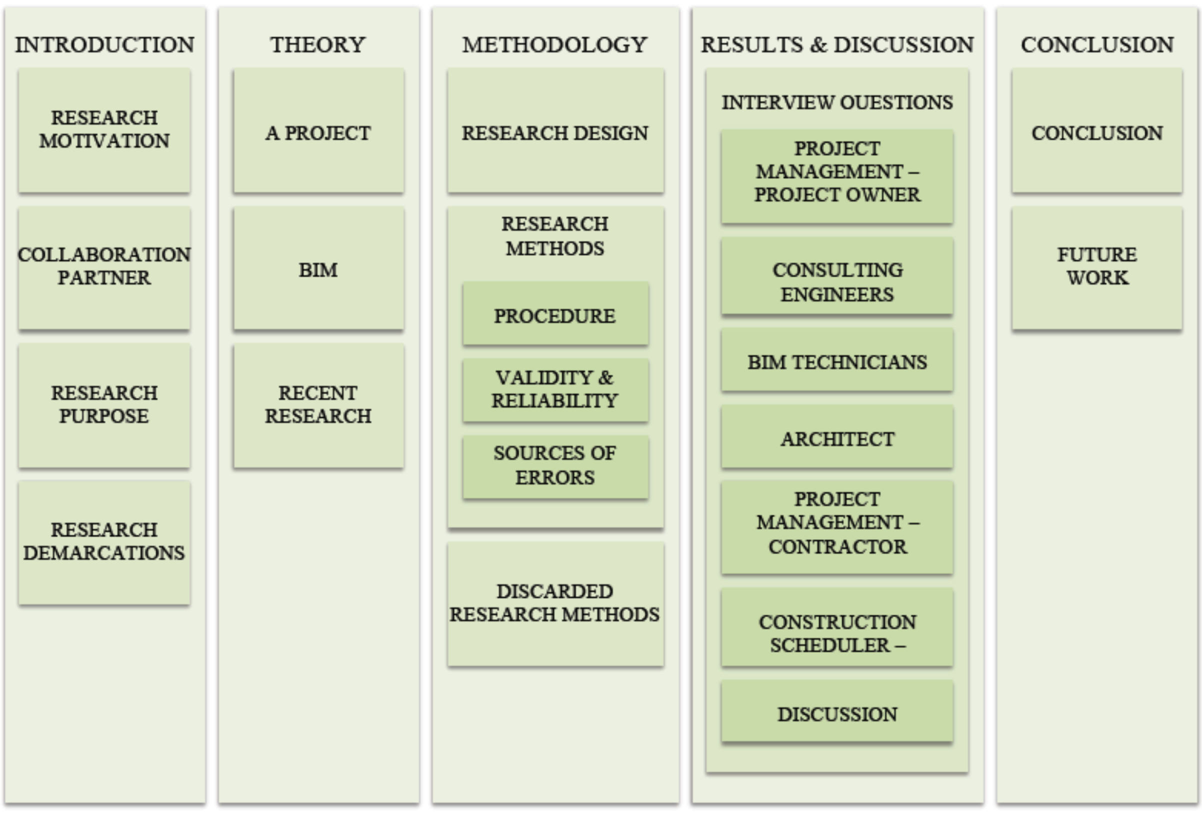


Figure 1 Report Structure Illustration

2 THEORY

Chapter 2 Theory gives the reader a review of the theoretical framework for this research. It includes all relevant theory encountered through the literature search, and the theory needed to understand the processes, the roles and the responsibilities involved in the implementation of BIM.

2.1 A Project

A project is a temporary endeavor undertaken to create a unique product, service, or result (PMI, 2004). A project has a limited duration and is the sum of a unique product, the project organization and the construction processes necessary to achieve completion. The project has an organizational structure designed to handle a situation of great uncertainty (Samset, 2008). A project is a complex, customer-focused, one-time process developed to resolve a clear goal or a set of goals (Pinto, 2013). A project either starts with a problem that must be solved or prevented, or with a desire to seize a present or future opportunity. This problem or this opportunity is usually the triggering factor for the client's wish to implement a project. The client then prepares a project mandate, a document describing the importance of the project to the client. This mandate shall include at least three items: A Mission Statement, the project's Effect Oriented Goals, and guidelines. The Mission Statement is a statement that describes what the project results will be used. The Effect Oriented Goals are gains the client wants to achieve by implementing the project. These may be the client's own gains, but can also be gains for users of the project product, for the executing organization, and for the society. The guidelines include the stakeholders and their expectations, and the project's success criteria. Success criteria are measurable indicators that can be measured during the project implementation and/or at a later time (Hussein, 2012a). The project initiation process is illustrated in Figure 2.

Figure 2 The Project Initiation Process

The project organization is responsible for arranging for project success. The organization prepares a project definition, which shall include at least three items: Performance Measures, a concretization of the success criteria, and the project success factors. The Performance Measures are specific results to be delivered in the project. Stating what criteria should be measured, when it should be measured, and how it should be measured is included in the concretization of the success criteria. Success factors are factors that must be present during the implementation of the project, in order for the project to be a success (Hussein, 2012c).

2.2 Project Success

All stakeholders and project participants seek success in a project. "The [project] challenges are great, but so are the rewards of success", (Pinto, 2013). The schedule and the milestones, the budget, and the resources limit a project and its success. The center of Figure 3 has traditionally been considered to represent the situation in which success is achieved.

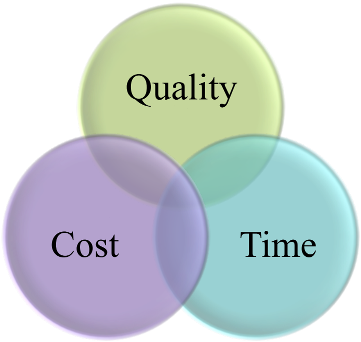


Figure 3 Traditional Success Criteria

Time symbolizes the fact that projects are constrained by a specific time frame in which they must be completed. The entire project can be broken down into deliverables and work packages. Doing so as early as possible can help project participants understand the content of the project, and reduce the amount of adjustments and changes. Work Breakdown Structure (WBS) is according to PMI "a deliverable-oriented grouping of project elements which organizes and defines the total scope of the project. Each descending level represents an increasingly detailed definition of a project component. Project components may be products or services", (PMI, 2004). An illustration is shown in Figure 4.

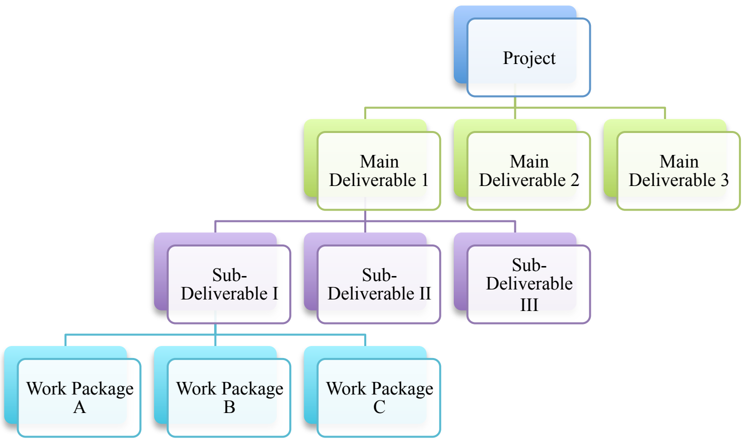


Figure 4 Work Breakdown Structure Illustration

The WBS tool helps visualize the scope of the project, and can help the project team see the weakest link in the project (Hussein, 2012b). A project schedule may be prepared by determining the work packages' execution sequence. The schedule can later be used for monitoring to make sure that the project is completed within the agreed project duration.

Cost in Figure 3 symbolizes the fact that all projects are constrained by their budget. Each item listed in the project schedule has a cost aligned to it. The cost includes materials, manpower, work, and time required to complete each work package. *Quality* refers to the quality of the materials used to build project components, and the quality of technical specifications with the final product, which are essential in order to meet the client's needs, goals and expectations. A delay, excess in resource usage, or deviations in terms of quality effect both the budget and the schedule. Focusing more on one of the three aspects creates imbalance and can cause the project to be considered a failed project.

Figure 5 introduces a fairly new, fourth success criteria: *User benefit*. The supereminent objective of all projects is to satisfy the client's needs within the constraints of cost, schedule, and quality objectives. All projects are initiated because a need has been discovered or because an opportunity has arisen. Client acceptance of the final product is the key variable, as it clarifies if the project fulfilled its intended purpose (Pinto, 2013). The new definition of project success is represented in the center of the Figure 5, and is the definition considered prevailing in this master thesis.

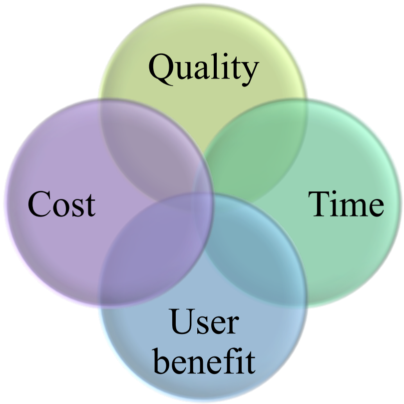


Figure 5 The Fourth Success Criterion

A functional collaboration between the different disciplines is necessary for successful implementation of BIM projects. Success is true when the project product is handed over to the project owner, and the product is conducive to the users' own production and profitability.

2.3 Project Phases

Even though projects are referred to as unique, most construction projects follow the same general project model and go through the same stages of the project life cycle. A project can be broken down into the general phases and sub phases shown in Figure 6. The size of the shapes in Figure 6 does not correspond to the duration of each phase or sub phase, and the illustration does not represent the only way to break down a project.

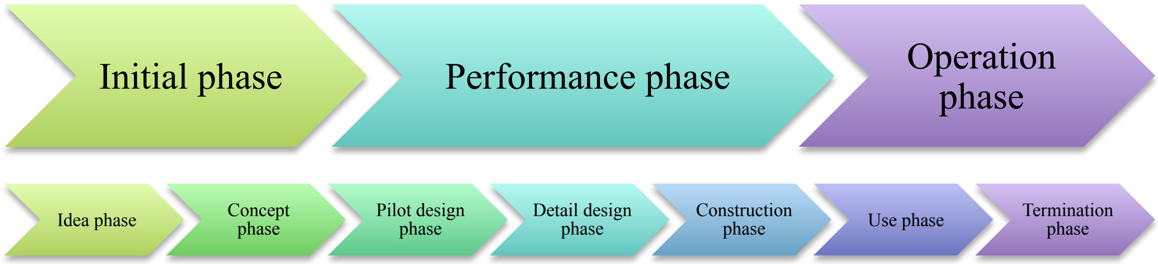


Figure 6 A Project's Main Phases and Sub Phases

The *Initial phase* is composed of the sub phases *Idea phase* and *Concept phase*, and is when the triggering need is identified, ideas are reviewed, and the study work starts. The *Pilot design phase*, *Detail design phase* and *Construction phase* together form the *Performance phase*. The Performance phase starts with a project concept, a pilot project and feasibility analyses. Once a concept is chosen, the process continues with general design and planning before the detailed engineering is conducted. Once all contracting roles are awarded, the implementation of the execution of construction and installation starts. The *Operation phase* constitutes of the *Use phase* and the *Termination phase*, and hence includes the rest of the building's life cycle after project completion. The project life cycle and the Operation phase end with the demolition of the building. This research focused primarily on the construction phase. All preceding phases have in this report been denoted as the design phases or the initial phases.

Rambøll Norge AS has developed a template to answer the growing demands for flexible, sustainable and cost effective solutions in increasingly complex projects called Ramboll Project Management (RPM). An illustration of RPM is shown in Figure 7.

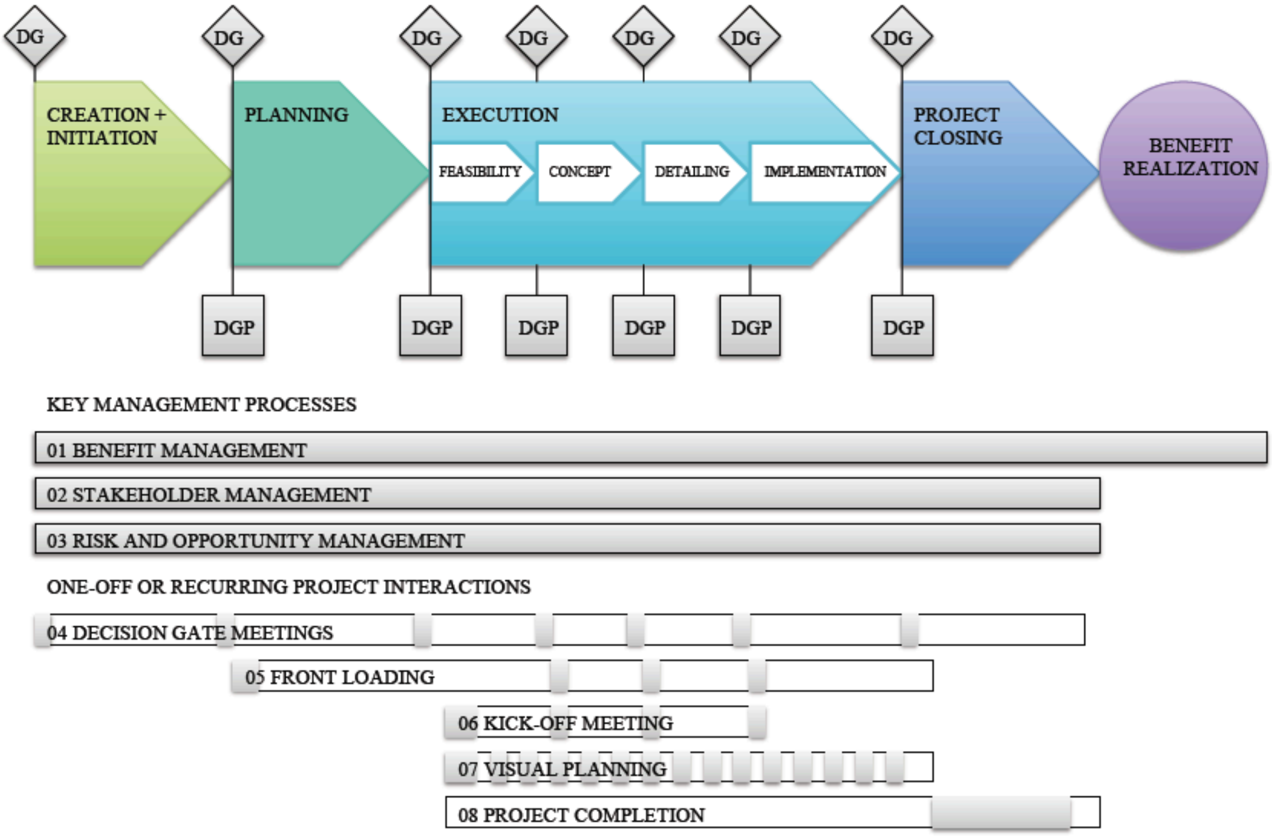


Figure 7 The Ramboll Project Management Model and 8 Tools

RPM includes a stage model covering all project phases, and eight practical tools that are based on internationally recognized standards and best practices developed by Ramboll experts. This approach has been design to maximize performance and customer benefits whilst providing a clear guideline throughout the project.

2.4 The Construction Phase

The construction phase comprises contracting, construction, and completion, and is the phase of focus in this thesis. The construction phase includes the actual manufacture of components and the actual construction of buildings or plants. Preparatory production planning must be conducted before the construction execution can begin. This includes selecting operation systems and methods for actual construction, as well as organizing and rigging of the construction site (Torp, 2010).

2.5 Project Organization

There are always at least two parties involved in a project: The project owner and the project organization. Project organizations are unique, put together and tailored for each project, and have a shared goal. Each project is a self-contained business unit with a dedicated project team. The project manager has sole control over the resources the business unit uses. An organizational structure designates formal reporting relationships, including the number of levels in the hierarchy and the span of control of managers and supervisors. It includes the design of systems to ensure effective communication, coordination, and integration of efforts across departments (Pinto, 2013). Project participants have traditionally focused strongly on the isolated project. That narrow focus and the short term interaction between loosely coupled partners in the supply chain lead to poor incentives for development of practices, methods and design that can be reused between disciplines, partners and projects (Jensen et al., 2013).

2.6 Construction Site Management

A construction site manager's most important tasks are planning and preparing the schedule. Planning is related to the work scope, sequences, requirements, and resources associated with each work package. Scheduling is related to the priority and timing of work (Moore, 2007). Activity durations are usually determined based on empirical data, and the schedule serves as a guidance document. It must therefore incorporate any limitations that may arise during the construction process. The schedule must be monitored throughout the execution, and updated in case of any schedule deviations or change orders. This applies to both permanent building components, and to temporary installations and preparatory work.

Planning the budget, and monitoring and updating accrued costs are very important tasks for construction site management. The project budget is closely linked to the schedule, and made up of project activities and their allocated resources, like manpower and materials. An accompanying cash flow projection is created through budget planning. The cash flow indicates when movement of money into or out of the project should occur in order for the project to be most financially beneficial. A negative cash flow, i.e. that the expenditures exceed the revenues, forces the project to borrow money to cover the shortage in funds, which is uneconomical (Hinze, 2012).

Planning, monitoring, and updating the schedule and the budget are definitely the most important construction site management tasks, but both are dependent on, and influenced by, a number of moderate sized tasks, as illustrated in Figure 8.

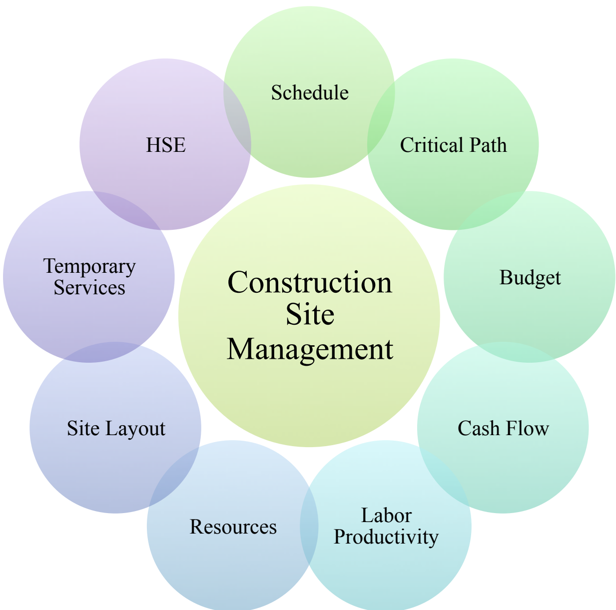


Figure 8 Construction Site Management Tasks

A huge share of construction costs is made up of labor costs, which is determined by the work hours and the applicable wage rates (Clark et al., 1996). This means that both the costs of labor, the project budget, and the associated schedule are affected by the attained labor productivity. Labor productivity can be defined as output over labor employed (Jonsson, 1996):

$$Labor\ Productivity\ =\ \frac{Output}{Labor\ Employed}$$

Estimating or predicting labor productivity, and tracking labor productivity are tasks that can have a huge influence on the budget, and in the end, on whether a project is successful or not.

2.7 Contract Strategy

A simple definition of contract strategy for construction projects is that it consists of contracting, contract structure and compensation terms (Lædre, 2010, Lædre, 2009), which is illustrated in Figure 9.

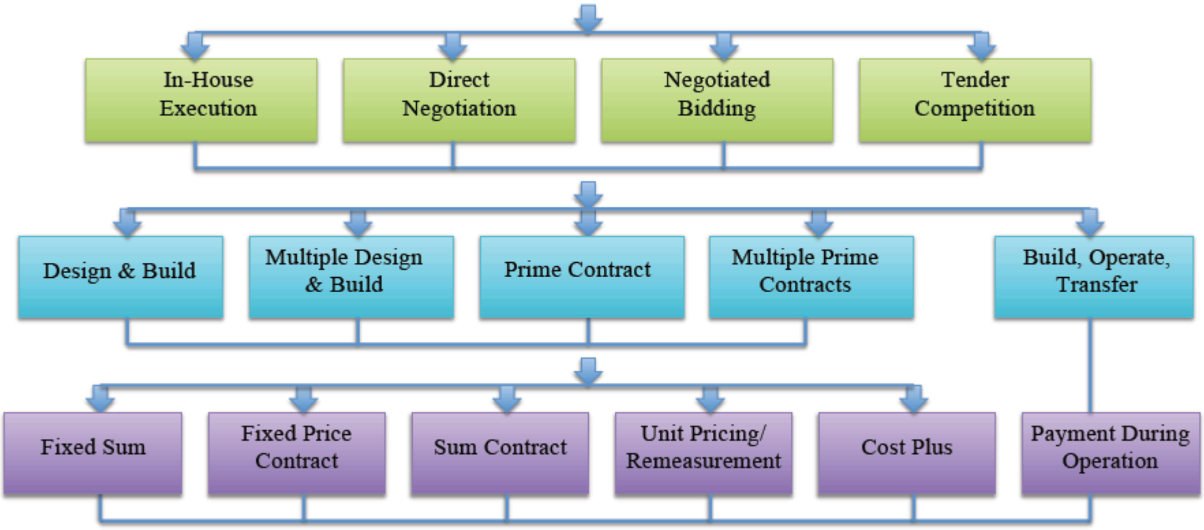


Figure 9 Contract Strategy

Contracting

Contracting means to enter into contract, and describes different ways to arrive at a contract between the parties. The builder or the client is the one who contracts the contractor. Contracting is usually divided into four forms in the Norwegian AEC industry, as illustrated in Figure 10.

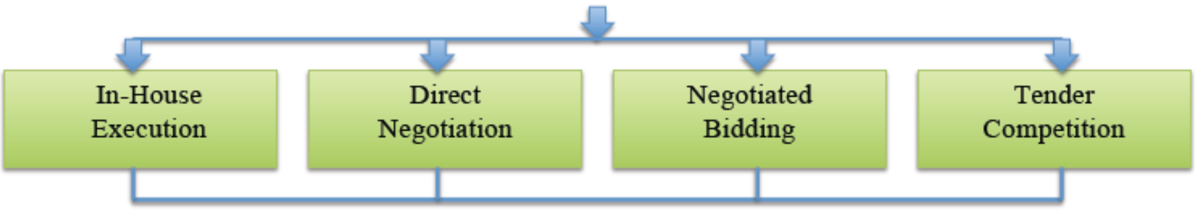


Figure 10 Contracting

- In-house Execution: Contracting method where builders choose to do the work themselves.
- Direct Negotiation: Contracting method where builders only ask for an offer from one selected contractor, or contracts one contractor directly without a prior offer.
- Negotiated Bidding: Contracting method where builders ask for offers from several contractors. The builder goes into negotiation with contractors who have given the best offers. Contractors often change their original offer during negotiations. The builder contracts the contractor with the best offer after negotiations.

- Tender Competition: Contracting method where builders ask for offers from several contractors. The builder contracts the contractor with the best offer, and is not allowed to negotiate before the contract is signed.

Contract structure

The contract structure allocates liability in the construction phase. The five common structures are shown in Figure 11.

Figure 11 Contract Structure

- Design & Build: The builder has a contract with one contractor who is responsible for both design and construction.
- Multiple Design & Build: The builder has a contract with a general contractor who is responsible for construction. The builder has separate contracts with designers.
- Prime Contract: The builder has contracts with one prime contractor and several side contractors. The builder has separate contracts with designers.
- Multiple Prime Contracts: The builder has contracted several contractors separately responsible for construction. The builder has separate contracts with designers.
- Build, Operate, Transfer (BOT): This is a collaboration contract between the public and private sector. The private sector takes a larger share of the responsibility related to the development and/or operation of the project.

Compensation terms

Compensation terms are settlement forms, and describe how the builder will pay for the contractors' performances. Compensation terms are shown in Figure 12.

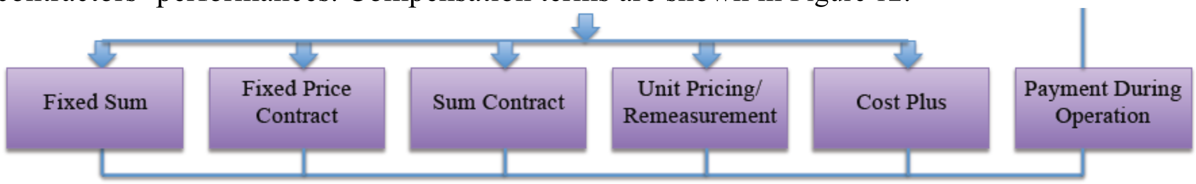


Figure 12 Compensation Terms

- Fixed Sum: The contract is neither adjustable for changes in quantities nor changes in prices.
- Fixed Price Contract: The contract is only adjustable for changes in quantities, not for changes in prices.
- Sum Contract: The contract is adjustable for both prices and quantities. The contract includes estimated quantities, which are measured afterwards.
- Unit Pricing/Remeasurements: The contract contains prices only. Quantities are measured afterwards.
- Cost Plus: The contractor will be reimbursed for all costs, plus a mark-up.
- Payment During Operation: The contractor won't be paid as work performed, but will receive payment during the operating period, over a specific time period.

Contract Strategy for the Design Phase
The builder or the client also needs a contract strategy for the design phase. This contract strategy has the same contracting and compensation terms as described above, but the contract structure is replaced with the design contracts illustrated in Figure 13.

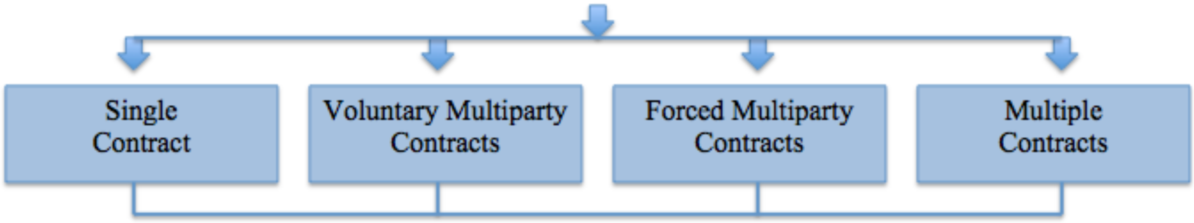


Figure 13 Design Contracts

- Single Contract: The builder has just one design and engineering contract. The project designers can contract several sub designers.
- Voluntary Multiparty Contracts: Several engineers form a group together voluntarily. The group gives a collective offer to the builder, who then signed a joint contract with the group. The group members are collectively liable for each other's deliveries.
- Forced Multiparty Contracts: The builder chooses the members in a group separately, and contracts them collectively. The group members are collectively liable for each other's deliveries.
- Multiple Contracts: The builder signs contracts with several designing engineers.

2.8 What BIM Is and Does

The acronym BIM has two meanings: Building Information Model and Building Information Modeling. A Building Information Model can be defined as "a digital representation of physical and functional characteristics of a facility that serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward" (Vandezande et al., 2011). Necessary discipline information can be inserted and extracted from a single 3D model. A BIM model is composed of a compilation of intelligent components that possess physical attributes and functional behaviors familiar in AEC. Building Information Modeling is the verb-part of the acronym and are the processes involving the generation and management of Building Information Models.

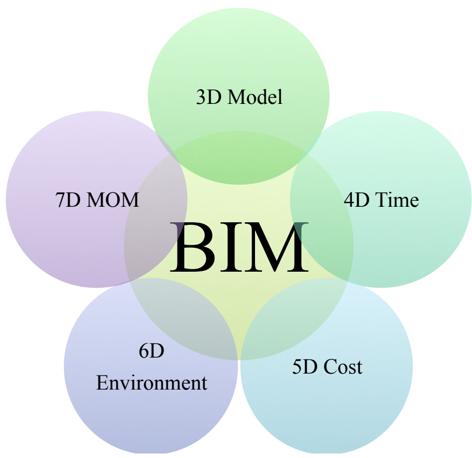


Figure 14 The Seven BIM Dimensions

Figure 14 illustrates that BIM has great potential in more than the three dimensions forming the digital 3D model. The 3D model provides for model walkthroughs, collision detection, project visualization, virtual mock-up models, and prefabrication. The fourth dimension is time, and the ability to plan, schedule, monitor, and manage a project. A 4D model provides for construction planning and management, and schedule visualization. The fifth dimension is cost, and the ability to extract quantities, generate complete lists of orders, and use for budgeting purposes. A 5D model provides for quantity take-outs, 'real-time' cost estimation, and whole-life cost and life-cycle cost. Together, 4D BIM and 5D BIM make it possible to simulate the project process in its entirety, and prepare the project's financial s-curve and the appropriate cash flow at an earlier stage than traditionally. A sixth dimension addresses the environmental strain, and involves energy calculations and analyses. The 6D model provides for improved space management, streamlined maintenance, efficient use of energy, economical renovations, and life-cycle management. The seventh dimension is intended for facility management, operation and maintenance. A 7D model provides for energy analysis and evaluation, and life-cycle analysis (Barnes and Davies, 2014). Some might argue that the sixth dimension includes both environmental management, and facility management, operation and maintenance. The user benefit of BIM dimensions beyond the digital 3D model is for the time being limited, as clients and AEC industry participants fail to see their potential utility value.

2.9 BIM Benefits

BIM facilitates leaner construction processes that can result in a greater degrees of utilization of prefabrication, reduced inventories of engineered-to-order components, improved workflow stability, and enhanced teamwork (Alarcón et al., 2013). Prior research states and concludes that using BIM in the construction phase has, but is not limited to, these benefits:

3D Model: The ultimate goals of BIM are to increase efficiency in terms of time, costs, accuracy and thoroughness, to increase communication, and to increase collaboration (Hardin, 2009). An accurate representation of a finished project product can be visualized at an early stage in intelligent Building Information Models. Communication of design and engineering solutions between stakeholders in the project is less complicated and more effective. Models and their integrated information are always updated, and BIM allows for real-time design adjustments and development. This generally improves communication and helps disciplines work together toward a common goal (Hattab and Hamzeh, 2013). The model's interoperability and the digital information sharing eliminate many possible communication errors. Digital Requests For Information (RFI) can be produced through BIM, and the installation of fabricated components is visible in the model (Hardin, 2009). Rework and downtime on site is reduced due to the fact that all discipline models are integrated into one central multidisciplinary model. This gives project participants the ability to assess the impact of changes on the overall design more realistically and in real time (Hattab and Hamzeh, 2013). Client involvement and client satisfaction are increased when using BIM. The client's involvement throughout a BIM project will translate the client's value preposition properly (Hattab and Hamzeh, 2013). And in the future, the 3D model can be made into a physical manifestation by using 3D printers (Vandezande et al., 2011).

4D Time: Adding one dimension opens for the ability to schedule systems, materials and quantities through 4D visualization. Multiple sequencing and scheduling alternatives can be tested and evaluated for cost and/or feasibility through this application (Harris and Alves, 2013). Using annotation on 4D BIM models can help explain prospective construction problems, making the model supportive to decision making. Trade coordination involves working and communicating with contractors and subcontractors, crew supervisors, supplier and fabricators, which becomes more demanding as the project size and complexity increases. Trade coordination is one of the areas where BIM really shines (Hardin, 2009). The project's constructability is ensured through analytical features such as collision control. The value of BIM as a multiple trade coordination tool increases every time collisions are found, tracked, and resolved before a project reaches the construction phase. The collision detection resolution and reporting allow construction site managers to utilize BIM as an organic means of finding issues with models provided by engineers and subcontractors (Hardin, 2009). Rafael Sacks et al. developed and tested a prototype experimental management information system comprising procedures, software and hardware designed to support lean workflow control on construction sites. The system is called 'KanBIM' and uses BIM models as foundation. KanBIM facilitates short-term work planning and monitoring by providing clear visualization of the maturity of tasks planned, and the status of current work (Sacks et al., 2013). Implementing the system pointed to positive potential effects for site personnel's ability to visualize the process itself, with reduced time wasted looking for work.

5D Cost: "The Stanford University Center for Integrated Facility Engineering revealed that using BIM yields numerous benefits, including an up to 40 % elimination of unbudgeted changes, cost-estimation accuracy within 3 %, an up to 80 % reduction in cost estimate generation time, saving up to 10 % of the contract value through clash detection, and an up to 7 % reduction in project time", (Chien et al., 2014). Planning the budget and monitoring costs accrued may be conducted more accurately with BIM.

6D Environmental Management: Analyses such as energy, lighting, solar impact, photovoltaic potential, rainwater reclamation, computational fluid dynamics simulations, and LEED documentation are different building performance analyses that can be performed on BIM models (Vandezande et al., 2011). The interoperability of the model's geometry and metadata between applications allows for such analyses.

7D Facility Management, Operation and Maintenance: A final project inspection is carried out before the handover of the completed project product to the owner (Hardin, 2009). Building Information Models can be used as punch lists for such work. A 7D Building Information Model is a facility resource with information on warranties, specifications, and maintenance schedules that can simplify the project closeout and make it a briefer process (Bryde et al., 2013).

"It should be stated that BIM in fact does *work* in the [construction] field and that it's often a misconception that although it's not completely intuitive and integrated that it doesn't function at all. There is plenty of room for improvement and smoother interoperability between field systems and tools; however, there is a great opportunity missed by contractors who choose not to utilize this technology and leverage it to some or its full extent on the construction site", (Hardin, 2009).

2.10 BIM Challenges

This is not a 'buy/don't buy'-comparison, so software license costs is not listed as a challenge, even though the software represents a considerable investment: About 1 percent of a company's size (Vandezande et al., 2011). The challenges listed here are the ones researchers have found and encountered whilst working with BIM tools and BIM processes.
What is considered an applicable challenge with BIM is AEC companies' need to invest in BIM education and training of staff (Bryde et al., 2013). Implementing BIM is not just an upgrade from traditional 2D CAD methods. A common misconception among project managers when first moving from CAD to BIM, is that staffing a project will be the same in both workflows. Staffing allocations, time needed to complete tasks, and the percentage of

work completed in each phase are all affected by the workflow changes resulted from the implementation of BIM (Vandezande et al., 2011).

The utility value of most BIM benefits is dependent on the model's level of detail. Models including non-constructible elements are presentations of inaccurate information in a highly detailed form, leading to the perception of accuracy and the incorrect detailing of adjacent assemblies, and do not bring value to the user (Spitler, 2014). Variations between modeled components and constructed building components decrease the constructability of the model, and therefore produce waste (Spitler, 2014). Deviations from the modeled components' geometry or location, and omissions, must be eliminated to increase constructability.

Previous research states that implementing BIM in the construction phase has several challenges. Some of the most common obstacles are: Cultural barriers, lack of interoperability, software and hardware issues, contractual and legal aspects, lack of training, lack of commitment, and lack of client requests (Alarcón et al., 2013). Trouble finding information sharing methods that ensure adequate sharing, and juxtaposition of efficient project teams poses significant challenges. Project participants are dependent on each other's contributions to get accurate digital models. Not modeling at the level of detail other disciplines need creates a situation where new models may be required (Eastman et al., 2011). Legal concerns are presenting challenges with regard to (1) who owns the multiple design, fabrication, analysis, and construction datasets, (2) who pays for them, and (3) who is responsible for their accuracy. The most significant change companies face when implementing BIM is the intensive usage of shared models as foundation for all work processes and collaboration during design, construction, and fabrication. The transition requires time and education, as well as significant changes in technology, technical equipment, and work processes.

The challenges with implementing BIM are relatively few, and most of them are focused on software or hardware issues. These challenges seem to relate to the change management associated with the adoption of BIM, and can be addressed through initiatives such as better training for all employees (Bryde et al., 2013). Scheduling BIM projects should be done in one single application so that the amount of parallel updates is minimal. Modeling in one application, planning in another, and creating schedules in a third application is cumbersome and difficult to manage (Hagelund, 2013).

2.11 The Ideal BIM Scenario

"In the ideal scenario, a BIM [model] simulates the life cycle of a building before implementation, and allows a building performance analysis to be carried out. As such, the efforts of individual specialists can grow to build a single pool of data, which people can work on at different levels without loss, regardless of time and location" (Hauschild and Karzel, 2011). The Norwegian AEC industry isn't there yet, partly because BIM is new technology the AEC industry has shown poor interest and commitment to implement, and partly because many BIM applications are somewhat underdeveloped. BIM can despite this have great utility value, as pointed out by Brad Hardin, and there are many benefits of using and implementing BIM.

2.12 BIM in the Construction Phase

The doubt amongst AEC industry participants that implementing BIM can be beneficial to work in design phase is diminishing. Building Information Models are designed and modeled in an increasing number of construction projects. BIM models make communication across contractual relationships more convenient, interaction more flexible, and allow for continuous information flow instead of interrupted batch flow (Hattab and Hamzeh, 2013). By project completion, the model is updated and handed over to the project owner for facility management, operation, and maintenance. BIM is however, only modestly utilized in the construction phase, even though a considerable number of AEC companies have experienced design benefit through utilizing BIM. It is a common misconception that computers are of little help on site because on-site operations are mainly physical work. Construction work requires careful planning, and skillful management of human and physical resources. Computer systems can assist construction site managers to plan ahead, evaluate different options, adopt, and execute construction operations efficiently (Sun and Howard, 2004). Traditional project management practices lack a mechanisms to manage workflow (Howell, 2003). Not utilizing BIM for planning and execution of site work creates a black hold in the implementation method of BIM projects. According to research found in the literature study, not utilizing BIM in the construction phase will imply a loss of many potential BIM benefits.

2.12.1 BIM Benefits for Construction Site Managers

A Building Information Model could ideally provide construction site managers with the following information (Eastman et al., 2011):

- Detailed building information contained in an accurate 3D model that provides graphic views of a building's components, and the ability to extract quantity and component property information.
- Reduced construction budgets and schedules as a result of better quality designs with fewer errors and of enabling greater degrees of prefabrication. A positive effect of the ability to develop design details fairly early in the process is that rework, which commonly results from unresolved details and inconsistent documentation, is mostly eliminated.
- Temporary components such as equipment and formwork can be modeled. These are critical to the sequencing and planning of a project.
- Specification information associated with each building component. Textual specification for every component the contractor must purchase or construct is linked in the model.
- Analysis data related to performance levels and project requirements such as structural loads, connection reactions, and maximum expected moments and shear, heating and cooling loads for dimensioning of HVAC systems, and targeted luminance levels.
- Design and construction status on each component to track and validate the progress of components relative to design, procurement, installation, and testing.

2.12.2 BIM Progress and Process

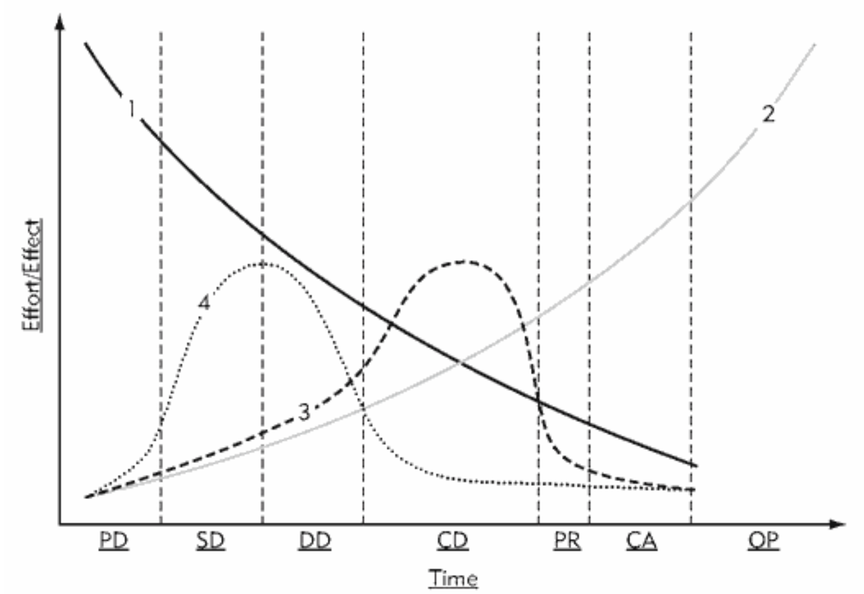
Implementing BIM is not just an upgrade from traditional 2D CAD methods. Several authors and researchers have suggested important and necessary steps that address implementation concerns. What follows below is an interlaced list of important steps for successful implementation of BIM (Eastman et al., 2011, Hardin, 2009, Kensek, 2014):

1) Motivation – A simple statement about how BIM aligns with goals of the company will help clarify what goals you are trying to achieve with BIM.
2) Identify a BIM manager – Every project is assigned a project manager. The implementation of BIM can be considered a project. A BIM manager must manage and facilitate all processes necessary to implement and manage BIM.
3) Goals – Identify goals for scope and BIM use across all project phases.
4) Plan – Develop an estimate of the cost and time investment for the initial changeover. Put together a tool, software, and hardware acquisition plan to give the management

an idea of the scale of the investment needed. Make a training plan, a hardware update schedule and a document explaining the company's shift into this new technology.

5) Prepare – Get familiar with the scope of standards or formats related to BIM and the exchange of BIM files. Get familiar with participating roles in the BIM process and interfaces between them.
6) Invest – Choose a BIM software program compatible with the staff and methods of the office, and upgrade hardware in the office. BIM files are much larger than CAD files, and require quality hardware.
7) Training – Begin with the BIM manager and a few dedicated associates. Start using the software and implementing it immediately after training on a smaller project.
8) Execute – Stick to the plan, but remain flexible as new software and other technologies become available, and other challenges arise.
9) Create resources – Develop internal tutorials and guides to create a reference and a learning point company-wide.
10) Analyze the implementation – Find out how BIM is improving or not improving processes. Measure to see what aspects of BIM are realizing the most savings and creating the most value. This gives the management an idea of where there's room for improvement.
11) Be observant – Monitor new software proposals and industry trends to stay ahead.

Implementing BIM projects requires a fundamental transformation in work processes and routines compared with traditional implementation and collaboration methods (Carlsen, 2013).



1	Ability to impact cost and functional capabilities	PD	Pre-Design
2	Cost of design changes	SD	Schematic Design
3	Traditional design process	DD	Design Development
4	Preferred design process	CD	Construction Documentation
		PR	Procurement
		CA	Construction Administration
		OP	Operation

Figure 15 The MacLeamy Curve[1]

[1] Patrick MacLeamy and The Construction User's Roundtable own the copyright to the graph, www.curt.org/. The graph was accessed and obtained from Eastman et al. *BIM Handbook*.

BIM processes pull project participants together earlier than traditionally, as all planning is to be completed before the model is analyzed and quality assured. This has a positive consequence, a gain, considering that the costs of changes increase throughout the project process. Curve number four in Figure 15 represents the design process in a BIM project.

2.12.3 Integrated Concurrent Engineering (ICE)

Integrated Concurrent Engineering (ICE) is a working methodology developed in the mid 90's. The methodology attempts to remove distractions that don't create value by allowing for clarification of common goals and methods, revealing secondary obligations, and minimizing the feedback waiting time. The idea is to gather relevant expertise and decision-makers in one common place to make it easier to manage interfaces, and to provide better flow in the process. ICE allows direct communication and more transparent flow of information between various actors. The result can be faster execution of the planning process and a better product (Østby-Deglum, 2011).

2.13 BIM Levels – Levels of Development (LOD) and Implementation Levels

2.13.1 Level of Development

The Level of Development (LOD) determines what the model should be used for, and the degree of accuracy that can be expected from analysis programs. The different levels indicate the intended use of the model in every phase of the project. There are five Levels of Development, as illustrated in Figure 16.

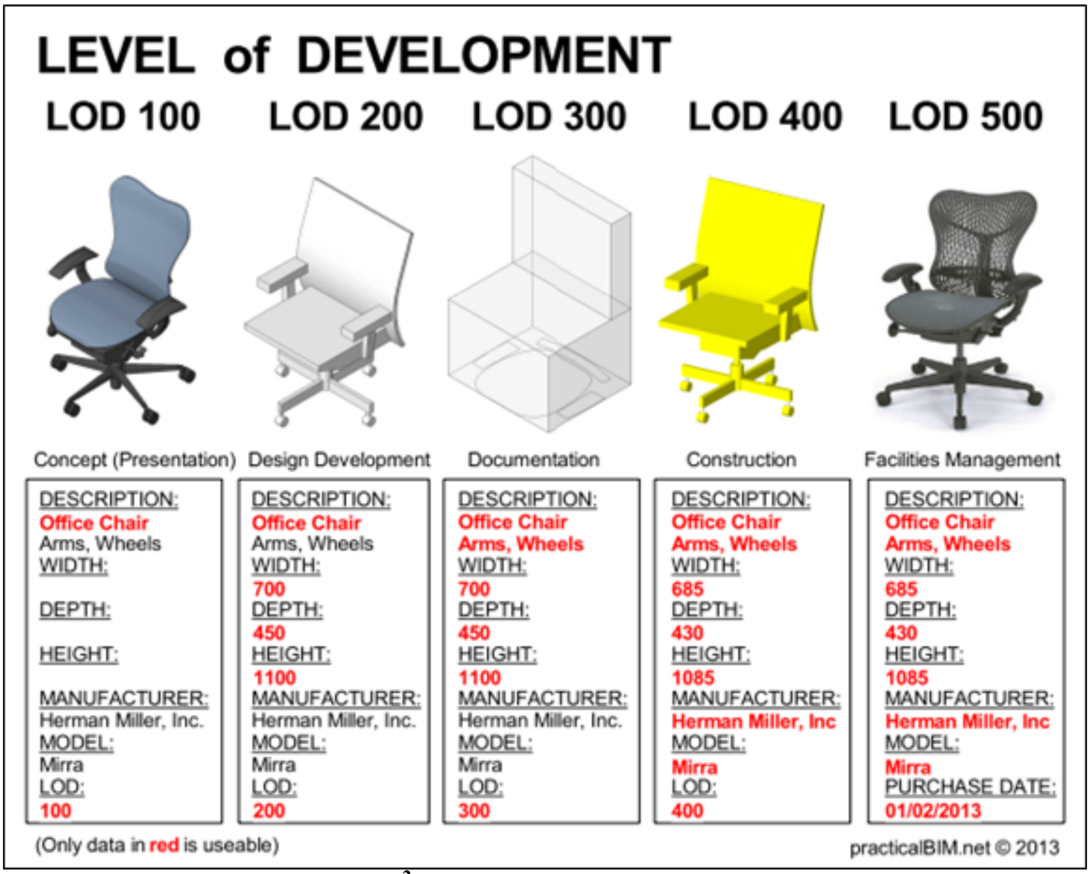


Figure 16 Level of Development[2]

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[2] Copyright belongs to practicalBIM.net, and the illustration was accessed and obtained from http://practicalbim.blogspot.com.au/2013/03/what-is-this-thing-called-lod.html

Definitions of the five levels are presented below (Kensek, 2014):

- LOD 100: Components may be represented by symbols or other generic descriptions. Only conceptual analyses can be conducted because of the type of data.
- LOD 200: The model contains model components, generalized systems, and assemblies that are approximate in quantities, size, shape, and location. Simplified estimates and schedules that show phasing of major components can be created.
- LOD 300: The model's level of development is similar to that in LOD 200, but the emphasis is on the increased accuracy. The model can at this level be used to generate construction documents, shop drawings, more detailed cost estimates, scheduling, and performance-based analyses.
- LOD 400: The model has an even higher level of complexity, with the intent to purchase, manufacture, install, and specify. Virtual components are highly detailed, and their representation is suitable for fabrication, cost estimating based on committed purchase prices, and scheduling of components including construction means and methods. LOD 400 is applicable for use by general contractors and subcontractors during construction.
- LOD 500: Components have been field verified in terms of their geometries, and records of accrued costs are available. Components may also include attributes for specifications and product data, which are useful for the operation and maintenance of the facility.

2.13.2 Level of Development vs. Level of Detail

LOD is sometimes interpreted as Level of Detail rather than Level of Development, but there are important differences. Level of Detail refers to how much detail is included in the model components. Level of Development is the degree to which the component's geometry and attached information has been thought through – the degree to which project team members may rely on the information when using the model (BIMForum, 2013).

The level of detail is affected by the size of the model, the time allotted for building it, and what critical items need to be communicated. The level of detail needed in the model may vary with its intended use. An architect may need a high level of detail to support a rendering for comparing materials and qualities. A consulting engineer may need a high level of detail in components for analysis purposes, while the contractor may elect to represent components as simple components or detailed components, dependent on the constructability complexity. One component may represent multiple activities and activity types (Eastman et al., 2011).

2.13.3 The Levels of BIM and BIM Maturity

Mervyn Richards, head of IT at T5 at Heathrow airport, and Mark Bew, former head of BIM Task Group, developed the "BIM wedge" in 2008[3]. The "2008 Bew-Richards Wedge" describes the evolution from traditional CAD to the integrated and interoperable Building Information Model. Its objective was to explain BIM maturity, to give people a sense of their BIM maturity, and to provide a strategic direction for BIM implementation development. The movement from one level to another is referred to as 'BIM maturity'. The levels of BIM are describes below (Barnes and Davies, 2014):

- Level 0 isn't really BIM at all. It relates to use of 2D CAD files for design and production information.
- Level 1 represents the first step toward genuine BIM and the use of 3D data to present design. Designers at this level usually use managed CAD in 2D or 3D format with

[3] http://www.bygg.no/article/1228053

collaborative tool providing a common data environment, where standards for data structures and formats are utilized. Finance and cost management packages are not integrated in the general BIM model.

- Level 2 is an organized 3D format held in separate BIM discipline software tools with data attached. 5D or cost driven engineering is performed using costing systems that utilize model data and is integrated with BIM via proprietary interfaces. 4D BIM is used to correlate the work schedule, and 3D models are used for manufacturing simulation.
- Level 3 will be a fully integrated and collaborative real-time project model that is likely to be facilitated through web services. This level of BIM will utilize 4D construction sequencing, 5D cost information, 6D project life-cycle information and other dimension management information, and will be driven by the development of standard libraries of object data, which will include manufacturers' information.

2.14 BIM Actions

So, what actions are necessary to reduce or eliminate currently experienced BIM challenges, and to improve the use of BIM in the construction phase? The actions discussed below are the ones uncovered and recommended during the pilot study (Hellum, 2014).

Further software development

The pilot study interviewees expressed that further software development was a necessity in order for them to be able to exploit BIM benefits beyond the intellectual 3D model. Chapter '8.5 Drivers of Change and BIM Impacts up to 2020' in *BIM Handbook* has listed aspects to which BIM looks forward to see significant enhancement (Eastman et al., 2011): (1) Improved import and export capabilities using protocols like IFC, (2) "lite" BIM tools for specific building type such as single-family residential housing, so that owners can virtually "build" the building or apartments, and transfer them to professionals for actual engineering and construction, (3) movement away from desktop applications to Internet-based applications, (4) BIM tools that support products involving complex layout and detailing, and (5) 4D scheduling software that supports simulation extensions for detailed assembly, installation, or erection procedures.

Standardization of BIM model structure

As a measure for better information to the market, Standard Norge has decided to quarterly publish a status overview online over the development of Norsk Standard (NS)[4]. The website shows the development status for each standard. 'NS 8360 BIM objekter – Navngivning og egenskaper for BIM objekter og okjektbiblioteker for byggverk' (English: 'NS 8360 BIM objects – Naming and properties for BIM objects and object libraries for building') is up for hearing. A number of key players in the buildingSMART Norway community have been campaigning for years to have this standard realized. BuildingSMART has published a document describing the standard's objective and scope[5].

The contractual specifications

BIM is a collaborative endeavor where all parties have a shared responsibility to linked project databases, and the data generated, inserted, and extracted from models. Contractual agreements between owners and design professionals, prime consultants and sub consultants,

[4] https://www.standard.no/standarder-pa-horing/arbeidsprogram-for-nasjonalt-utviklet-norsk-standard/

[5] http://www.buildingsmart.no/sites/buildingsmart.no/files/07_ns8360_20141113.pdf

and owners and contractors must address this shared responsibility in order to establish accountability. Clearly defined BIM appropriate contracts at the start of the process will enable the entire project collaborative mentality faster, and establish trusting relationships sooner. Such aspects are absolutely essential for the success of any project (Kensek, 2014). The contract agreement of any BIM project should include key issues such as BIM deliverables and ownership of deliverables, team leadership and responsibilities, processes, tools, schedules, and an Execution Plan.

Increased level of skills in the AEC industry
Training is critical, and must be done at every hierarchy level at the office and in the AEC industry chain. There are many types of training instructions (Kensek, 2014): Training guides that come with software and books, courses, online courses, seminars, customized courses with a paid consultant, user groups, and websites. Replacing traditional contract strategies and approaches may be an appropriate first step toward achieving an increased level of skills industry-wide. Integrated project delivery (IPD) is a relatively new contract strategy gaining popularity (Eastman et al., 2011). IPD offers potentially increased project value and greater rewards for participants to manage uncertainty and risk, thus eliminating the fear that causes participants to focus on their narrow self-interest (Barnes and Davies, 2014). Integrated projects are distinguished by effective collaboration among the owner, the prime and sub designers, and the prime and sub contractors. Such collaboration takes place from early design and continues through project handover. The key concept is that the project team works together using the best collaborative tools at their disposal to ensure that the project will meet the owner's requirements at significantly reduced time and cost. This way, the contractor is involved with design decisions and can contribute with construction knowledge.

Having the right attitude
Full BIM adoption requires two to three years to become effective (Eastman et al., 2011). Instant significant industry-wide productivity gains are unrealistic, but measureable reductions in construction costs can be expected. Successful early adopters in both design and construction will profit from their foresight until the rest of the industry catches up. Aslani et al. stated that if individuals among the designers or the contractors are not committed to the BIM process, those entities will either diminish the value of the collaborative product, or be unable to take advantage of the benefits it offers (Aslani et al., 2009).

2.15 Recent Research
BIM is a hot research and discussion topic at the moment. Research papers and journal articles reviewed in the literature study discussed and researched the following aspects.

2.15.1 The Prevalent Definition of BIM and the Perceived Impact on Success Measures
Zuppa et al. administrated a survey of 202 AEC professionals to gain an understanding of the prevalent definition of BIM, and to identify the perceived impact of BIM on the success measures of construction projects (Zuppa et al., 2009). The results showed that BIM was most frequently perceived as a tool for visualization and coordination of AEC work, for avoiding errors and omissions, and for improving the productivity, schedule, safety, cost, and quality of construction projects. A chi-square test showed that the perceived impact of BIM on one success measure was significantly associated with perceptions of the other success measures. The researchers concluded that recognizing the high likelihood that many AEC professionals perceive BIM to have a positive impact on construction success measures could enhance the collaboration process of stakeholders working with BIM.

The Interviewees' Definition of BIM and a BIM Project

The interviewees interviewed in this master thesis were asked to give their definition of BIM and of a BIM project. The question was asked to survey AEC industry participants' prevalent definition of BIM, to gain an understanding of their perception of BIM. The intention was also to see if they had a difference in opinion in how they define a BIM project. There is no official, unique definition of a Building Information Model, of Building Information Modeling, or of a BIM project. The interviewees' definitions are as good as any others.

Project Management – Project Owner: BIM is Building Information Modeling, where a digital 3D model is utilized for planning and designing, and as a communication tool. BIM is a visual 3D representation of the 2D drawings, and a digital compilation of all the information available about the building throughout its lifetime. A BIM project is at the moment a project where a 3D model is modeled and used actively. The model should be the basic foundation for visualization of principles, preparation of solutions, and communication with internal stakeholders and other external parties.
Consulting Engineers: BIM is digital 3D modeling in which the software libraries contain information that you can assign to building components and extract from a constantly updated model. Building Information Modeling is active use of Revit and Solibri in which disciplines work on their own model to fit into one combined multidisciplinary model. A project is a BIM project when the model is of such a high level of quality that it is considered sufficient without having to create separate 2D drawings, and the model is used in meetings.
BIM Technicians: BIM is Building Information Modeling and the process of modeling in three dimensions, adding information to building components to make buildings as collision-free as possible, as well as extracting drawings, quantities and other information throughout the project and in retrospect for all it's worth. What defines a BIM project is currently in sliding transition, but a BIM project is a project where the model is actively utilized, and not a project where 3D models are created but 2D drawings are used.
Architect: Building Information Modeling is often defined as creating a 3D model that contains more than just physical information; it contains metadata or other data about the building components and their placement. All projects today are basically BIM projects, but the question is whether one uses BIM smart or not. This depends on what the data is used for, and the level of information that is considered satisfying.
Project Management – Contractor: Building Information Modeling is about 3D design and workflow. The BIM process is implemented by designing in 2D, pulling the elements up in 3D, collecting discipline models, merging these into one multidisciplinary model, and exporting that model to an IFC file. A BIM project is a project where everyone is required to design in 3D. 4D and 5D BIM are not yet utilized, but work schedules and budget plans are closely connected to the model and to the design.
Construction Scheduler – Contractor: BIM is a 3D model of all building components, with all the information that is necessary in order to build the building. A BIM project is a project where the building is designed and modeled in 3D, and information is attached to individual building components.

The interviewees seem to have a uniform definition of BIM, but they have somewhat contradicting definitions of a BIM project. The researcher does not consider one of them more correct than the others.

2.15.2 BIM Benefits and BIM Challenges

Azhar studied and researched the current trends, benefits, possible risks, and future challenges of BIM for the AEC industry, and stated that BIM is emerging as an innovative way to virtual design and management (Azhar, 2011). Azhar claimed that the predictability of building performances and operations was greatly improved by adopting BIM, and concluded that collaboration within project teams should increase as the use of BIM accelerates. This should lead to improved profitability, reduced costs, better time management, and improved customer-client relationships. A BIM Return on Investment (ROI = earning/cost) analysis was conducted on ten projects. The average BIM ROI for projects under study was 643 %, which clearly depicts BIM's potential economic benefits. However, the researcher warned that teams implementing BIM should be very careful about legal pitfalls, which included data ownership and associated proprietary issues, and risk sharing.

An owner's willingness to pay for BIM is vital to a contractor's decision to use BIM. Giel and Issa gathered data from three case studies to show the returns on the investment (ROI) of paying additional fees (Giel and Issa, 2013), and presented the cost savings associated with implementing BIM. The potential savings were estimated based on measurable cost benefits associated with reduced schedule overruns, fewer requests for information (RFIs), and reduced change orders. The ROI of BIM in the three case studies varied from 16 to 1654 %, and the researchers claim to have confirmed that BIM is a profitable investment.

Inadequate standards pose challenges to design technologies such as BIM. The British government blames the industry's inefficiency and lack of collaboration on the low level of standardization. Maradza et al. investigated the development of standards in the USA and the UK (Maradza et al., 2013). The researchers stated that infrastructures provide systems with integrity and rigidity to span across practice boundaries, but that the development rely on trust and active cooperation between actors. They found that trust and confidence in the process were particularly lacking in both countries.

2.15.3 Successful BIM Adoption

The adoption of BIM has according to Zuppa et al. been slow due to the ambiguity concerning its definition, purpose and business value (Zuppa et al., 2009). Won et al. researched the critical success factors for four questions commonly asked by companies considering adopting BIM, by administrating an international survey (Won et al., 2013). A list of consideration factors was collected for each question, and the respondents were asked to rate the importance of each factor from 1 (very strongly disagree) to 7 (very strongly agree). Project participants' willingness to share information was considered the most critical success factor. Other important factors were: Standard work procedures and information exchange protocols, detailed BIM Execution Plan for different projects, and education to motivate senior managers and project participants to help them get accustomed to BIM.

Mayo et al. wrote that an increasing number of owners are mandating that BIM be utilized on new construction projects, but that they're often unsure of what BIM deliverables and processes to demand, and how proficient the stakeholders they choose to contract with are in using such technologies (Mayo et al., 2012). Their research aimed to assist facility owners in the adoption and mature implementation of BIM processes. They found that owner's demand specifications vary greatly in level of detail. A survey was distributed to members of the Florida Chapter of the Construction Owner's Association of America (COAA), and the twenty respondents indicated that the prime obstacles included: lack of interoperability, misunderstandings of information handover requirements, and lack of general software knowledge required to utilize BIM deliverables.

Technology is always embedded in a social context, and its successful adoption depends on that context. Dossick et al. researched how strategies, such as co-location, support stronger team orientation to projects through informal communication (Dossick et al., 2009). They were particularly interested in researching how second and third tier consultants, suppliers, and subcontractors who aren't part of the primary architect-owner-contractor agreements should be engaged. Their observations and interviews revealed that organizational and cultural barriers inhibited collaboration and communication within AEC teams, even though digital exchange was possible. They found out that the informal communication in co-located environments allowed project participants to more fully participate in the decision making process. They also found out that where BIM tools appeared to be an enabler of informal collaboration, BIM tools did not appear to be a driver for organizational change, i.e. the industry is using BIM in traditional formal ways of working as well as innovative ways of working.

Ghafar et al. researched the effects of cultural and human factors on BIM technologies in industrialized building projects (Ghafar et al., 2014). The researchers concluded that despite having competent technological support, fabrication efficiency was much affected by cultural knowledge between professionals during the design phase, which could affect production of waste. Ospina-Alvarado et al. stated that AEC + FM (facility management) integration is essential to improve the overall performance of the AEC industry, and that improving project communication and information exchange is the most important factor in order to achieve true integration (Ospina-Alvarado and Castro-Lacouture, 2010). They further claimed that BIM is able to foster integration because it, not only improves communication and information exchange, but also creates a platform that serves as a framework for collaboration. Their article also included a moderately detailed citation from Kymmell on how VICO Control technology can be used to generate and manage a BIM-based schedule (Kymmell, 2008).

Responsibility Distribution Changes in BIM Projects

This research's interviewees were asked to describe the distribution of responsibilities in today's BIM projects. The researcher wanted to find out if implementing BIM has affected the distribution of responsibilities in projects, if there are any differences between the distribution in traditional project and BIM-based projects, or if BIM has just been applied to the same organizational structure and project processes as before.

Project Management – Project Owner: The primary question is: Is the responsibility actually distributed? There are no industry standards for how responsibilities should be allocated differently in BIM projects. BIM is currently rarely included as part of the contractual documents. The designers and the consulting engineers are responsible for modeling, just as they were responsible for create 2D drawings in traditional projects. A BIM model is currently almost always modeled, but if the project isn't defines as a BIM project, the model cannot be regarded as a legal document because the model may include inaccurate information intended for visual presentation purposes only.

Consulting Engineers: The tasks and responsibilities of consulting engineers are very similar contractually, except that the amount of work has increased. One amongst the HVAC consulting engineers has taken upon the overriding responsibility for the model and it's maintenance. Not because he was assigned the BIM Coordinator role, but because he had a greater interest for BIM, and competence to lift the model to such a level that it could be utilized for better visualization. The rest of them work with modeling of technical equipment and installations.

BIM Technicians: A BIM Coordinator is appointed in larger projects, with the responsibility to technically manage the multidisciplinary model and make sure that the model structure is kept at a satisfying level. A "super user" that has slightly greater understanding for modeling is appointed in smaller projects. Each discipline should have a BIM Coordinator, not just one

for the entire project. Contract agreements in PNN claim that “a BIM model shall be delivered”, without further specifications. Contracts and descriptions are extremely important, and in many cases undervalued regarding to BIM. Statsbygg has developed a detailed BIM handbook for model structuring, but the contract agreements do not specify the satisfying level of detail, meaning a non-intelligent 3D model is considered satisfactory. The model is only modeled because it is mandated, while 2D drawings remain the legal documents.
Architect: The implementation of BIM hasn’t changed the distribution of responsibilities dramatically. Nor has it changed the way competitive biddings are conducted or the contract agreements in BIM projects. The BIM Coordinator role has been introduced, which has been assigned the responsibility is to check for collisions between discipline models and the multidisciplinary model. Many seem to think that Solibri analyses replace the need to check their own work thoroughly, which is untrue.
Project Management – Contractor: Neither the distribution of responsibilities nor the administrative organization has changed considerably. We had a Design Group in PMF including all consulting engineers, and one design manager from Buer managing the group. The design manager was a resource for me as the project manager. This organization structure gave me the opportunity to both receive and give input, without being too involved in the design, which I think was a good solution.
Construction Scheduler – Contractor: I feel that the traditional distribution is just as valid in BIM projects, even though new tasks and a need for increase BIM understanding and skills have arisen. Designing managers should probably acquire help from BIM Coordinators to assist them in designing and engineering. A BIM Coordinator should only be a resource for the Design manager, and not liable for how the project is implemented.

The interviewees' answers give reason to believe that the implementation of BIM has affected industry participants’ work culture and work to a very small degree compared with what the literature indicates is required in order for the implementation to be value-generative for users (Barnes and Davies, 2014, Eastman et al., 2011, Hardin, 2009, Kensek, 2014). This may indicate that potential BIM benefits remains unexploited, even as users become more accustomed with BIM tools and processes.

2.15.4 Bringing BIM to the Construction Site

The functions for which BIM will be the most beneficial to contractors include preparation of schedules and estimates, tracking and managing changes to the work and shop drawings, and managing site logistics and temporary structures and services, with particular attention to site safety (Aslani et al., 2009). Aslani et al. attempted to identify contractors’ requirements for the preparation of BIM models during the design phase so as to most efficiently address the concerns of designers, contractors and owners.

Wang et al. developed a conceptual framework to investigate how BIM can be extended to the site via Augmented Reality (AR) (Wang et al., 2012). AR is a live direct or indirect view of a physical, real-world environment whose elements are augmented by computer-generated sensory input. The focus of their research was the discussion on scientific and practical rationales of extending BIM onto construction sites for daily detailed activity work, and how AR could play a critical role in facilitating the effectiveness of BIM information access. The researchers proposed a work pattern based on BIM + AR, and claimed that the overall concerns of site work were more prominent to all concerned parties, and identifying and exploring alternative solutions were made easier.

Roles granted access to the BIM Model in the Construction Phase
This question was asked as part of the interviews to give the researcher an indication of how far along the BIM implementation has come on construction sites, and how well the implementation has been received and utilized on site. Answers to this question could give an indication of why BIM until now haven't been fully utilized in the construction phase. Project participants need access to the model in some form in order to be able to utilize it and experience utilization value from it.

Project Management – Project Owner: The project management, the consulting engineers and the building managers have access to the model at all times. All crew supervisors should have access to the model, especially with regard to ordering materials. It is important to distinguish between access to the actual model and access to a viewer of the model, but no one should be excluded in a BIM project. One or two BIM kiosks will be place on each floor at PNN during the construction phase. Site workers can use these to visualize engineering solutions and placement of building components, and to view 2D drawings.
Consulting Engineers: Giving model access to everyone involved during any project phases will help expand the implementation of BIM. Everyone must have access to the IFC file, but not our model files. IFC files are like PDF files: Other users can review and rotate the model, but not make changes. The project client, consulting engineers and all main contractors are granted access to the model. The main contractors will give their subcontractors access, so everyone involved in PNN will have access to the model. If the goal is 4D and 5D BIM, foremen need model access to estimate durations, budgets, and staffing. But it is at the same time important to assess who needs access. A model astray is most unfavorable, as it contains an incredible amount of information.
BIM Technicians: Every Rambøll employee has access to the PNN BIM model via a web server. The architect is granted access using a username and password. The contractors won't be granted access, but will receive updated files weekly. The craftsmen are granted access to Solibri Model Viewer files through BIM kiosks stationed at each story on site, making it possible to print out paper drawings directly from the model. Everyone involved should have access to the model, at least the IFC files.
Architect: The BIM model is in most projects available for everyone involved through a web server or a shared project space. This gives the contractor easy access to the model, but it is mostly used by site managers. Craftsmen out on site still prefer to use 2D drawings.
Project Management – Contractor: Solibri Model Viewer was downloaded on every PCs at the site office at PMF to give everyone in the administration, from project managers to crew supervisors, the opportunity to use BIM and practice. Only a few took advantage of this opportunity. The craftsmen had access via their supervisors' tablets or at the site office.
Construction Scheduler – Contractor: The construction management and the main contractors have model access. The question is what contractors want their subcontractors, foremen and crew supervisors to spend their time on, and whether they're able to use BIM. I think it is unnecessary for craftsmen to have access to the model at any given time. Crew supervisors should have access, as it is their responsibility to ensure that the execution proceeds according to the schedule, in the correct order, and that the crew has what it needs to execute the activities.

The interviewees seem to disagree on who has been granted access to BIM models in past projects, but seem to agree that every project participant should be granted access, one way or another: Model access to the project administration, consulting engineers and main contractors, access to readable, non-changeable models to contractors' contracted parties, and model review access to craftsmen and other site workers via BIM kiosks.

2.15.5 Benchmarking

Unlike evaluation, which mainly focuses on ascertaining the achievement of BIM utilization within an organization, benchmarking is more interested in comparing one organization's BIM performance to their industry peers. Du et al. proposed a cloud-based BIM performance benchmarking application (Du et al., 2014), called Building Information Modeling Cloud Score (BIMCS), which could automatically collect BIM performance data from a wide range of BIM users across the USA. The application was intended to provide an overview of the industry status quo of BIM utilization, and for development of a protocol for BIM performance on the basis of better knowledge discovery process. The researchers stated that BIMCS data would help individual companies compare and improve their performance in BIM utilization with respect to their industry competitors.

2.15.6 Lean Principles and BIM

Sacks et al. have stated the Last Planner System (LPS) and BIM together have the greatest impact on workflow when interacting positively (Sacks et al., 2010). Khan and Tzortzopoulos researched the effects of interacting LPS and BIM on workflow in two building design projects (Khan and Tzortzopoulos, 2014). The LPS WWPs (weekly work plans) provided practitioners in the two building design projects with a systematic process of production planning and control that focused on improving work flow reliability. With more predictable workflow, the two building design teams were able to make better decisions about resource allocation, scheduling, and coordination. The researchers concluded that building designers might use LPS WWPs to improve collaboration and commitment, and thus improve workflow.

3 METHODOLOGY

Chapter 3 Methodology provides a detailed description of the research methods, and their validity and reliability. The purpose of this chapter is to explain and justify the procedures utilized to answer the research questions, as well as to discuss the strengths and weaknesses of the approaches. Reflections on the choice of method are included to show the underlying considerations for the implementation of the research. How the research methods actually worked, and any sources of errors, is also discussed.

3.1 Research Methods

A method is a procedure, a means to solve problems and discover new knowledge. Any agent that serves this purpose, belong in the arsenal of methods. A method tells us something about how we should proceed to obtain, provide, or test knowledge. The reason for choosing a particular method, is that we believe it will give us good data and highlight our research question in a professionally interesting way (Dalland, 2012).

Every research method rests on assumptions about the truth, and beliefs about the world. Every method has its advantages and disadvantages, but the main question about a research method is whether it contributes to answer the research questions or not (Everett and Furseth, 2012). A major strength of case study data collection is the opportunity to use many different sources of evidence, and hence, many research methods combined (Yin, 2014) It is simultaneously important to consider the limited time available when choosing research methods.

3.1.1 Qualitative and Quantitative Methods

Theory within the field of project management is mostly qualitative, and rests a great deal on empirical knowledge and experiences. Qualitative research methods are used when researchers wish to research a smaller topic thoroughly. Many variables within a narrow field of research are studied, which gives researchers a holistic view and an outline of the topic. Qualitative methods capture opinions and experiences that can be hard to quantify or measure, and their results are most often presented in text format, as oppose to quantitative methods.

The differences between qualitative and quantitative research methods are primarily related to the use of numbers and digits (Johannessen et al., 2010), and the way one collects data, but not necessarily the way one interprets the results from the two (Dalland, 2012).

Quantitative research methods provide data in the form of measurable units. Analyses and presentations of data are illustrated visually with graphs, tables and figures. Quantitative methods are used if the researchers' intention is to focus on fewer details and variables from a vast number of research objects. A questionnaire or a survey with multiple answer options provides statistical results.

3.1.2 Inductive and Deductive Approach

The strategy in an inductive approach is to collect data without theoretical basis, and later arrive at general patterns that can be made into theories or general concepts: An approach from empiricism to theory. Conversely, the strategy in a deductive approach is to derive from the general to the specific or concrete: An approach from theory to empiricism.

This research is based on AEC industry participants' experiences with BIM in the construction phase.

3.1.3 Evaluation Criteria

Different research methods are assessed on different basis. Careful consideration of a method's validity, reliability and adequacy is always important when determining what methods to use. A brief discussion of the methods' strengths and weaknesses is also included in subchapters 3.2, 3.3 and 3.4.

3.1.4 Selected Research Methods

It was decided to carry out this research work using an inductive research approach, and qualitative research methods to collect data. An extensive literature search was conducted in order to gain understanding of theory and previous research on the topic. The literature search was an extension of the literature search conducted during the pilot study (Hellum, 2014). Knowledge gained during the pilot study had an impact on the second literature study. The pilot study gave pointers to new or deeper search areas. Empirical data was collected through twelve semi-structured open-ended interviews of experienced BIM users involved in one of the two case projects. The selected case projects are presented in Chapter 1 Introduction, and detailed information about the case projects and their BIM goals can be reviewed in Appendix B and C. A brief document study of unpublished house documents was conducted to get a better understanding of the project organizations and the planned, or actual, project implementations. Justification for choosing the chosen research methods can be found under the next three subchapters, as well as detailed information on the data collecting processes.

3.1.5 Sources of Errors

Research related to literature studies, document studies and interviews is prone to almost always have errors. Potential sources' origin must be assessed and discussed, just like how data should be collected must be assessed. The amount of data and the quality that is considered sufficient should also be assessed (Everett and Furseth, 2012). Source criticism is a collective term for methods used to distinguish verified information from speculations.

3.2 Literature Study

A literature study is done by researching and reviewing current knowledge including substantive findings, and theoretical and methodological contributions to a particular topic. The purpose of a literature study is to identify areas other researchers have overlook, which will emphasize how this research will contribute to new knowledge (Everett and Furseth, 2012).

A literature study is a necessary part of a scientific project. A literature study discloses what information is already out there, and clarifies what research is still unexplored. By accounting for literature in the field, the researcher shows that he or she is familiar with relevant and important literature on the area. A literature study also prevents one from doing unnecessary work or rework. A thorough literature study was conducted prior to writing this master thesis, and the search was conducted based on knowledge gained through the pilot study (Hellum, 2014). The purpose of the initial literature study, which was conducted during the pilot study, was to review what information about BIM was already out there, and to become aware of what research was still unexplored. The purpose of the second literature study was to find verification of the pilot study's results, conclusion and recommended actions. A second purpose was to search for new additional actions, and see if such actions would be recommended by anyone during the next round of interviews. A third purpose was to link the research to the lean construction world, and make it IGLC friendly, by using search words like 'BIM waste' and 'BIM value'. A contribution to this year's IGLC conference was initially intended to constitute a part of this thesis. This matter is further elaborated under subchapter 3.5.1.

3.2.1 Procedure

A lot of information about BIM, and its ranges, exists. Useful information about BIM for the master thesis was found in NTNU's libraries, and through online databases. Books from the libraries provided basic information on how BIM works and how it effects, or should effect, and change the culture and strategies of companies implementing BIM tool and processes. Books aren't necessarily filled with the newest or freshest updates within the field of BIM, but they contain fundamental information and knowledge, and gave the researcher a solid understanding of Building Information Modeling. Library books, and technical and scientific literature from previous university courses became the primary sources of supporting information, supporting theory, and on how to conduct a scientific research.

Online databases were used to get insight in recent research discoveries and inventions, through journal articles and conference papers. They helped shape the focus and the purpose of this master thesis by providing information about BIM's many potential future functions and research areas. Databases such as NTNU BibSys, Elsevier Journals, and Engineering Village or Compendex were the only databases utilized in the initial literature study. DiVA, American Society of Civil Engineers [ASCE] and IGLC's Conference Paper website were used for the dominate part of the second literature study. Table 1 shows the search words and search combinations that gave the most suitable, valuable and adequate hits.

Table 1 Online Databases Search Words and Search Combinations

Search words	Search combinations
BIM	BIM + Reduce Challenges
Building Information Modeling	BIM Challenges + Actions
Bygningsinformasjonsmodellering	BIM + Utility Value
Improve BIM	BIM + Reduce Waste
BIM Development	BIM + Construction Phase
Construction Phase	BIM + Legal Issues
BIM Waste	BIM + Contractual
BIM Value	BIM + Attitudes
	BIM + Willingness
	BIM + Production Phase

Published journal articles and conference papers may be considered more reliable than traditional master theses due to the fact that such publications have been carefully reviewed and revised by a panel before being published. Scientific articles and papers were utilized for four reasons: (1) To become familiar with recent research on BIM, (2) to find an incomplete and appropriate research area for the master thesis, (3) to use the publications' contents as theoretical framework, and (4) to use the publications' references to find additional literature.

3.2.2 Validity and Reliability

Literature is commonly evaluated based on its validity, reliability, objectivity, accuracy, and adequacy. The literature study's validity and reliability, and the literature's reliability, and relevance to the research problems were considered most important in the selection process.

The researcher attempted to ensure the research method's validity by reviewing and utilizing articles with various focus areas within BIM, which together provided a fairly comprehensive outline of BIM. The literature search should however not be regarded as complete, considering the limited time available for this research work. Most of the literature selected deals with BIM in the construction phase. Some literature about use of BIM in earlier or later phases was however included to outline possible assumptions and other factors that must be taken into consideration when implementing BIM in the construction phase. Only literature relevant to the research problem was used as theoretical framework in Chapter 2 Theory.

BIM is not as new a technology as one may think, so there is a lot of information available about it. The concept of BIM was first published decades ago (Eastman et al., 2011), and a variety of BIM tool, BIM applications, and other applications able to communicate with BIM applications, have been developed since early 2000. The reliability and objectivity of research on and information about BIM varies greatly, partly depending on who has ownership over that information. The data's reliability was primarily evaluated based on the authors' reputation in the context of research, the authors' objectivity and whether the content matches independent research.

The dominant weakness associated with this literature study was the limited time available. The search was fairly quick but the review was very time consuming. A literature study's strength is the literature's availability for later review. What the researcher perceived as a benefit can simultaneously be considered a challenge: The number of articles, journals and books about BIM can be overwhelming.
A smaller number of the reviewed articles focused on BIM in the construction phase. Misguiding titles might have caused relevant articles to be overlooked.

3.2.3 Sources of Errors

Literature from lecture notes and research reports formed important parts of this research, and their sources are traceable, but their reliability can be somewhat lower than that of scientific literature. Literature included and referenced in this report was however selected based on the authors' credibility and objectivity, and the publication firms' reputation and quality assurance.

3.3 Document Study

A document study gives insight to unpublished, house-documents. The purpose is to understand and gain knowledge of how a company has applied process theories in practice.

A brief document study was carried out in the preparation of this master thesis to get a better understanding of the project organizations in the two case projects and their planned project implementation, especially concerning BIM.

3.3.1 Procedure

A smaller number of Rambøll Norge AS's unpublished documents were reviewed and studied in the document study to ensure that this research would become useful to Rambøll Norge AS. Information about Rambøll's project management processes was requested by the researcher and provided by the researcher's external supervisor. The following documents were reviewed:

- Rambøll's Project Management documents
- Rambøll's Quality System documents
- Rambøll's Environmental Management documents
- PNN's Project Organization Charts
- Rambøll's Quality Plan in PNN
- PNN's BIM Project Execution Plan
- Selected chapters from Statsbygg's PNN Project Administrative Handbook

- Statsbygg’s Schedule Planning and Monitoring Procedure documents
- PNN’s Main Progress Schedule
- PMF’s Demand on the Property Developer
- PMF’s BIM Requirement Specification documents

Sensitive information was not reproduced in this master thesis.

3.3.2 Validity and Reliability

Rambøll Norge AS selected the documents to which the researcher was granted access, meaning that the collection of documents may be incomplete, and the researcher’s perception might have been bias as a result. The researcher had no way of verifying the documents’ validity or reliability, but the documents’ relevance was assessed to be intact.

A document study is a good source of case information in case study research. It makes the research and findings less hypothetical, and less simplified. The documents contain exact names, policies, and processes, which can be reviewed repeatedly. However, retrieving these documents can be difficult as they may be hard to find or deliberately withheld (Yin, 2014).

The research method had little relevance to the research questions, but made it possible for the researcher to identify links between the theoretical framework and Rambøll Norge AS's project processes.

3.3.3 Sources of Errors

BIM is still fairly new to AEC industry participants, and there are currently no standards for how BIM projects should be implemented. This meant that a portion of the reviewed documents might have little relevance in other BIM projects, without the researcher’s awareness.

3.4 Semi-Structured Open-Ended Interviews

The word ‘interview’ is actually defined as an “exchange of views” between two people about a common theme (Kvale, 1997). Interviews are guided conversations on a topic chosen by the interviewer. The purpose of a qualitative research interview is to obtain qualitative knowledge, and to interpreting the interviewee’s opinions on key topics (Dalland, 2012).

Interviews were chosen over a survey as primary research method because qualitative information was considered more suitable than quantitative information for the purpose of this research. Empirical knowledge was preferred over statistics as the ‘how’ and the ‘why’ were just as important as the ‘what’. An interview is a qualitative research method characterized by its flexibility, as there are no fixed answers. Consideration factor for why interviews were considered more appropriate than a survey are summarized in Table 2. Reasons for discarding survey as a research method is elaborated in section 3.5.2.

Table 2 Qualitative Methods vs. Quantitative Methods

Qualitative Methods: Interviews	Quantitative Methods: Survey
Few interviewees	Sample of population
Many variables	Few variables
Information depth	Information width
Detailed data collecting	Extensive data collecting
Comprehensive scope	Single circumstances
Results are presented as text	Results are numeric-based information

Interviews were chosen to gain a holistic view of BIM users' experiences. The purpose of the interviews was to get accurate interpretations of what benefits and challenges BIM has brought to the interviewees' workdays. Equally important was the interviewees' recommendations of necessary actions. The common objective of those actions is to increase BIM's utility value by reducing the challenges or further increase the magnitude of the existing benefits. The interview questions therefore dealt with the following BIM aspects: Phase transitions, responsibility distribution, analytical features, information sharing, communication, visualization, collaboration and cooperation, lean construction, waste, and schedule and budget planning and monitoring.

3.4.1 Use of Case Study Projects

A case study is a research method involving an up-close, in-depth, and detailed examination of a subject of study, as well as its related contextual conditions.

The interesting thing about BIM is not what it is, but what is does to a company implementing it. Access to information based on experience and empirical knowledge is necessary when researching the effects and impacts resulted from implementing BIM. Gathering actual experiences was crucial in the attempt to improve BIM's usability and to increase the utility value of BIM in all project phases. Two BIM projects were desired as case study projects for five different reasons: (1) As a way to get in contact with a sufficient number of potential interviewees with BIM experience, (2) to give the interviewees common reference points in the interviews, (3) to find out whether people involved in a project have the same opinion or not, (4) to obtain actual experiences, and (5) to make this research less hypothetical.

For a project to be an appropriate case project with regard to the purpose of this research, these two criteria were set as requirements: (1) BIM must be well implemented in the project, and (2) the project ought to be in the construction phase or completed.
The experiences and knowledge the interviewees gained in one of the case projects were the aspects of interest, not the specific case projects. This master thesis does not contain nor treat sensitive project information.

3.4.2 Procedure

The interviewees were asked to participate based on their prior experience with BIM, their technical BIM skills, or their role and responsibilities in one of the case projects. The interviewees may be divided into three categories: Project New National Museum participants, Project Mesterfjellet school participants, and people with distinctive approaches to BIM. All communication with the interviewees, except from the actual interviews, was conducted via email.

The researcher's external supervisor was the one who found and proposed both projects as case projects. He was also the one to request permission to use them as case projects. Two informants, one from each case project, were appointed to the researcher. Their role was to collect and provide the researcher with necessary project information, and to recommend potential interviewees. The informants each made a list of potential interviewees and contacted them to encourage them to participate as interviewees. The actual invitations to participate were sent out by the researcher.

The New National Museum, PNN, was proposed because the project builder has set a goal for this project to be a reference project concerning the use of BIM. The project is currently in the detailed design phase, which isn't optimal. The researcher decided to continue to use PNN as a case project because of the work that was done in the pilot study, and the experience gained during that work (Hellum, 2014). Permission to use the PNN as a case project was given by Statsbygg during the pilot study project, and extended for this research. No Statsbygg employees were involved in either the pilot study or in this research. Statsbygg's permission was nevertheless needed as they represent the project owner and hold the rights to the project. Permission was requested in mid September 2014, but not granted until October 30th 2014 – Less than two months before the submission deadline for the pilot study. Rambøll employees who according to the project organization charts held BIM responsible roles were asked to participate as interviewees. The PNN informant's list of potential interviewees became very helpful. All eight of them were asked to participate, and five of them said yes. Six of the interviewees, including one from the pilot study, are involved in the New National Museum project.

The researcher's external supervisor proposed the Mesterfjellet project, PMF, because it fulfills both criteria set by the researcher. BIM was well implemented in the initial phases, and attempted implemented in the construction phase. The project was completed in August 2014. Permission to use PMF as a case project was requested by the researcher's external supervisor in mid January 2015. The project manager granted the researcher permission at the start of February 2015. A total of five persons involved in the project were asked to participate as interviewees, and three of them said yes.
The remaining three interviewees were asked to participate based on their distinctive use of or approach to BIM. Their contributions were considered important in the attempt to get an overall impression of benefits and challenges the implementation of BIM has brought the AEC industry.

As mentioned, the interviews focused on the benefits and challenges with using BIM in the construction phase, and the actions necessary to reduce those challenges. The initial interview guide was a revised version of the one used in the pilot study. The interview guide used in the pilot study focused heavily on benefits and challenges with BIM, and less on necessary actions. The revised version was equally focused on benefits and challenges with BIM, necessary actions, and whose responsibility it should be to initiate those actions. The initial interview guide can be found in Appendix F. The interview questions were formulated with the intention of answering the three research questions:

1) *What are the benefits and challenges with using BIM in the construction phase?*
2) *What actions are necessary to increase the utility value of BIM in all project phases?*
3) *Who should be responsible for implementing the actions?*

The interviews were held in week 7, 8, and 10, and were held in Norwegian to not disable the interviewees or the interviewer. The researcher translated the results from Norwegian to English at a later time. The researcher takes full responsibility for any translation error or any misinterpretations of the interviewees' answers.

The interviews were conducted as a series of single semi-structured open-ended interviews in the following manner:

- An interview guide was composed.
- The interview guide was sent via email to each of the interviewees days beforehand, to give them the opportunity to prepare themselves.
- The interviews were for the most part conducted in person. Two interviews were conducted via Skype due to scheduling conflicts.

- The interviews were audio recorded to ensure no loss of information, and to prevent misinterpretations.
- The interview results were transcribed, processed, analyzed and used to write Chapter 4 Results and Discussion.
- A typed version of each interview was sent to each of the interviewees via email. This was done to give them the opportunity to correct their own statements or to comment on the interviewer's interpretation.

One of the interviewees took advantage of this opportunity, which made the processing of that interview less complicated, and the results more reliable.

3.4.3 Validity and Reliability

The interviewer had two responsibilities throughout the interview process: (1) to follow the interview guide in order to make the results comparable, and (2) to ask conversational questions in an unbiased manner that served the line of the interview guide. Even though the interesting thing is to know 'why' a particular process occurred as it did, Becker pointed out the importance of actually posing the question as a 'how' question (Becker, 1998). The first may create defensiveness on the interviewees' part, while the latter is perceived as a friendlier conversational wondering.

The selected case projects make up a very small sample in a national context. The projects were considered representative for the implementation of BIM in the construction phase based on these points:

- Rambøll Norge AS was involved in both projects, but had completely different roles in the two. This suggests that the projects were not or will not be implemented the same way.
- The rest of the project organization was different in these two projects. This suggests a somewhat broader interviewee selection.
- Only one of the projects was located in Oslo. This suggests that the results may be relevant for projects nation-wide.

Case 2 satisfied both criteria, while Case 1 only satisfied one of them. Case 1 was still chosen because of the project management's goal for the project to be a reference point for BIM projects. This means that it is unknown whether the project will achieve its goal or not. This situation also made PNN as a case project less important and central in this report's results, discussion and conclusion. This is one of the reasons why it was assessed as necessary to have two case projects, and why PMF was chosen. The fact that both projects are public projects might be used as an undermining argument against the research method's validity. It is unknown whether the report's results, discussion and conclusion are valid for private projects as well.

The validity of the selection of interviewees was considered intact based on the following:

- Individuals from various companies
- The companies represents different AEC industry segments
- Individuals from different projects
- Individuals with different roles
- Individuals of both sexes, although the group was dominated by men
- Individuals from different age groups

- All interviewees have previous experience with BIM, or are currently working with BIM

The interviewees constituted a target group with diverse backgrounds, and represented a variety of roles. The group consisted of: Four people with roles in the client's project management, design management and construction management, three consulting engineers, one architect, two people with roles in the contractor's project management, one BIM technician, and one BIM technician professor. The group consisted of one woman and eleven men, and their age ranged from 25 years old to 55. The percentage of women in the Norwegian AEC industry was 8,5 in 2014[6]. One of the twelve (8,3 %) interviewees was a woman, which can be used as an argument for the validity of the selection of interviewees. The majority of the interviewees are employed at Rambøll Norge AS. The interviewees were divided into these six subgroups in Chapter 4 Results and Discussion:

1. Project Management – Project Owner
2. Consulting Engineers
3. BIM Technicians
4. Architect
5. Project Management - Contractor
6. Construction Scheduler – Contractor

The purpose of this thesis was to identify what benefits and challenges using BIM in the construction phase brings. Subchapter 1.6 'What are the benefits of BIM? What problems does it address?' and 1.7 'What challenges can be expected' in *BIM Handbook* describes benefits and challenges of BIM, regardless of the project phase (Eastman et al., 2011). Chapter 3 'BIM and Construction' in Hardin's *BIM and Construction Management* explores and describes how BIM can become useful in contractors' main tasks (Hardin, 2009). Websites for software programs such as Autodesk Revit[7], Graphisoft ArchiCAD[8], and Solibri[9] state what their programs may be utilized for. These books and websites, and other similar books were used as inspiration in the preparation of the interview guide. The interview questions addressed the aspects that best reflect how BIM can be used in the construction phase. The validity of the question selection in the interview guide was therefore regarded as protected, but the included aspects should not be considered the only appropriate ones. One of the last questions in the interview guide reads: 'What more can BIM be used for in the construction phase?' The answers were merged into the corresponding aspect in Chapter 4, but the interviewees had few or no applications for BIM to add. This can be viewed as another argument in favor of question selection's validity.

The collected data's relevance to the research questions was assessed based on the interviewees' previous and current job descriptions and roles:

- Three interviewees have roles that are central in the construction phase: The construction manager, the contractor's project manager and the contractor's scheduler.
- The BIM technician will eventually be placed out on PNN's site office.
- The BIM technicians and two other interviewees have previous experience as craftsmen.
- The rest of the interviewees have roles that facilitate for construction phase work activities.

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[6] https://www.ssb.no/arbeid-og-lonn/statistikker/aku Tabell: 07686: Sysselsatte, etter kjønn og næring (SN2007) (1 000 personer)
[7] http://www.autodesk.no/products/revit-family/features/all/gallery-view
[8] http://www.graphisoft.no/archicad/oversikt/
[9] http://www.solibri.com/

The researcher was strongly recommended to have at least ten interviewees, and was pleased with getting twelve interviewees, considering the limited time available.
The interviewees' personal benefit from participating is stated in the interview guide: "Those interviewed will in return for their participation get access to the final version of the thesis. This will give the interviewees the opportunity to use the results to improve their own BIM implementation. Interviewees will also be contributing to work that may influence the realization of BIM gains that up to the present remain unexploited". The interviewees' contributions can be deemed reliable based on this statement, but their reliability cannot be guaranteed.

One of the most important sources of case study information is the interview (Yin, 2014). Interviews focus directly on the case study topic, and give insight to perceived causal inferences and explanations from actors in the AEC industry. The biggest weakness with interviews is the risk of bias responses. Either due to poorly articulated questions or the interviewees' responsibilities to their roles and their employers. Being informed of the research's purpose might also have influenced the interviewees' responses.

The first interview took more than twice as long as anticipated. The researcher assessed the issue to be two-parted: (1) The arrangement of the questions in the interview guide did not promote a good conversation flow, and (2) the introduction at the beginning of the interview was too brief. The sequence in the interview guide was intended to make the processing process more convenient for the researcher afterwards. The interview results were initially thought to be structured according to: *Benefits and Challenges*, *Actions*, and *Responsible Party*. This resulted in unfortunate repetitions, and a less smooth conversation and interview.
The introduction to the interview should have been more thoroughly presented, as its purpose was to get the interviewee into the right mindset. The purpose of the research should have been explained better, and the topic should have been emphasized. The goal was to find out why people in the AEC industry still choose to use traditional methods in the construction phase after implementing BIM in the initial phases.

The interview guide was revised after the first interview. The revised version of the interview guide can be found in Appendix G. The revised version was not sent out to the remaining interviewees to refrain from creating confusion. The new interview structure was instead explained at the beginning of each interview, along with a thorough presentation of the research purpose. Several interviewees commented that they preferred the new structure to the initial.

3.4.4 Feedback

The feedback received from the interviewees was overall positive. The researcher was pleased with the feedback, and very grateful for the interviewees' participation.

The interview guide had good and timely relevant questions, and a few questions concerning BIM applications some interviewees hadn't considered before. The interviews were conducted in a well-structured manner, and the interviewer received nothing but positive feedback on the changes to how the questions were asked. The interviews took less time than some of the interviewees had expected.

3.4.5 Sources of Errors

Aspects that may have been perceived as benefits or challenges with BIM in these projects might not be true for other projects. Participants in other projects might experience greater benefits, more severe challenges, or benefits and challenges not mentioned in this thesis.

The interpretation of both the questions and the answers were possible sources of errors in the interviews. The interviewees received the interview guide days prior to the actual interviews. The guide included a presentation of the chosen topic and purpose of the interviews, as well as all the questions. Being aware of this purpose might have influenced their answers. Either toward what might have been most advantageous for the research's intended purpose or what might have been most beneficial for them and their company, as the interviewees have responsibilities toward their roles in the case projects.

3.5 Discarded Research Methods

3.5.1 Scientific Article

The International Group for Lean Construction, IGLC, is a network of professionals and researchers in architecture, engineering and construction (AEC). Their goal is to improve both AEC processes and products by diminishing the current lack of explicit theory of construction. IGLC organizes annual conferences where scientific papers addressing specific themes related to AEC processes and products are presented. All IGLC conference papers are available for free download at their website.[10]

A scientific article was originally intended to be part of this thesis. The researcher's supervisor at NTNU suggested this, and researcher's external supervisor supported the suggestion. The researcher agreed to write a scientific article, a contribution to this year's IGLC conference, after persistent encouragement from her supervisors. The researcher found the increased publicity to be the most appealing with the proposal. The proposal was nevertheless discarded in late February 2015. The researcher chose to write a traditional master thesis rather than an article-based thesis based on the following bullet points:

- **Formatting requirements** for the article was this year reduced from 12 pages to 10 pages, and the page count was to include the list of references. Precise sentence formulations would have been extremely important in order to not impact the quality of the content negatively.

- **The deadline for submitting** a first draft of the article was set to March 16th 2015. This was less than 9 weeks after the research work started. The article's content was only required to be " as complete as possible" at that time. The master students were allowed a total of twenty weeks for their research work. The research work was generally governed by different submission deadlines set by IGLC's academic committee, which the researcher assessed as challenging.

- **The data collecting process and the processing process** were more time-consuming and extensive than initially predicted. The researcher's target was to conduct all new interviews during week 7 and 8. Two interviews were pushed back to week 10 due to scheduling conflicts. Both transcribing the interviews, and processing the interview results took longer than anticipated. Work with and preparation of Chapter 4 Results and Discussion was as a consequence started later than planned.

[10] http://www.iglc.net/Papers

- **The amount of data collected** during the interviews was larger than anticipated. The researcher assessed it to be very challenging to present such large amounts of data in a proper and dignifying manner in a ten-page long scientific article.

3.5.2 Survey

A survey was initially considered a possible research method. The idea behind the suggestion was (1) to assess project participants' expectations and prejudices toward BIM, and (2) to survey people's attitudes toward BIM, and their willingness to acquire greater knowledge of BIM, and implementing BIM. Craftsmen, foremen, subcontractors and contractors were the intended survey participants, as they hold the main roles in the construction phase. The suggestion was however discarded based on the assumption that it would be extremely difficult getting enough people to take the survey. The researcher was recommended to get 100 to 250 people to take the survey, in order for its results to be regarded as sufficient research data. It was also assumed that people who are motivated to and committed to implement BIM would have constituted a dominant share of the survey participants.

4 RESULTS AND DISCUSSION

The central content of Chapter 4 Results and Discussion is the interviewees' response to the interview questions, and discussion of the results.

The interview guide's main topics were benefits and challenges with using BIM in the construction phase, as well as proposed, necessary actions that should be implemented to reduce or eliminate these challenges, and the role or party responsible for imposing the actions. The main focus was on the construction phase, but the interview guide also addressed the transition from the design phase to the construction phase, and the transition from the construction phase to the operation phase. The interview questions corresponded to familiar BIM aspects and were formulated with the intention to answer the research questions in section 1.3. The initial and revised version of the interview guide can be found in Appendix F and Appendix G, respectively.

It was decided to prepare a combined result and discussion chapter rather than two separate chapters. The intention of this was to minimize repetitions, and to make the text intelligible and more interesting to the readers. Summarizing discussion tables can be found under each subchapter. Their purpose is duplex: To give readers a summary of the results, and to provide a basis for the discussions. Gaps in the tables indicate that the interviewees were unable to give an appropriate contribution.

4.1 The Transition from the Design Phase to the Construction Phase

4.1.1 Project Management – Project Owner

If the BIM model is only to be used for visualization purposes in the construction phase, no special changes are required. Activities, durations, milestones and costs must be added to model components if the project management is tempted to try 4D and 5D BIM features. This work should start right after the pilot project is completed, and contractors should enter the project at this time, and be involved in planning. 6D and 7D BIM require the entire AEC industry to utilize BIM tools and processes, and are therefore unrealistic today. Simple requirements must be met for today's models to be used on construction sites: Models must be interdisciplinary coordinated, and have a satisfactory high level of detail. Once these requirements are met, it is the executing parties' responsibility to utilize the model actively for their planning and implementation, and to use available tools.

4.1.2 Consulting Engineers

Temporary components must be modeled for the model to be suitable for site use. Areas where contractors start construction execution must be completely designed and engineered. The problem with sending out models on site is that projects are prone to changes. Being able to mark areas in the model that are fully designed, controlled and ready for construction with a status system of green, yellow and red could solve this challenge.

The BIM model is in PNN exported to IFC format so that contractors have access to everything consulting engineers have. If the goal is to adopt 4D and 5D BIM planning and monitoring, information on how we intend to execute construction must be inserted in the model, including the intended activity sequence. Contractors are responsible for planning the construction schedule, based on information they receive from us. Contractors and consulting engineers should collectively plan schedules earlier than traditionally. Contractors have more experience on how activities should be efficiently executed. An appropriate action is a *collaboration period* dedicated to engineers and contractors working together on schedule planning, where what, how, why, durations, crew shifts and general thoughts can be discussed. One arising obstacle for such periods is that contractors usually enter projects at a later time than when the periods should take place. The project client and builder must allow the parties adequate time, as both parties are already pressure on time. This extra time could result in a shorter and more efficient construction phase, and should therefore not prolong the project duration.

4.1.3 BIM Technicians

The model should by the end of the design phase be an exact representation of the final project product, which requires the model to be modeled correctly. As an architect or modeler you have to think three-dimensional and two-dimensional simultaneously, and take into account future use of the model by modeling slightly differently than just expanding from 2D to 3D. No cheating is tolerated if the model is to be used on site: concrete slabs must cut columns properly, etc.

The actual modeling would have taken less time if architectural students had been drilled in 3D digital modeling during their studies. Today, in 2015, they spend time creating 3D models in architectural cardboard, which is absolutely ridiculous. The client utility value of these is considered diminished. Architectural students should be able to work with ArchiCAD and Revit, and control in Solibri. Contracts with clear definition of the correct level of detail and specification on what the client is paying for is a necessary action to address this challenge. Most project participants that choose to not use BIM models in the construction phase do so because they don't know how to use BIM tools properly. One important reason why people don't know how to use these tools properly is that educational institutions fail their role.

4.1.4 Architect

The model made for tender drawings is the same model used in the construction process. The model is continuously updated as information is reported back from contractors and consultants. The transition of the model requires no changes if its components are modeled correctly the first time, which is done by structuring the model with 4D and 5D BIM in mind. Other participants' utilization of the model depends on this to be done correctly and carefully. It is critical that all objects in the model are defined correctly: An exterior wall is defined as an exterior wall, an interior wall is defined as an interior wall, etc.

4.1.5 Project Management – Contractor

Considering the level of detail in today's BIM models, we're unable to handover the model to the craftsmen and say: "Build this". Most clients today demand the model to be adequate for future facility management, which is insufficient during the execution of construction. Nor is it sufficient for monitoring and control during the construction process. A higher level of detail must be mandated by the client, and modeled by consulting engineers. One challenge that occurs when the model is enriched with all information necessary for construction is that the file becomes so large that it is no longer functional to work with. BIM applications appear to be too insufficient for construction site detailing. Major contractor companies will require use of BIM in all project phases once they recognize the utility value from BIM's enhanced 3D visualization. Ultimately, it all comes down to money, and right now engineering and designing in BIM is too expensive. The AEC industry needs to agree that BIM is the current and future implementation method, without increasing all costs of services.

4.1.6 Construction Scheduler – Contractor

As the construction scheduler, you divide the building into smaller zones, like one room or five rooms, to help structure the schedule planning after the design phase is completed. We should be able to extract material quantities from individual zones, but the current model structure isn't adequate for such use. Models that aren't structured according to logical scheduling zones are only useful for visualization purposes during schedule planning. The necessary action involves project control and management. The fundamental challenge is that the builder doesn't prepare a schedule proposal before inviting actors to participate in the project tender, except for a completion date. A second challenge is that the design is finished before contractors and schedulers enter the project. It is too late to define zones at this time, because the model is already completed. Schedulers should be granted access to the model as soon as the concept phase and a LOD 100 model is completed. Consulting engineers model components in their entirety, but a wall that is planned to be built in two cycles must be modeled as two separate wall segments. For technical discipline to be able to segment their components into zones, they're forced to insert joints at zonal boundaries, which contractors may charge. A possible solution to this problem is to develop a "zone function" in modeling software: A function capable of highlighting areas or volumes, and summing up quantities within their boundaries.

4.1.7 Discussion

Table 3 The Transition from the Design Phase to the Construction Phase

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Using BIM models for visualization purposes only requires no changes.	4D and 5D BIM purposes require additional information in models.	Contractors should enter projects earlier, and be involved in planning.	Contract agreements must state level of detail and BIM purpose.
Consulting Engineers	Contractors get access to models and all information once the model is complete.	Models lack construction process appropriate detailing. Contractors enter projects too late to make 4D convenient.	Both permanent and temporary components must be modeled in detail. Engineers and contractors need collaboration periods.	Client must give the project extra time to allow collaboration periods, and modelers extra time to increase level of detail.
BIM Technicians	Model represents completed product before construction starts.	Model must be modeled correctly but modelers tend to cheat.	Contract agreements must define future model utilization purpose.	The client must specify what he's paying for beforehand.
Architect	Easy phase transition.	Modelers tend to cheat.	Correct component definition is vital.	Architect or other modeling parties.
Project Management - Contractor		Not enough details in today's models for construction site and construction process purposes. BIM engineering too expensive.	Client must demand more details. Engineers must model more details w/o increasing the cost on their service as much. Contractors must utilize BIM.	Everyone in the AEC industry.
Construction Scheduler - Contractor	Great visualization.	No schedule proposal prepared before competitive tendering. Scheduler involved too late. Disciplines have trouble segmenting their components.	Give scheduler access to the model once a LOD 100 model is completed. Develop 'zoning function' in software programs.	Project management. Modeling software producers.

This question was asked to find out if a BIM model produced in the design phase is suitable for construction phase work. The interviewees seem to agree that today's models are appropriate for 3D visualization purposes as long as modelers don't cheat when modeling, but that the models are too immature for 4D and 5D BIM purposes. Clients must clearly state intended use of BIM for the project process and the future, in contract agreements. Many owners are mandating that BIM be utilized on their projects without having an understanding of what BIM deliverables and processes to demand, exactly like stated by Mayo et al. (Mayo et al., 2012). Many owners today demand BIM be utilized, without specifying, and receive a 3D model without sufficient construction site and construction process information as a result. The interviewees also agree that contractors enter the project too late to make 4D and 5D BIM convenient. The consulting engineers proposed that clients should allow the project extra time for collaboration periods by the end of the design phase, while the scheduler expressed a desire to be granted access to the model as soon as a LOD 100 model is completed. See section 2.13.1 for LOD definition. The scheduler augmented that the intention of such early involvement was to determine appropriate zoning for the building. An additional action, partly suggested by the researcher, is developing a 'zoning function' in BIM modeling applications: A 'zone function' capable of highlighting areas or volumes, and summing up quantities within their boundaries. The researcher believes such a function may be useful for other parties than just the scheduler, like crew supervisors and foremen.

4.2 Distribution of Responsibilities

4.2.1 Project Management – Project Owner

One major benefit of thoroughly implementing BIM in projects is that everyone designs and engineers in the same model, and checking discipline models' collocation is made possible with collision tests. Many perceive the exposure of work in BIM as a challenge. Every solution and complete production instruction is visible, and the ownership of models' content is not yet established. Multidisciplinary models make it very easy to track down parties responsible for errors. This is highly beneficial for the quality of the project process and the final product, but it has made many companies reluctant to BIM adoption. A fundamental challenge with continuing using BIM in the construction phase is the sprawling BIM skills found in the AEC industry. Having inexperienced people involved in a BIM project can be incredibly damaging to the project, and training is therefore absolutely necessary. Contractors have so far required too little of themselves and their subcontractors related to BIM. It is vital that the project management is focused on using BIM actively.

Two new roles have been introduced along the implementation of BIM: The BIM Coordinator and the BIM technician. The interfaces around the BIM Coordinator role may still be somewhat unclear, but BIM Coordinators are responsible for controlling all discipline models, checking that components are defined properly with the correct physical characteristics, and checking that no component overlap, and for running collision tests. This role is essential for successfully implementation of BIM projects. There should be a federal requirement that a BIM coordinator shall be appointed, almost regardless of project size. Even though BIM Coordinators are responsible for daily work with BIM, project managers and design managers still need to acquire BIM knowledge and experience. A BIM technician is a discipline modeler, with or without discipline knowledge or background, and may also be the one to coordinate the interdisciplinary model, and set up rule sets and classifications in analyses. These are time-consuming tasks, and the appropriate action may be to develop preset rule sets that can adapt to various project phases.

4.2.2 Consulting Engineers

The present distribution of responsibilities works fine. BIM is still new to a lot of people, so it's difficult to get everyone on board. The roles are mainly the same, but most have gotten a new responsibility: Following up and updating the model continuously. It's important that one person is responsible for controlling that models are modeled properly and according to the same template, so that they comply with each other. This person is often assigned the role of BIM Coordinator. It is important that he or she has prior work experience and is able to distinguish real collisions from false ones, depending on the current project phase. Without an appointed BIM Coordinator, the responsibility of running collision tests falls on various discipline managers. An appointed BIM Coordinator is useful even as people in the industry gain BIM skills and experience. A proposed change to the distribution of responsibility in BIM projects reads as follows: If contractors have satisfying levels of BIM skills, they could take over modeling responsibilities after receiving the model, and model the As Built model themselves.

4.2.3 BIM Technicians
Engineers and designers hand over the BIM model to contractors and expect them to use the model on site, without any arrangements to ease contractors' BIM adoption. Modelers could help contractors by setting up views ready for construction. Currently, contractors and other site workers don't have enough experience to do this themselves. Contractors will have to hire help that can give them BIM training in order to increase their level of BIM expertise. It is in PNN assumed that the contractors have experience with using a 3D model, which is rarely the case. Statsbygg has been too vague in their specification of 'required BIM skills'. Intended use of BIM in the construction phase must to be clearly specified by the client, as well as the party responsible for modeling during the construction phase.

4.2.4 Architect
The benefit of having a BIM model is the ability to detect errors, but errors must be detected early enough. All disciplines are responsible for controlling their work, and for not blindly rely on the results of these analyses. It's easy to become less active if you feel that the responsibility of analyzing lies with others. It is the project management's responsibility to ensure interdisciplinary analyses are carried out and prioritized. Interdisciplinary analyses, and a participating project management are very important for project success.

4.2.5 Project Management – Contractor
The distribution of responsibility hasn't changed drastically parallel to the implementation of BIM, but certain changes could be beneficial: Regardless of BIM, the engineering manager should push consulting engineers more on delivering work on time. Additional interfaces should be set up, taking into account disciplines' different needs, and the project progress. Regarding BIM, I wish the contract agreements would demand involved engineers to be 100% focused on the present project for two to three months. In that period of time, everyone involved should be gathered in a common area and works on their models collectively, and regularly discuss model assembly, immediate clarifications and reconciliations, and status updates on preceding and proceeding work for every discipline. As contractors, we should have our own BIM Coordinator, even as we gain experience with BIM.

4.2.6 Construction Scheduler – Contractor
The distribution of responsibilities in traditional projects is equally valid in BIM projects and traditional projects, at least for the design phase, which is when models are modeled. The challenge in the construction phase is the missing standards for how BIM should be utilized on site. Different engineering disciplines models differently, which makes it hard to use the interdisciplinary model for schedule planning. Having the project BIM Coordinator determine the appropriate model structure is a challenge, as it may not be transferable from one project to the next. I feel it is the project managers, design managers, construction managers and construction managers' responsibility to develop a strategy for how BIM should be adopted

and applied for it to have utility value in projects. BIM is currently for the most part an information tool. There is a need for management tools to control and manage progress and finances. A national or international standard for model structuring should be developed. An article[11] about the British BIM implementation stated that the Ministry of Finance should be responsible for establishing such a standard, as the incentive for adopting BIM is cost savings. In Norway, this may be a task for Standard Norge. However, it's important to remember that we work with many foreign AEC companies, and we should therefore aim for a European standard.

4.2.7 Discussion

Table 4 The Distribution of Responsibilities

Actor	Benefits	Challenges	Action	Responsible Party
Project Management - Project Owner	Everyone engineers on the same basis. Easy track down of error responsible party.	Exposure of work. Undetermined ownership of models' content. BIM competence is sprawling. Rule setting is extremely time-consuming.	Standardize ownership of model content. BIM training. Develop preset rule sets adapted to various project phases.	Each party is responsible for own training. Software producers.
Consulting Engineers	BIM Coordinator role has been created to assign one person the responsibility of controlling models and checking for collisions.	Contractors are currently unable to take upon modeling responsibility, which is unfortunate for the construction phase workflow.	BIM Coordinator should have prior site experience. Beneficial if contractors had sufficient BIM skills to take over the modeling responsibility after construction start.	Contractors need to obtain BIM skills and knowledge.
BIM Technicians		Too vague description of 'BIM skills'. Party responsible for modeling in construction phase not clarified early enough.	Ease contractors' adoption to BIM. Contractors must increase own BIM competence.	Every consultant and architect involved before and after construction start, and contractors.
Architect	The ability to detect errors.	People become less active in controlling their work if they feel it's not their responsibility.	Project management is responsible for ensuring interdisciplinary analyses are conducted and prioritized.	Every discipline, and the project management.
Project Management - Contractor		A need for a new organization of the design phase is identified due to the implementation of BIM.	Introduce collective collaboration phase where consulting engineers have full focus on the present project.	Requirement must be included in contract agreements by the client.
Construction Scheduler - Contractor	Traditional distribution equally valid in BIM project	Missing standard for how disciplines should work in BIM on site.	Create national, European, or international standard for model structuring.	Ministry of Finance, or Standard Norge.

This question was asked to find out if the interviewees find the current distribution of responsibilities sufficient in BIM projects, and to identify improvement areas. Two new roles have been introduced and become essential to the implementation of BIM in the design phases: the BIM Coordinator and the BIM technician. No new roles have been introduced to help along the implementation of BIM in the construction phase. The project owner

[11] http://www.bygg.no/article/1228053

management interviewee group pointed out that having inexperienced people involved in a project can be incredibly damaging to the project, and their statement is supported by the literature (Eastman et al., 2011). The consulting engineers would like contractors to have sufficient BIM skills to take possession of the modeling responsibilities after receiving the model at the start of the construction phase, so that they could model the As Built model themselves. Some of the interviewees expressed that they feel the traditional distribution of responsibilities is equally valid in BIM projects, while the contractor project manager meant that a new or revised project implementation process would be beneficial. The changes the contractor project manager proposed are very similar to the strategies researched by Dossick et al. (Dossick et al., 2009). Their research showed that the informal communication in co-located environments allowed project participants to more fully participate in the decision making process, something the researcher assesses as an action that can contribution to increase the BIM maturity in the Norwegian AEC industry.

4.3 Analytical Features

4.3.1 Project Management – Project Owner

The benefits of BIM's analytical features are more predictability, fewer errors, and a more efficient construction process. The challenge with the latter is that cost and time resources are moved from the construction phase to the design phase: The design phase becomes more expensive and perhaps extended, but the predicted result is a more efficient and shortened construction phase. This, however, requires all parties to have a certain level of BIM skills. Otherwise the design phase becomes more expensive while the construction phase requires the same costs as traditionally, and the project ends up being more expensive.

Solibri analysis rule sets can be customized for each project, which gives incredibly accurate results. Setting up correct rule sets is a very important and time-consuming task, and one where BIM technicians become extremely important. Collision analyses conducted early in the project bring up countless collisions, and many irrelevant to the present phase. It can be challenging sifting out the ones that are important and real. This is why it's extremely important that components are identified correctly. Being able to define for the application how detailed and accurate the analysis should be considering the present phase would have been very useful. This might be solved by assigned components statuses such as 'engineering not complete', 'ready for construction', 'built', etc. It would also be very useful if analyses took the prevailing contract strategy into consideration. Analytical features and software application for 4D, 5D, 6D and 7D BIM are currently too deficient to be considered valuable because they lack BIM interoperability. However, developing applications accommodating such analyses might be the logical next steps in the AEC industry's BIM adoption.

4.3.2 Consulting Engineers

The enhanced visualization that allows one to detect far more errors and omissions than one did before is a major BIM benefit. The software we use for collision analyzing is working okay, but there's always room for improvement. Models are exported to IFC format before testing, which is unfortunate. BIM applications are continuously improving, but software producers have yet to found a solution to the IFC export-problem. Analytical tools for structural support constitute another challenge: They don't take demands for cover for reinforcement stated in Norsk Standard into account. An algorithm that adjusts models to analytical models should be developed. Being able to use BIM applications for dimensioning is potentially a huge benefit; especially as the project size increases. Inserting correct building components in the model is a necessity in order for technical performance analyzing to be feasible. Existing analytical features work fine, but many industry participants assess the exporting and importing problems to be big obstacles. It is also cumbersome to use analyses in early project phases for quick assessment. Software producers should continue improving their applications so that models can be analyzed before they're completed. Solving these problems should be software producers' responsibility, but industry participants' input should be taken into account.

4.3.3 BIM Technicians

One benefit of using a model is the ability to detect errors and collisions much earlier than traditionally, which can save a lot of time on-site. Solibri and BIM kiosks are incredibly important tools. Solibri can be actively used in ICE meetings to generate reports, conduct interdisciplinary collision tests, take out material quantities, etc. Setting up rule sets and general settings, and controlling models are challenging tasks. Manually setting up rule sets poses the risk of excluding important things from the analysis. Statsbygg's BIM handbook poses another challenge: It is too detailed, and many AEC companies end up creating their own, simplified handbook, which is slightly adjusted for every project. The government or Statsbygg is bound to develop a user-friendly, national standard BIM handbook.

Analytical features will improve each year, so the most important and underestimated challenges are people's willingness, and their ability to master BIM tools. If people hadn't had such trouble mastering the applications, people might have been willing to explore how BIM projects can be implemented. People's mastery of BIM applications is too poor, and many are satisfied with mastering just one application. The combination of several applications, and skilled users with construction experience, is highly underestimated. BIM technician students at FOA are currently looking into BREEAM certification. We are able to automate environmental classification by using BREEAM's certification point system and BIM models combined.

4.3.4 Architect

Collision testing in Solibri is quite good, and these analyses make up a large share of the analytical use of BIM. Rule sets are set up to detect errors and collisions, but it's important to not rely on the results completely, as the analyses may be excessively picky. Manual controls and thorough reviews should still be conducted, as real tolerances may be more tolerant than what analyses allow, which is something a skilled BIM Coordinator with experience from the construction site understands. Too many inexperienced people are preoccupied with having the perfect BIM model because they don't have experience enough to assess where focus is needed. A necessary action is to enrich people and software programs with understandings of tolerances.

4.3.5 Project Management – Contractor

The only analysis we have adopted is collision analysis of BIM models and IFC files, which has its benefits and challenges. The first collision test conducted at PMF resulted in thousands of collisions because a steel beam hit a concrete wall. The steel beam was suppose to hit the concrete wall, but the software perceived it as a collision. We were forced to define actual collisions and false collisions for the software, which was very time consuming. Applications' rule sets are the biggest challenges. Applications should, with input from the AEC industry, become more intelligent, and be able to understand construction structure. Once real and false collisions were define, the collision tests worked very well, and lists of colliding disciplines were reported. We experienced minimal collisions and errors on-site, which resulted in a good production flow. We did however have trouble managing how we should work to correct collisions. All parties rectified their collisions on their own, came back, and it turned out that everyone had adjusted their components in the same direction. This meant that the exact same collisions were reported again, but relocated 10 cm away.

4.3.6 Construction Scheduler – Contractor

Collision tests conducted during the design phase provides a higher quality project product, and many indirect benefits for work in the construction phase. The enhanced visualization of the building can also be regarded as an analysis, which provides direct benefits in the construction phase. By analyzing the model, project participants can consider other disciplines' work in their planning to a greater extent. An appropriate action is simply to get people to take advantage of the tools they have available.

4.3.7 Discussion

Table 5 Analytical Features

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	More predictability, fewer errors, and a more efficient construction process.	Analyses don't take present project phase or contract strategy into consideration. 4D, 5D, 6D and 7D analytical features not mature enough.	Develop phase intelligence in existing analyses. Develop user-friendly 4D, 5D, 6D and 7D analytical features.	Software producers in collaboration with AEC industry participants.
Consulting Engineers	Enhanced visualization, and error and omission detection. Analytical applications available for: dimensioning, collision control, and technical performance.	Export and import to IFC format. Analytical features lack construction intelligence. Most analyses require high level of detail.	Solve IFC exporting-problem. Continue application development to acquire analyzing needs in early project phases.	Software producers.
BIM Technicians	Results in a much more error-free project product, which saves time and money.	Setting up rule sets requires focused attention. People lack skills and willingness to learn. BIM manual not user-friendly.	Continue improving applications. Increase people's BIM skills. New national standard BIM handbook.	Everyone is responsible for own learning - At least our willingness to learn. Government or Statsbygg.
Architect	Detect errors. Verification of constructability.	Real tolerances not included in analyses' assessment.	Enrich people and software w/ tolerance insight.	Participants, and software producers.
Project Management - Contractor	Real collisions were identified and corrected. Minimal collision out on site. Good production flow.	Defining real and false collisions for the application is time-consuming. Procedures for correcting collisions are needed.	Make rule setting less complicated. Develop more intelligent applications. Establish collision correction procedures.	Software producers. Consulting company's management and contractors' management.
Construction Scheduler - Contractor	Collision test provides many indirect benefits. Visual analysis of the model can provide direct benefits.		More people should take advantage of the tools they have available.	Everyone involved in the construction phase.

This question was asked in order to survey the analytical features of BIM currently used, and the users' perceived benefits and challenges with the analyses. The interviewees expressed that models provide enhanced visualization and that analyses provide more predictability, fewer errors and omissions, and a more efficient construction process, as long as the rule settings for the analytical programs were set properly. The interviewees as a group identified four dominant challenges: (1) Setting up rule sets requires focused attention and sufficient application skills that some project participants lack, (2) analytical features don't consider the present phase, contract structure, or compensation terms, (3) export and import to IFC format, and (4) the fact that the BIM handbook prepared by Statsbygg is unwieldy. The third challenge has an impact on the first. Importing IFC files into analytical program often causes shifts and deviations in the model. This problem can be solved superficially by developing procedures for correcting reoccurring deviations, or fundamentally by either correcting the issue with the IFC format or by developing a new format that can replace IFC. Both the third and fourth challenge calls for a standardization of how BIM shall be used and how models shall be modeled. Maradza et al. wrote that "Standards underpin the full utilization network benefits, in that they foster knowledge sharing, and encourage the maximization of economies of scale during construction" (Maradza et al., 2013). Economies of scale are the cost advantages enterprises obtain due to size, output, or scale of operation, with cost per unit of output decreasing with increasing scale as fixed costs are spread out over more units of output. Software programs will continue to develop as time goes by, but the interviewees have expressed in what direction they'd like to see the development go: They'd like software programs to have phase intelligence and tolerance insight embedded. The researcher agrees that such developments may contribute to increase the utility value of BIM in all project phases.

4.4 Information Sharing

4.4.1 Project Management – Project Owner

BIM offers a new kind of information sharing. The project product is first modeled by the architect, and later sent out to all disciplines, which will work on the same, shared model. However, huge challenges are created if the initial model contains serious errors. This can be avoided by demanding continuous model control. It has become more important to get parties involved at an earlier time than traditionally, and to contract people with prior BIM experience. Younger employees currently form the majority of those with sufficient BIM skills, and their generation will contribute to expand the implementation. BIM should be introduced to younger employees first, and then up through the age groups.

BIM offers free flow of information. The actual information sharing must be done in a proper manner and on a constant basis. Models contain a great deal of information, but are currently not included in contract agreements, which may create uncertainty among project participants. Proper actions to reduce this challenge are to include BIM in a project's contract strategy, and to let people draw experience with time. A project's utility value of BIM depends on persons involved, and challenges occur in organizations where BIM isn't well implemented.

4.4.2 Consulting Engineers

The current information exchange format, i.e. IFC files, is a text format, and thus not based on modeling logic. The text is converted into components. This conversion often causes shifts in the model, which is unfortunate and time consuming to fix. IFC files are utilized because no better substitutes exist, so the necessary action is therefore development of a format that can replace IFC. This is a call to all software producers, as well as buildingSMART committees and similar actors. The interviewees also want a better information sharing system. A cloud can contribute to faster sharing to a wider network. This can raise more questions, and thus reduce neglected errors. However, models available on clouds should not be changeable or possible to download, to prevent them from being forwarded to people who have not been granted access.

It is important to remember that, if the builder orders a 3D model without the 'I' in BIM, the model components will still contain information, but not the right information. Clients must request, order and pay for the enrichment of correct information.

4.4.3 BIM Technicians

One of the benefits with using BIM is giving everyone involved in the project access to the model through a web server or something similar. The challenge with this is that models' security is quite vulnerable against hacking. A model contains many secrets, especially in construction of prisons or similar classified projects. A necessary action to eliminate this challenge can be to induce safety procedures in-house for information submission, and to increase applications' security and credibility. The responsibility for implementing the latter lies with those who have web server ownership.

Information was traditionally sent back and forth between the architect and engineers, and then between engineers and contractors. This still appears to be the primary way of exchanging information, even in BIM projects, even though better methods exist. The Empire State Building, with its 102 floors, was built in 410 days back in 1931[12]. The utilized methodology surpasses many of today's projects' methodology. The first step toward a better project methodology is modeling correctly, and the second is to understand good cooperation by adopting ICE meetings. Methodology and organization are the keys to success.

4.4.4 Architect

The purpose of BIM and IFC is to have a shared, updated file, but defects in the IFC format or in the way various applications wield IFC are known challenges. Different applications wield information in the model differently. Actions must therefore be taken to enable applications to play better together for BIM to be useful and user-friendly. Much time is spent exporting BIM models into IFC files and importing IFC file into Revit, ArchiCAD, MagiCAD etc. Export from and import back into the same program work reasonably well, but something is lost every time models leave the native format. Every application has its own problems in this context, and the producers cannot seem to agree on a standard. This challenge increases with increased information complexity. A better standard than IFC must, in the big picture, be developed so that applications can work better together. A less drastic action is to prepare good practices for information exchange between applications so that reoccurring export and import impacts become familiar to users. When it works, the benefit of utilizing BIM is that information from every discipline is assembled in one model. Errors can be detected, and the shared model gives everyone insights to other disciplines' work.

4.4.5 Project Management – Contractor

My experience is that information in models, and information exchanges aren't used correctly. The first necessary action is to enrich models with information needed in the construction phase. The second is to insert information of the selection of suppliers, goods, and materials received from contractors. We were very focused on the 'B' and the 'M' at PMF, but not on the 'I'. The information in the model was only aligned with the client's operation management documentation, and not proper construction information.

[12] http://edition.cnn.com/2013/07/11/us/empire-state-building-fast-facts/

4.4.6 Construction Scheduler – Contractor

People involved in the construction phase must be given easy access to information, and to readable models on tablets or something similar in order for information sharing to function well. Using a web hotel to notify errors and discrepancies was suggested in a project on the west coast of Norway. Pictures of discrepancies, or 'catchers', can be uploaded to the web hotel for discussion, together with information on disciplines involved in the discrepancies. I think this is a good suggestion, as it promotes efficient communication.

4.4.7 Discussion

Table 6 Information Sharing

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	One model contains every discipline's information. Free flow of information, and constant access for everyone is possible.	Serious errors in initial model crucial for project. BIM is not included in contract agreements.	Strict model control demands. Choose people w/ BIM experience. Make BIM model a legal doc. and include in contract agreements.	Client's responsibility to state all these demands in their contracts.
Consulting Engineers	A reduction of neglected errors may be possible as the model is available to more people and more questions are asked.	Trouble exporting and importing IFC files. Good system for information exchange missing.	Develop a format that can replace IFC. Utilize cloud solutions for information exchange.	Current and future software producers, and actors similar to buildingSMART.
BIM Technicians	Constant access to the model and other information is given to everyone involved.	Web servers are vulnerable against hacking and intruders.	In-house safety procedures for information exchange and increase security.	Individual companies and web server owners.
Architect	One shared, updated project model and file, which gives participants increase insight.	Deviations due to export and import. Applications' IFC interpretation.	Increase applications' interoperability. Develop new standard exchange format.	Software producers. Consider feedback from AEC industry.
Project Management - Contractor		Model information was too aligned w/ client's operations management to be useful on-site.	Model must be enriched with appropriate construction information. Information from contractors must be inserted in models.	Requirement must come from clients. Modelers or consulting engineers must add information received from contractors.
Construction Scheduler - Contractor	Easy access to information promotes better communication.	Available information and exchange systems aren't used properly.	Using web hotels to notify errors and colliding disciplines.	Project management.

The intention behind asking this question was to find out if sharing information had improve with BIM, and if having easy access to information have had a positive impact on communication and construction productivity. The interviewees seem to agree that free flow of information and constant access to information can promote better communication, but that the IFC issue poses a major challenge, that a good system for information exchange is missing and that BIM models are lacking appropriate construction information in many cases. Eastman et al. listed "improved import and export capabilities using protocols like IFCs" as one of the areas where enhancement is expected in the near future, and very much welcome (Eastman et al., 2011). The consulting engineers expressed that they'd like to see cloud solutions be utilized for information exchange, while the BIM technicians pointed out that web servers are vulnerable against hacking and intruders. The consulting engineers seem to think that buildingSMART and similar actors are just as responsible as software producers for developing a new import and export format, and a functional exchange system. The interviewees also seem to agree that it's the client's responsibility to specify what information should be included in models, as well as classifying BIM models as legal documents as parts of the contract agreements. The researcher however feels that Standard Norge should develop a standard contract strategy for BIM project implementation, preferably in collaboration with buildingSMART. BuildingSMART has worked hard toward the realization of NS 8360 (see section 2.14), which goes to show that their influence power is remarkable.

4.5 Cooperation and Communication with Other Parties and Hierarchy Levels

4.5.1 Project Management – Project Owner

Cooperation and communication across roles and levels have benefitted heavily from having all disciplines working in the same model. The improved visualization has been utilized to solve problematic situations and disciplinary disagreements in collaboration, to find good interdisciplinary solutions. This should save time and money during the construction process. BIM makes it possible to ask more specific questions, and to direct the question to the right person. Present positive attitudes toward BIM, and adequate technical framework are the two most dominating requirements for achieving these benefits. A BIM room at the site office, furnished with projectors, PCs, and smart boards is necessary in order to utilize BIM in the best possible way during the construction phase, and should be used in all kinds of meetings. Tender documents should specify that persons involved be required to have BIM process skills and tool skills. BIM models on tablets make it possible to bring models out on site. These tools make construction execution control, and error reporting simpler. A picture says more than a thousand words. What remains to be seen is whether contractors are willing to adopt BIM, considering BIM has been a one-way communication tool in the construction phase of previous project. PNN aims to be a BIM reference project. We deliver what is required of us, and have a strong wish to reach a new level of BIM maturity.

4.5.2 Consulting Engineers

Good communication depends on individuals involved in the project, and on their culture and work ethics. We are all responsible for creating cultural changes, and for our willingness to attract new knowledge. BIM training is necessary, but willingness and interest from participants is also required. Cooperation often depends on the utilized modeling applications. Different programs have been developed for different segment of the market. An action would be development of programs that can be used by all parties. Using different programs in a project has three sources of error: Wrong input, export out, and import misinterpretations. This creates a legal gray zone: Who takes responsibility for errors in the imported file when the model that was exported was correct?
IFC models offer excellent visualization, which makes it easier to understand why you have chosen the solutions you have, what the other disciplines plan, and what needs they have. A challenge is that models don't account for different project phases. Missing remarks for recesses in concrete slabs in models have for instance created confusion among contractors.

4.5.3 BIM Technicians

Too much communication is conducted via email with copy lists and forwards today. Modeling applications have integrated "chat"-rooms where everyone can see what is being said, and contribute, but this feature is not utilized. Stakeholders are, for uncertain reasons, afraid to use such open communication tools. We need openness and cooperative spirit within the project in order for cooperation to work even better. In spite of the flat structure in the Norwegian AEC industry, communication lines are too lengthy and time consuming. BIM is no magic formula, but improved cooperation is achievable through proper use BIM and ICE meetings, and by leaving touchiness at home. These tools give people a greater understanding of other people's roles in the project.

4.5.4 Architect

A BIM model is a shared project file that highlights problem areas. It is beneficial that all the consultants can sit together, and solve problems. Others involved, like the contractors, should also participate in such BIM review meetings so that we at an early stage can solve problems that may arise on site. BIM improves communication, which saves both time and costs. Review of the interdisciplinary model in collaboration meetings is usually done during the design phase. It would be beneficial to hold cooperation meetings in the construction phase with everyone present and participating in the preparation of working drawings, and for continuous model adjustment.

4.5.5 Project Management – Contractor

The kind of cooperation and communication we have today is completely independent of BIM. We work in 2D, and communicate via email and phone calls because we fail to avail ourselves of the 'I' in BIM. One of the biggest challenges in larger projects is providing everyone the right information, and not excessive information. The necessary action to reduce these challenges is the aforementioned collaboration months, because cooperation often depends on individuals involved in the project, and on the present contract strategy. I feel there are three main barriers connected to the implementation of BIM: Knowledge, willingness, and software. This combination makes it difficult to know what to grasp first. The AEC industry's BIM knowledge and competence generally need to be increased, and technology and software must become user-friendlier. The AEC industry is a conservative industry, and many actors neither want to use BIM nor see the usefulness of this technology.

4.5.6 Construction Scheduler – Contractor

I think BIM is an excellent communication and cooperation tool. Construction organizations are complex: Creating an organization chart for an entire project will show you what it means to communicate with everyone. BIM should be communicated among crew supervisors, as they are the link between craftsmen and consulting engineers. A strategy for how BIM should be utilized must be established in order for crew supervisors to be able to cooperate in BIM. The purpose of BIM is open communication. Planned and arranged BIM days or BIM hours where the model is reviewed collectively could be an appropriate action to redeem. The entry level becomes so much higher without good strategies. Sprawling or missing BIM skills among contractors and subcontractors must be taken into account in such strategies. The entry level for contractors becomes so much higher if the premise of implementing or utilizing BIM requires complete reorganization than if the project management arranges good BIM strategies for them. Contractors and subcontractors are still responsible for acquiring BIM skills and getting the training they need. It is a shame that everyone is waiting to see whether the first BIM projects are successful or not before making the decision to implement BIM themselves. It is a shame that the AEC industry cannot seem to agree on pursuing this concept just because everything is measured in money. It is very unfortunate for the implementation of BIM that we fail to stipulate the cost benefits with adopting BIM.

4.5.7 Discussion

This question was asked in order to find out how cooperation and communication among participating parties and across hierarchy levels have benefitted from the implementation of BIM. The interviewees all agreed that the enhanced visualization has promoted improved cooperation and good communication, which has resulted in increased product quality and savings of time and costs. However, the improved collaboration and communication seem to only apply when the project participants are co-located, and the improvement seems to diminish with increased use of email. The BIM technicians suggested that people should begin to utilize “chat”-rooms available in BIM applications, but this action is restricted by another challenge pointed out by other interviewees: Project participants are using different BIM applications, if at all. The project owner’s management group claimed that contractors have shown little interest in implementing BIM in previous project, while the project manager on the contractor’s side explain that this is because the model lack appropriate construction information. The project manager and the architect agreed that the contractors, the architects and the engineers should induce ‘collaboration meetings’ or ‘collaboration months’. The researcher would like to propose that such ‘collaboration months’ should be included in a future standard for implementation of BIM projects, and predicts that it would increase people’s BIM willingness, interest and skills.

Table 7 Cooperation and Communication with Other Parties and Other Hierarchy Levels

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Improved visualization used to find good interdisciplinary solutions, which saves time and costs.	Contractors have shown little interest for implementing BIM in previous projects.	Present positive attitudes, and adequate technical framework. Set BIM skills as contract award requirement.	Contractors are responsible for utilizing existing and available software and hardware tools. Clients must require this of contractors.
Consulting Engineers	Excellent visualization results in good cooperation and increased product quality.	No BIM culture. Using different application causes exporting problems. Models don't account for different project phases.	Willingness, interest, training, and BIM culture needed. IFC problem “fixed” if everyone uses same software program.	Everyone involved. Software producers.
BIM Technicians	Shared model invites good cooperation.	Email not efficient communication portal. Touchiness counteracts cooperation.	Utilize "chat"-rooms available in BIM applications. Introduce ICE meetings.	Everyone involved.
Architect	BIM improves communication, which saves time and costs.		Collaboration meetings where contractors participate.	Such meetings must be demanded in contract agreements.
Project Management - Contractor		Communication currently conducted via emails and call b/c of the lack of 'I' in BIM models.	Collaboration months. Increase level of detail and BIM knowledge and skills in the AEC industry.	First two actions must be stated in contract agreements. The last applies to everyone.
Construction Scheduler - Contractor	BIM is an excellent communication and cooperation tool.	Entry levels become so much higher w/o good strategies for BIM use.	Establish strategies for site use.	Project management.

4.6 Client Collaboration and Client Satisfaction

4.6.1 Project Management – Project Owner

BIM gives clients the opportunity to visualize their project product early. Rooms or installation can be extracted, and assumptions and conditions can be explained to people with no engineering background. We are however currently experiencing that the benefits of BIM, those beyond great visualization, depend on the client's engineering knowledge or technical skills. The client's utility value of BIM strongly depends on the client's own willingness to invest in BIM. Everyone talks about the great benefits associated with BIM, yet, too many restrain from demanding BIM in their projects. The predicted gains of BIM, and the appropriate project size for implementing BIM are still unanswered questions, but we need more people to be willing to defy their fear. We need to create success stories and key figures so that we can expand the implementation of BIM. This is very hard to achieve with the skepticism found in the AEC industry. It is our responsibility to make BIM attractive for inexperienced clients, but the first step should be to convince the AEC industry that the benefits of BIM exceed the extra time BIM projects currently require.

BIM skills, tools, or interest are scarce in most counties and municipalities outside of Oslo. The municipalities should be the local pioneers considering the number of building project they're involved in each year. The government should demand such parties to have a certain level of BIM skills, and give them training through seminars accommodated them. The demand should be stated in the Planning and Building Act.

4.6.2 Consulting Engineers
A shorter construction phase after a project is engineered with BIM will increase clients' satisfaction. The savings of time are predicted to increase as people get more experience and the tools get better. Clients' desires and expectations can be communicated and easier achieved. The downside is that BIM projects are much more expensive to implement, something private clients react strongly on. It is important that we show clients that BIM is a useful tool that can process a lot of data relatively easily. Public clients are more willing to try out BIM projects, but could have been even more eager in order to give the industry more experience. More experience and research on BIM implementation profits would help convince clients considerably. Cooperation with Statsbygg's site manager and the scheduler at PNN benefitted from the use of BIM. We experienced that locations and sequences can be determined earlier, and more efficient.

4.6.3 BIM Technicians
BIM is faster and more efficient than any other implementation method, if users master it and use it properly. Clients' incentives to buy the service remain small as long as people are slow to learn how to use BIM tools, because BIM appears to be slower than traditional methods.

4.6.4 Architect
Using 3D actively for project review with the client is very important and central in what we do. This gives a higher understanding with clients who aren't educated architects or engineers than 2D drawings. We also experience that 3D printing of smaller models extracted directly from the BIM model is a very good instrument. The challenges with BIM in regard to client satisfaction are the expectations clients have to BIM, the clients' lack of understanding for what that involves, and clients' lack of willingness to pay for the service. Design is cheaper than construction. Using BIM to find and solve problems requires more work and a slightly different implementation method, but the result is hopefully fewer construction errors. The necessary action is to inform or enlighten clients of the workload related to BIM, the expected returns from a given level of effort, and the allocated time and costs required.

4.6.5 Project Management – Contractor
Using BIM can create better client collaboration and increased client satisfaction, but I think having an expectation clarification in an early phase, like we had at PMF, is essential. We made a document together with the consulting engineers, explaining to the client what we

were able to deliver in BIM and what we were unable to deliver. You risk getting an unsatisfied client without such a clarification. Missing building components in the libraries of utilized BIM applications were the primary restriction for what we were unable to deliver. Another challenge is that very few clients request BIM in their projects.

4.6.6 Construction Scheduler – Contractor

Reading and interpreting architectural and engineering drawings aren't always easy for future users of the building. Models increase clients' understanding drastically. Implementing projects using BIM methodology won't happen unless clients mandate that BIM be utilized.

4.6.7 Discussion

Table 8 Client Collaboration and Client Satisfaction

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Great visualization and better understanding of assumptions and determining conditions.	Challenging making BIM attractive for clients when the AEC is skeptical. Municipalities and counties lack BIM skills and interest.	Convince AEC industry first, then clients. State BIM skills demand in the Planning and Building Act.	Everyone that has experienced gains and benefits from using BIM. The government.
Consulting Engineers	Better visualization and better final product for the client.	Still very few clients who choose BIM. Research on potential gains is sought.	Public clients should choose BIM more frequently to give the industry experience.	Public clients.
BIM Technicians	A more efficient and faster implementation method.	Clients' incentives remain minor until users learn how to use BIM properly.	AEC industry participants must master using BIM tools.	Everyone involved in a project.
Architect	Better visualization, and increased client understanding.	Clients' expectations to BIM, and their lack of willingness to pay for BIM.	Enlighten clients of workload related to BIM.	Architects or parties hire to represent clients throughout the project.
Project Management - Contractor	Having an expectation clarification increased the client's satisfaction.	Missing building components in BIM application libraries. Few clients request BIM.	Expand BIM application libraries.	Software producers in collaboration with suppliers.
Construction Scheduler - Contractor	BIM models increase clients' understanding drastically.	BIM implementation will only happen if mandated by clients.		The party that creates the model.

This question aimed to map AEC industry participants' perceived BIM benefits and incentives for owners and clients. The interviewees all seem to agree that a BIM model and its increased visualization increase the clients' understanding. The contractor's project manager pointed out that an expectation clarification early in the project also increased clients' satisfaction. The researcher agree that it is wise to conduct such a clarification as long as BIM skills across the industry are as sprawling as they are today. It can contribute to ensure that clients know what they're paying for, it may increase their willingness to pay, and result in a good experience, which may influence others to mandate BIM in their projects. Mayo et al. stated that it is critical that the owners be informed and aware of BIM's capabilities so that they can adequately select and manage the stakeholders they choose to contract with (Mayo et al., 2012).

4.7 Replacing 2D Paper Drawings

4.7.1 Project Management – Project Owner

Construction sites without 2D paper drawings are unrealistic considering the way projects are performed today, but there are many potential benefits. 3D views are better than 2D views, as long as the model is user-friendly and intuitive, and 2D views can be extracted. Paperless construction sites are an amusing thought, and can become realistic eventually. It requires time, the right conditions, and demands set by the client, and increased BIM skills industry-wide. One potential benefit is reduced risk of mixing updated and outdated drawings. Another is the visibility of technical solutions, a benefit that increases with increased building complexity. The challenge is the technical requirement for better-equipped sites. Although transferring models from PCs to tablets is painless, craftsmen often need to see drawings in larger scales. Models on tablets are excellent for controlling, but not necessarily optimal for construction execution. It is challenging getting site and construction managers to use new tools. To increase production efficiency, they should be responsible for isolating smaller areas in the model and sending these out on site. Some projects today have placed BIM kiosks around their site, which are perceived as good visualization tools, but not good enough for actual execution. Both carpenters and technical craftsmen have expressed that they need 2D paper drawings. They are much more competent in reading and interpreting 2D drawings than project administrations are. Even if the model isn't physically available out on site, it should be used more actively at the site office. Having a BIM room could prevent a lot of paper waste. The lack of BIM demands in contract agreements pose a challenge once again.

4.7.2 Consulting Engineers

This is not realistic at the moment considering the range in both age, and 3D and data experience among construction site workers. We are currently delivering both BIM models and 2D drawings to contractors, and will probably continue this way for a while. Craftsmen are accustomed to reading 2D drawings, and better at interpreting them than consultants. Consulting engineers would benefit from having paperless sites: We model a complete model, and spend a lot of time on preparing 2D sections and floor plans from the model afterwards. The tools we have today must be further developed in order for us to gradually become less dependent on old methods. This necessary action applies to both software and hardware producers. However, contractors are responsible for using the model we provide. An appropriate action would be to have engineers deliver models only, while contractors print out necessary drawings. This would force contractors to get familiar with the model.

Replacing paper drawings may have environmental benefits, but alternative tools might be made of other environmentally harmful materials. Paper drawings are inexpensive, easy to copy, carry, and write on, and insensitive toward weather. Tablets must be handled with caution, and both batteries and screens are sensitive to cold.

4.7.3 BIM Technicians

Paperless construction sites are not feasible because there'll always be a need for paper drawings to some degree, and tablets are too expensive for each worker to have their own. A lot of paper waste can nevertheless be reduced with BIM. The first step is to place many BIM kiosks around the site, a kind of hybrid between models and traditional 2D drawings. Long distance to a BIM kiosk, or queuing, won't be tolerated: Many kiosks are therefore needed. Craftsmen can retrieve sections or floor plans directly from the model, rather than having consulting engineers preprint all possible drawings. The benefit of using models on-site is evident in BIM applications' ability to combine 2D and 3D view. The contractor must own any tablets and BIM kiosks utilized, as they're the ones who utilize the tools. Modelers give contractors the opportunity to use models, but it is the contractors' responsibility to exploit this opportunity. It is nevertheless important to emphasize that a more appropriate level of detail is necessary for the model to more accurately reflect what is to be built. A BIM kiosk storage issue may arise at the end of a project, which may be solved by renting them out, or by renting BIM kiosks instead of owning them.

4.7.4 Architect

BIM cannot replace 2D paper drawings, but should rather be seen as a supplement. Today's BIM models aren't detailed enough to be the primary source of information during construction execution. Critical information traditionally stored in 2D drawings is missing in BIM models. The ArchiCAD BIMx Viewer application combines 2D and 3D by displaying 2D drawings by clicking on model components. This is a good hybrid tool in the transition phase from traditional 2D to 3D BIM, but one of the undervalued challenges is the quality in these 2D drawings. The automatic generation of details from 3D to 2D comes out as lines with uniform line weights (thickness). This makes BIM generated working drawings less precise and readable. BIM is capable of retain information, but the ability to convey information is impaired. It doesn't matter that the model is correct if 2D drawings extracted from it are incorrect or not conveyed properly, as long as 2D drawings are what's used for construction execution. Placing BIM kiosks out on sites would be interesting. These could be used for clarification in situations where information given in 2D drawing is considered too scarce.

4.7.5 Project Management – Contractor

Considering what I know about the AEC industry today, this goal needs a 20-years perspective and a parallel growing interest among industry participants, and continuous development of technology. We are totally dependent on 2D drawings, much due to the current level of detail in BIM models. BIM will probably become a more important means of communication as an increasingly larger proportion of craftsmen are of foreign origin. We are currently offering craftsmen both 2D drawings and models. Crew supervisors and construction site managers' willingness to use the model is, however and unfortunately, absent. We haven't utilized BIM kiosks yet, even though this was inquired by one of the craftsmen at PMF. What stopped us was the construction site's vulnerability to theft. Having to replace tools means loss of money, progress and production flow, for both the project and its participants. How can we ensure BIM kiosks against theft? I would gladly place BIM kiosks around the construction site, in hope of creating increased BIM interest.

4.7.6 Construction Scheduler – Contractor

Using BIM models can reduce the amount of paper that is printed as supplementary information, and in many case immediately thrown in the recycling box. Having a paperless construction phase, however, is not very realistic. Giving craftsmen a tablet each will have little value compared to the cost. It is sufficient enough for them to have access to a model they can print out views and sections from.

4.7.7 Discussion

This question aimed to survey how mature the implementation of BIM really is in the Norwegian AEC industry, or to what degree industry participants still rely on traditional methods. An article[13] from bygg.no stated that people in Norway talk a lot about achieving BIM level 3, but that the reality is that we're somewhere between level 1 and 2 in most projects. See section 2.13.3 for BIM maturity level definitions. Eastman et al. wrote: "Paper

[13] http://www.bygg.no/article/1228053

drawings – or at least 2D drawing formats which can be communicated electronically – will remain common forms of construction documentation", (Eastman et al., 2011). The uniform perception among the interviewees is that 3D visualization exceeds 2D paper drawings, but that replacing 2D drawings is constrained by three types of obstacles: Technical obstacles (i.e. technical equipment), virtual obstacles (i.e. inconclusive information in BIM models) and mental obstacles (i.e. getting site workers to utilize BIM). A higher level of detail is necessary for the BIM implementation to expand, which evidently won't become customary without demands from clients. The need for better-equipped construction sites shouldn't come as a surprise when the industry is moving away from traditional methods by adopting digital methods. The researcher considers a BIM room, as proposed in section 4.5.1, as a reasonable upgrade of construction site offices. Expecting site workers to adopt BIM applications and processes without overcoming the technical and virtual obstacles is naïve.

Table 9 Replacing 2D Paper Drawings

Actors	Possible Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Reduced risk of mixing updated and outdated drawings. 3D views have greater scopes than 2D.	More technical equipment required on site. Models not adequate for construction execution.	BIM rooms at site offices. Construction and site managers must acquire BIM skills.	Greater BIM demands on contractors in contract agreements from client.
Consulting Engineers	Less work for consulting engineers. More model experience for contractors.	Challenging getting craftsmen to use models. Electronic equipment sensitive to weather and rough treatment.	Move drawing preparation task from engineers to contractors. Further software and hardware development.	Contractors. Software and hardware producers.
BIM Technicians	BIM applications are able to combine 2D and 3D views.	2D drawings cannot be completely replaced. Tablets are fragile and expensive.	BIM kiosk can ease and speed up the transition from 2D drawings to 3D models.	Contractors are responsible for exploiting the opportunities BIM offers.
Architect	3D presentation of elements.	BIM model not detailed enough.	Model viewing features and BIM kiosks placed around site.	
Project Management - Contractor	Model could be helpful communication tool when working with foreigners.	Dependent on 2D paper drawings due to inconclusive model information. BIM kiosk is theft vulnerable.	Increase level of detail in models. Find a way to ensure BIM kiosk against theft.	Modelers must increase level of detail.
Construction Scheduler - Contractor	BIM can reduce the amount of paper that goes straight back to recycling.	The cost of giving craftsmen tablets exceeds the utility value.	Give craftsmen access to a model they can print out views from.	Contractors.

4.8 Errors and Misunderstandings in the Production Specifications

4.8.1 Project Management – Project Owner

This is considered one of the greatest benefits with using BIM. If the model is of high quality, error and deviation detection is very easily conducted in the design phase or during control rounds. It can prevent production errors, and material and progress wastage. This is obviously completely dependent on having modelers capable of modeling correctly, because if the initial model is of poor quality, the result will be poor. We have detected many errors through collision tests in the design phase of PNN. Far more than what is possible with traditional methods. We assume that BIM can give similar benefits on-site.

4.8.2 Consulting Engineers
The increased visualization, and the analytical features make it easier to detect errors in an earlier phase, and to see that components fit. This benefit requires a high level of detail, and cooperativeness from participants. It is more expensive to fix executed errors than virtual errors. The model would achieve an even higher level of detail if suppliers' products and assembly instructions had been linked to the model, but the IFC exporting-problem is the biggest challenge.

4.8.3 BIM Technicians
What's missing for "BIM results in fewer errors and misunderstandings" to be a true benefit, is a higher level of knowledge among users of BIM's analytical features. Detected errors are reported to the colliding disciplines, which discuss and find a solution together, and send an updated IFC file to the BIM Coordinator, who then controls that the error is in fact corrected. Even though the BIM Coordinator is responsible for the assembly and control of the interdisciplinary model, discipline managers should control their model against the other discipline's models. This would contribute to reduce errors and misunderstandings in product specifications. For this to be possible, every discipline manager and consulting engineer must have a satisfying level of BIM knowledge. With increased level of knowledge follows increased level of detail in the model. The number of errors and omissions in the product specification corresponds to the level of detail agreed upon. A given level of detail corresponds to a given model and modeling quality.

4.8.4 Architect
The ability to reduce the number of errors in the production specifications using BIM is a huge benefit. The challenge is that models still almost always have errors, which human errors and underdeveloped BIM applications are partly to blame for. Errors may be caused by the fact that everyone uses different applications, and the way information is interpreted in these. Industry standard BIM applications should be appointed and announced.

4.8.5 Project Management – Contractor
This would have been one of BIM's biggest benefits if the analytical features had been more intuitive and user-friendly, and if the model had been enriched with adequate construction site information. See more in section 4.3.5 and 4.4.5.

4.8.6 Construction Scheduler – Contractor
I think BIM is the tool necessary to increase the quality of design and engineering, along with the collision tests. Using these tools holds the greatest potential quality improvement of the construction phase and the AEC industry, and interfaces between the different disciplines. Contractors usually catch errors and displacements in models they receive, either before execution or after. Either way is too late because contractors don't plan far enough ahead. The moment the contractor detects an error, a delay has occurred.

4.8.7 Discussion
Fewer errors and omissions due to enhanced visualization is one of the highlighted benefits of BIM, according to software producers[14]. The intention with asking this question was to see if

[14] http://www.solibri.com/

this is a true benefit, or if AEC industry participants have experienced challenges in this context. The interviewees all agreed that utilizing BIM models and conducting collision tests have resulted in fewer errors and omissions, and thus saved time and costs in the construction phase, but they also agreed that such benefits don't come for free. That fact that different project roles are using different BIM applications and modeling software programs forces the use of IFC, which causes deviations. Many analytical tools are also perceived as too advanced compared with the level of BIM skills among users. The researcher assessed the architect's recommendation of 'announcing industry standard BIM applications' to be the appropriate action to implement. The architect would however probably disagree with the researcher in her opinion that the standard modeling application should be Autodesk Revit. Graphisoft ArchiCAD is allegedly more designer friendly, while Revit is more suitable for engineering. The researcher assesses engineering to be more important for construction execution than visual design.

Table 10 Errors and Misunderstandings in the Production Specifications

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Uncomplicated error and deviation detection is one of BIM's greatest benefits.	Poor quality on initial model will result in poor results.	Involve capable modelers exclusively. Continue running collision test in the construction phase.	Architectural and engineering companies. Contractors.
Consulting Engineers	Easier and earlier error detection.	Requires a higher level of detail in the model. IFC exporting-problem is a major challenge.	Include suppliers' products and assembly instructions in model.	Suppliers must create BIM product libraries. Someone must develop IFC replacement.
BIM Technicians	BIM helps detect errors and omissions on an interdisciplinary level.	A higher level of skills among users is required.	Increase level of skills among discipline managers.	Everyone is responsible for own practice.
Architect	Reduced number of errors in production specifications.	Use of various applications. Wrong info interpretation.	Announce industry standard BIM applications.	
Project Management - Contractor	This could be one of BIM's biggest benefits.	Analytical features too advanced. Models must be enriched with adequate site information.	Make rule setting less complicated. Develop more intelligent applications. Enrich BIM models.	Software producers. Modelers.
Construction Scheduler - Contractor	Collision tests and BIM models increase the quality of both the design phase and the construction phase.	Errors detected by contractors result in delays.		

4.9 Schedule Planning and Monitoring

4.9.1 Project Management – Project Owner

Schedule planning and monitoring are poorly integrated in BIM. The dominating challenge is the amount of work required to accomplish 4D BIM, as there's no seamless link between the scheduling software and BIM models. Once proper software is developed, accomplishing 4D BIM won't involve more work than traditional scheduling. It's feasible to link Navisworks or Microsoft Project to BIM models, but not seamlessly. Many AEC industry participants seem unready for such applications, but we wish to generate schedules with BIM, either according to construction zones, or individual activities. 4D simulation can provide better visualization of what is already built and what remains, or of the entire construction process. It is vital that models are structured for such use by breaking components down into manageable execution activities. The model can until such link or new software is developed be used for quantity summation, and as a helpful work activity identification tool. Some indirect tasks, such as administrative tasks, are difficult to define as posts or activities, and pose a challenge.

4.9.2 Consulting Engineers
BIM models are currently most often utilized to sum up quantities. These quantities help us plan and schedule sequences, workloads throughout the construction process and activity durations. Adequate BIM scheduling tools are seldom used due to insufficient software programs, but such programs would be extremely beneficial. There's a lot of downtime on-site, and time can be saved by using the model for schedule planning and monitoring purposes. For 4D BIM to be feasible, engineers must be granted time with contractors to plan a good schedule, and time to assign each component and activity a start date, and durations.

4.9.3 BIM Technicians
There are many contingencies from creating schedules with BIM tools. One benefit is the detailed overview of the building components, which make it possible to plan everything from transportation, on-site location, transport into the building, and installation. Schedules can be organized according to floors, time periods, amounts, etc. BIM models are seldom used for schedule monitoring, but color-coding model components according to status may be a very useful tool. Such color-coding requires craftsmen to report statuses to their supervisor, who reports to the scheduler for schedule and model updating. Adding dates and durations to components takes time, especially in large projects. Various applications can import the model and generate 4D simulations based on components' start date and duration, but adding 'Week 1', 'Week 2', etc. as a component parameter when modeling might make scheduling easier. Scheduling applications are able to sort components according to such parameters. Inadequate software is an obvious challenge, but the biggest challenge is craftsmen and contractors' willingness to adopt BIM tools.

4.9.4 Architect
I believe contractors would have an easier time planning their deliveries and their construction phase schedules based on the information availability existing in BIM projects. Being able to sort components according to zones and phases, and then visualize the order should be a big advantage, as this can be done once models are modeled. The important thing is to give components proper classifications and proper names. Exterior walls can be divided into layers if their execution is divided, but that's not the correct way to model. It is more correct to divide components according to floors, considering the way BIM applications work.

4.9.5 Project Management – Contractor
We used the model for visualization to arrange interfaces, to get good activity sequencing during schedule planning. I'm not missing having an application that can generate schedules based on BIM models, and this is because I have had bad experiences with storing too much information in one file. A schedule should preferably only embrace 500 – 1000 m^2 because it may become unfavorable to use for progress monitoring if it exceeds this limit. We have so far not used BIM to monitor progress. A higher level of computer skills is required if monitoring is to be done with BIM models, which requires quite a lot from construction site managers.

4.9.6 Construction Scheduler – Contractor

The enhanced visualization in BIM is the biggest schedule planning benefit. The opportunity to gather performing disciplines, and review the entire project collectively is exceptional, and a good start for schedule planning. Schedule planning has four main steps: (1) Identify the scope of work, (2) create an activity network diagram, (3) generate a schedule, and (4) assign resources to activities.

I've experienced difficulties with identifying the scope of work using BIM models because of the zoning issue. Setting up activity sequences in a network diagram in BIM works well, and is done with discipline managers' cooperation. Logical activity sequences can often be determined after a quick review of the model. Unfortunately for the client, BIM isn't a good schedule management tool, and so we use Primavera P6, Microsoft Project or similar applications to create and manage the schedule. I feel that this is a convenient way to do it, and that clients would be the ones who would benefit the most from having the planned progress simulated in a BIM model. The problem with combining BIM and scheduling falls back on the zoning issue. Solving this problem would solve most challenges associated with BIM and scheduling. Every discipline manager wants a rational allocation of their work activities so that their resources are in continuous work. This allocation calls for a different methodology than BIM. Contractors who have tried 4D BIM recently say that the amount of work required exceeds the utility value.

Many projects today lack proper schedule management procedures. Schedules are created at the beginning of the construction phase, hung up on the wall, and too often only updated by drawing a new front line, which indicates how far behind their initial schedule they are. This isn't management. Proper schedule management requires rescheduling every 14 days, and involves moving activities, constantly seeing the consequences of deviations and changes, and re-planning to achieve approaching milestones. Poor planning in the design phase results in unforeseen incidents on site. BIM ensures that things aren't omitted, but this ability is not exploited often enough. A better methodology for schedule planning and monitoring is needed in construction projects, and building managers, contractors, and construction site managers need a resource that understands scheduling methodology. The productivity present in construction projects today is associated with poor planning.

4.9.7 Discussion

Most companies that have implemented BIM have so far only explored the three-dimensional opportunities of BIM, but many of them have a desire to take the implementation to the next level, and utilize 4D BIM. This question aimed to survey what aspects of 4D BIM industry participants are currently able to utilize, and what they perceive as challenges and obstacles against taking the implementation further. The project owner management interviewees and the consulting engineers claimed that quantity summation has improve, while the scheduler expressed that he is unable to extract quantities according to appropriate scheduling zones. BIM was however assessed as a great visualization tool when determining activity sequences. Azhar wrote a list of different BIM purposes, including: "Construction sequencing: A building information model can be effectively used to coordinate material ordering, fabrication, and delivery schedules for all building components", (Azhar, 2011). He did not state that BIM may be used for construction activity sequencing, which may imply that existing software programs aren't mature enough for such use. Kymmell, however, stated that combining BIM and scheduling is very much possible if using VICO Control technology (Kymmell, 2008). But he also said that the main problem associated to VICO Control was that the model had to be created on the same software.

Table 11 Schedule Planning and Monitoring

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Quantity summation, and work activity identification is improved.	Seamless link between scheduling software and BIM doesn't exist.	4D BIM for construction activities can be possible if proper software is developed.	Software producers.
Consulting Engineers	Models are utilized to sum up quantities.	No sufficient BIM scheduling tool exists.	Software development, and collaboration time for engineers and contractors to create good schedules.	Software producers, and time approval from client.
BIM Technicians	Detailed overview of components. 4D simulation possible.	Requires some extra work. Inadequate software. Craftsmen and contractors' willingness to adopt tools.	Add 'week' parameters to components to ease the scheduling workload. Adopt tool.	Modelers. Crew supervisors, foremen, contractors and their subs.
Architect	Easier scheduling due to information available in BIM.	Divide components into floors is the correct way to model components.	Give components proper classifications and proper names.	The modelers.
Project Management - Contractor	Visualization in BIM helps achieve good activity sequencing.	Schedule planning and monitoring with BIM requires higher level of computer skills.		
Construction Scheduler - Contractor	BIM is a great tool for determining activity sequences.	The problem w/ combining BIM and scheduling falls back on the zoning issue. Proper schedule management requires more frequent rescheduling.	Solving the zoning issue would solve most problems associated w/ combining BIM and scheduling. Reschedule every 14 days.	Modeling software producers. Contractors, or contractors' scheduler.

4.10 Budget Planning and Monitoring

4.10.1 Project Management – Project Owner

Allocating costs to each component in a large project is very time consuming, and thus a huge cost for the client. Still, 5D BIM is assumed to be very helpful in achieving accurate calculations. Software that communicates well with BIM models is still missing. BIM is currently used for material quantity summation, which is later plotted into a separate spreadsheet program. Another challenge is the model structure, which doesn't accommodate the needs of budgeting software. Technical disciplines like plumbing do not calculate pipes per meter. They estimate their costs based on tacit data and square meter prices. Certain costs, like costs incurred before a final project proposal is finished, are hard to link to model components. But being able to compare estimated production costs and actual accrued costs would have been very useful. BIM should eventually be utilized for quick visualization and determination of cost and other consequences of changes in design.

4.10.2 Consulting Engineers

Neither of the consulting engineers has experience linking BIM and budget planning nor monitoring. Such work is currently done in applications similar to Microsoft Excel. They agree that such linkage would be beneficial for monitoring actual costs incurred, and a tool they want to use if applications are improved.

They tried connecting IFC files and G-Prog descriptions in PNN, but errors in the IFC export created problems. The proposal was dropped, largely due to the project size.

4.10.3 BIM Technicians

Budget planning in BIM was not utilized in PNN because it required even more work than 4D BIM. Contractors choose the suppliers, and it is therefore their responsibility to register unit prices. 5D BIM becomes very challenging when considering contractors' lack of BIM skills, and the required level of detail. Suitable actions are primarily that software producers must develop decent 5D BIM applications, and secondarily that contractors adopt these by entering the project at an earlier time. Closer collaboration between engineers and contractors is also necessary. Even though applications that "seamlessly" import BIM models and generate cost calculations exist, a ton of settings, templates, layouts, and import/export deviations still need attention. These are best set up by people with construction site experience like carpenters, plumbers, bricklayers, etc. An error-free calculation is only possible if people master BIM applications and their settings correctly, and even more so if they have site experience.

4.10.4 Architect

Project descriptions created in G-prog are used as tender documents, and later priced by contractors. G-prog is an application that can open IFC models and register components quantities, so descriptions are semi-directly extracted from the model. We prepare a cost estimate based on these descriptions by the end of the pilot design phase. Retail prices, and actual prices reported by contractors might differ, and comparing the two can help uncover any discrepancies or large errors in the initial estimate.

4.10.5 Project Management – Contractor

I think linking costs and BIM models can be extremely beneficial. Adding prices with unit durations to components would generate a rough schedule outline automatically, if software programs were adequate for such use. But this would only be manageable if buildings were broken down into reasonably sized areas, to prevent the budgeting file from becoming too big or complex. The challenges are currently exceeding the usefulness considering that both sufficient applications and computer skills among construction site managers are missing. Right now, it would just result in 'shit in, shit out', but at the same time, you have to dare to evolve, meaning that we should adopt existing technology despite its obstacles. The AEC industry is so conservative that it has hardly changed the last 40-50 years. This is a huge challenge we have to respect while implementing BIM.

4.10.6 Construction Scheduler – Contractor

I only estimate the costs of main activities. When these are 50% completed, the work that's done corresponds to 50% of the costs. I haven't used BIM for this work other than to find activity sequences. The zoning issue prevents me from estimating exact durations and costs. External scheduling applications like Microsoft Project provides us with the project's cash flow, and budget monitoring is registered in a financial program called ISY G-prog.

4.10.7 Discussion

5D BIM is the logical next step along with 4D BIM. This question was included in the interview guide to survey whether the Norwegian AEC industry is ready for this kind of BIM use, and to identify the perceived dominant challenges associated with such use. A quick look at Table 12 suggests that the AEC industry is not ready. The benefits stated by the interviewees are potential, untried, plausible benefits, and the group generally agreed that sufficient BIM budgeting software is missing. This is the dominant challenge, closely followed by the zoning issue and contractors' lack of BIM skills. The contractor project manager is however, and interestingly, the only one who suggested that the industry should utilize the imperfect, existing tools, something the researcher supports. Producers need to know what's wrong in order for them to be able to fix it. But the researcher also feels that this particular aspect of BIM is too unexplored by the interviewees for their responses to be considered research evidence or maybe even valid research data.

Table 12 Budget Planning and Monitoring

Actors	Potential Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	BIM should be utilized for quick determination of consequences of changes in design.	5D BIM software is missing. Models currently not fit for 5D use. Model adjustment would mean a huge cost for clients.	Develop link between existing calculation software and BIM, or develop new software.	Software producers.
Consulting Engineers		BIM budgeting not utilized due to missing link between BIM and calculations software.	Develop link between existing calculation software and BIM, or develop new software.	Software producers.
BIM Technicians		Primitive software applications. Contractors lack BIM skills. Settings need careful attention.	Continue developing manageable software. Increase contractors' skills.	Software producers. Contractor companies.
Architect	Price calculations generated from BIM model. Discrepancies uncovered.	Price calculations aren't estimated until after the pilot design phase is finished.		
Project Management - Contractor	Adding prices with unit durations to components would generate a schedule outline automatically.	Sufficient BIM + Cost applications and computer skills among site managers are missing.	Adopt existing technology, despite its obstacle. We have to dare to evolve.	Everyone currently not utilizing BIM budgeting.
Construction Scheduler - Contractor		The zoning issue prevents schedulers from estimating exact costs and durations. Neither budget planning nor monitoring possible in BIM applications.	Fix zoning issue.	Modeling software producers.

4.11 Changes in Project Costs

4.11.1 Project Management – Project Owner

Working with new tools takes a little longer in the beginning, meaning that BIM modeling and engineering will take a little longer in the first few BIM projects. People increase the costs of their BIM services because they believe BIM is double the work. If the modeling and engineering is done properly, BIM projects should eventually become less expensive for the client because there are fewer errors, more efficient work, and a shortened construction phase. The workload curve for BIM projects is a little different from traditional projects, and not everyone sees the benefits of that. The workload curve the interviewee referred to was the MacLeamy curve, which is shown in Figure 15.

Projects where the construction site management successfully exploits the potential time and cost savings facilitated in the design phase are likely to be the most profitable. Reduced time, and better communication, logistics, material transport, and material ordering, and more efficient activity sequencing can save major costs. One of the interviewees expressed that previous research has discovered that a well-performed design phase can result in an up to 30% reduction of construction time. This is because up to 30 % of the construction phase is made up of unproductive and counterproductive time.

4.11.2 Consulting Engineers

The enhanced visualization requires a longer and more expensive design phase, which results in cost changes. The additional cost is assumed to decrease over time as software programs becomes smarter. The extended design duration is suppose to reduce the construction phase duration, but this is dependent on the contractor's BIM skills. The question commonly asked by contractors is: 'Why should we pay extra for this?' Models are used for visualization and analysis in early phases, but 2D drawings dominate in the construction phase. Clients should demand contracted contractors to have sufficient BIM skills because their profits and saving of time depend on it. Without this demand, consulting engineers have trouble defending their increased cost. Experience and research can help defend the cost changes by making it feasible to present and predict lifetime saving for BIM projects.

4.11.3 BIM Technicians

Consulting engineers argue that the design phase is more expensive in BIM projects because their services are more extensive, but that the project duration is reduced because many potential problems are solved before reaching the site. The first part of that statement is only true as long as consulting engineers struggle with using BIM properly and efficiently. BIM is a much more rational way of working than 2D CAD. Changes are automatically updated in every floor plan and section in the model, and consulting engineers have the ability to detect errors earlier, and get out quantities. As long as people master AutoCAD better than BIM, engineering and designing of BIM projects will continue be more expensive. People use projects, especially public projects, to learn how to master BIM applications. The costs of construction execution services have incorporated a certain error and rework percentage to account for errors that occur on site. If this percentage is adjusted as BIM projects have fewer errors, BIM projects will become more efficient and less expensive than traditional.

4.11.4 Architect

Designing in BIM requires a slightly different time and cost allocation in the initial project phases. A BIM project's construction phase may not necessarily be shortened, but several errors should be avoided compared with traditional projects. Execution errors on site mean rework and additional costs. BIM is about executing construction correctly the first time.

4.11.5 Project Management – Contractor

We experience that consulting engineers admit that their services are more expensive and extensive in BIM project, but that they claim that the construction process will be shorter in return. Contractors are already pressured to price their service as inexpensive as possible because they are competing for contract awards at any given time. Builders wish to minimize their construction loans, and already squeeze contractors in terms of shortened construction process duration. There is a limit to how fast we can build, and still deliver a completed project product with the agreed quality. We may be able to save money on using BIM in terms of better production flow and minimal collisions, provided that BIM is utilized properly during preceding project phases.

4.11.6 Construction Scheduler – Contractor

I think consulting companies are wrong in saying their services become more expensive with BIM, considering 85-90% of the total turnover of engineering and construction are realized at the construction site. Errors detected on site usually cost a lot of money to correct, and consulting engineers are often to blame for their occurrence. The fact that consulting engineers get paid for correcting their mistakes is, in my opinion, a strange regime. Errors corrections are additionally priced without competition, which is appalling. BIM projects should be less expensive than traditional projects because of the collision tests BIM models undergo.

4.11.7 Discussion

Table 13 Changes in Project Costs

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	A well-performed design phase can reduce the construction phase with up to 30%.	Savings of time in the construction phase depends on whether contractors use BIM or not. Most contractors lack sufficient BIM skills.	Contractors and other site workers must acquire a satisfying level of BIM skills.	Contractors and others construction site workers.
Consulting Engineers	BIM provides better visualization.	Design phase in BIM projects are longer and more expensive. Contractors are currently not utilizing BIM in a way that saves construction time.	Clients must demand contractors to have BIM skills in order to claim the savings of time BIM projects offer.	Project clients.
BIM Technicians	Construction process can be shortened due to fewer errors and reduced need for rework.	Design phase is currently more expensive and extensive b/c users still struggle with BIM.	Increase users' BIM skills.	Everyone.
Architect	Fewer errors on site due to a more thorough design phase.	Design phase requires more time and money than traditionally.	Explain to client that time and money spent in design phase will save time and money later in the project.	
Project Management - Contractor	BIM can induce better production flow, and minimize collisions on-site, which saves money.	There's a limit to how fast one can build and still deliver a product to the quality agreed upon.	Proper use of BIM in construction preceding phases is essential.	Consulting engineers, modelers and architects.
Construction Scheduler - Contractor		Consulting companies are wrong in saying their services become more expensive with BIM.	Higher level of BIM skills with modelers.	Modelers.

The rumor has it that BIM projects are more expensive to implement than projects implemented utilizing traditional processes and methods. This question was asked because the researcher wanted to know how the interviewees would explain or justify the increased costs. Their responses show many pointing fingers. The researcher supports the interviewees stating that "the savings of time in the construction phase depends on whether contractors are using BIM or not". But the researcher disagrees that the design phase should be more expensive, when the main reason why these phases are extended is because the parties responsible for modeling, still struggle with BIM. Designers and contractors are together responsible for fulfilling the client's needs and requirements, and should therefore be more willing to meet each other halfway. The project clients are not to blame for the AEC industry's lack of BIM experience and lacking skills, and should therefore not be the ones to suffer because of this. Modelers should adjust the model structure somewhat to make it more adequate for site use.

The management of contractor companies should equip their site offices as discussed in section 4.7.7. The researcher believes that the collaboration periods as proposed in section 4.5.7 would contribute to help the situation for all parties involved.

4.12 Waste Reduction

4.12.1 Project Management – Project Owner

A huge advantage is that a BIM project can be planned much more carefully in terms of what the building consists of. BIM can reduce waste in terms of: Less time required for drawing production and interpretation, better utilization of components, increased use of prefabricated components, and a more efficient construction process with fewer hours needed on-site. These benefits should be better utilized in the construction phase.

Use of different programs, and switching between local and global datum in models result in displacements because the different systems are unable to communicate properly, and repeated exports and imports to and from IFC require adjustments each time. Having everyone involved working in the same application and model would eliminate time wasted and required to fix these displacements. The client, or perhaps the government, should determine a “standard BIM application” for the project, or for the industry. It is important to choose software programs all parties are able to model and design in.

4.12.2 Consulting Engineers

BIM may actually increase waste in the beginning while people are unfamiliar with the tools. Engineers, architects, and contractors will eventually be able to planning better and earlier, and reduce downtime and rework as they gain BIM experience. This will contribute to less waste. Experience gives insight to success factors and successful solutions, and optimal use of materials and manpower.

4.12.3 BIM Technicians

Utilizing BIM makes it possible to save time and money by utilizing prefabricated components and precut materials to a greater extent, and the model for material orders. A larger share of the AEC industry must use BIM for planning to achieve this, and a higher level of detail is required. The concepts of Lean Construction are based on doing everything at the right time, and reduce waste, which works very well as long as the process isn’t disrupted. Lean is partly a reaction to waste associated with storage areas in terms of materials being damaged, transported to the wrong place at the wrong time, etc. The challenge is the lack of buffers in case of unforeseen challenges such as major strikes or natural disasters. BIM models can be used to promote Lean concept, but humans execute the construction, so a certain level of waste is unavoidable.

4.12.4 Architect

Contractors are able to calculate quantities more accurately using BIM, if they wish to. BIM makes it possible to plan a more efficient construction process with reduced waste. It is the contractor's responsibility to utilize all aids available. There are for instance features and functions available that optimize material usage for complex façade systems using parameters and 3D modeling.

4.12.5 Project Management – Contractor

The feedback from technical subcontractors at PMF, especially the plumbing subcontractor, was that they thought BIM was absolutely brilliant. They received exact and detailed quantities from their respective consultants, making them able to order exactly what they needed, without producing unnecessary waste. If you plan thoroughly, and create logical activity packages, a much better workflow is possible, which results in less material waste, less time waste, and elimination of terribly costly time thieves. The enhanced visualization, and the collision tests make these waste reductions feasible.

4.12.6 Construction Scheduler – Contractor

BIM can offer consulting engineers more rational planning, while giving the client an optimal solution by maintaining interfaces between the various disciplines. Contractors save time on estimating quantities by extracting them from the model, and achieve a better production flow that is less confined by errors and rework.

4.12.7 Discussion

Table 14 Waste Reduction

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Time, material and cost waste can be reduced in BIM projects.	Use of different software programs creates displacements, and thus wastes time.	Appoint standard BIM applications that all parties are able to use.	Government.
Consulting Engineers	Waste reduced in the form of time, money, materials, and manpower.	BIM might increase waste while people are unfamiliar with BIM tools.	Increase BIM skills. Gain BIM experience.	Engineers, architects, and contractors.
BIM Technicians	Resources are saved through better planning, and higher utilization of prefab and precut.	A larger share of the AEC industry must use BIM. A certain level of waste production is unavoidable.	Broader implementation of BIM in the AEC industry.	AEC industry participants.
Architect	Efficient construction process with reduced waste production.	Getting contractors to take advantage of aids and tools available.	Contractors must utilize aids available.	Contractors.
Project Management - Contractor	Better workflow, and less time and material waste produced, which saves money.		Requires thorough planning and an adequate level of detail in models.	Consulting engineers in collaboration with contractors.
Construction Scheduler - Contractor	Contractors save time on quantity summation, and can have a better production flow.			

Many researchers have recently explored and researched the possible link between Lean Construction principles and BIM (Dave et al., 2013, Ghafar et al., 2014, Khan and Tzortzopoulos, 2014). This question was asked in order to find out if BIM alone promotes leaner construction than traditional methods. Some of the interviewees actually said that utilizing BIM methods might increase time wastage as long as project participants are using different software programs, and especially while people are unfamiliar with BIM tools. This claim has not been confirmed in any literature the researcher has come across, but the researcher assesses the statement to be reasonable and logical. However, every interviewee said they've experienced that time, cost, and materials waste have been reduced due to the utilization of BIM tools and processes. Their statement is well supported by the literature.

4.13 Reuse of Knowledge and Experiences from Previous Projects

4.13.1 Project Management – Project Owner

Inspecting technical solutions from previous projects located within the walls has become much easier with BIM, and is far more helpful than physical inspection of the actual building. Time pressure at the end of a project is one obstacle that prevents people from conducting evaluation rounds, even though it should be prioritized. We make the same mistakes project after project, because we don't have time to evaluate what was successful and what wasn't. This problem hasn't diminished with BIM, but well-implemented BIM projects should be evaluated so that we can learn from ourselves. Spending a few hours on such evaluations may be extremely cost beneficial for future projects.

4.13.2 Consulting Engineers

The fact that model components are parameter-controlled gives the advantage of reusing components for future projects. The enhanced visualization presents a second advantage. It allows for quick review of projects we haven't been involved in, so that we can learn from others' mistakes and successes. Evaluation of the project implementation is most often done after failed projects. Final evaluations have become more common in BIM projects, and are very useful for further implementation of BIM.

4.13.3 BIM Technicians

It is difficult to assess whether learning from own successes and failures has become easier in BIM projects. The kind of visualization BIM offers make it undoubtedly easier for people to understand technical solutions, whether these solutions involve other disciplines than your own, or the solutions are used in projects you haven't been involved in.

Rambøll Norge AS has administrated evaluation rounds to survey how things have worked so far, and how things can improve. The general feedback from the construction site is that BIM models can be useful tools, and there are some tips and feedback on how things should have been done differently. More extensive house-evaluation rounds should become routine in the future, and written feedback from project participants should be requested, but such arrangements don't have to be connected to the model directly. Rambøll Norge AS has additionally a house-arrangement similar to LinkedIn, where every employee has a personal profile. Embedded skills and other experience are listed in ones profile, searchable to other users.

4.13.4 Architect

The tacit knowledge people are left with after a project is of interest when planning for the next project, and not necessarily the drawings or elements in previous BIM models. Everyone learns something from each project, especially what pitfalls to look for in the next project. It is theoretically possible to create routine rules for what to look for in Solibri based on previous problems and obstacles, but I believe very few are exploiting this. We hold internal evaluation rounds, but haven't done it on an interdisciplinary level yet. Everyone is paid for his or her service by project completion, and the client may be a non-recurrent client. That is why few people are interested in investing time and money in such final evaluations. However, it should be clear that a final evaluation round should be conducted. Everyone involved would without a doubt learned something from it.

4.13.5 Project Management – Contractor

If you master BIM, and you're able to review models of projects you haven't been involved in, such reviews can be extremely beneficial. The benefits of learning from others' mistakes or successes are huge, and this is something we can and should utilize better. We evaluate every project, regardless of the outcome, and evaluate everything, including BIM. An evaluation report is written, and made available to every employee via an internal portal.

4.13.6 Construction Scheduler – Contractor

Approximately 80 % of a schedule can be reused if a 'BIM project implementation' standard is established. Most projects today have a peculiar way of grouping components and project participants, peculiar work processes, and many BIM Coordinators have their own ways of doing things.

We must carry out final evaluation rounds if we are to learn anything from our previous projects. This is completely absent in the AEC industry today, but such a transfer of experience would most definitely increase people's BIM skills. We make the same mistakes over and over again, but there are no better ways to learn than evaluations. Companies' management must understand that we should start doing this. Evaluation rounds are services clients must pay for, but AEC companies ought to be willing to cover parts of the costs, considering their own potential profits. They could for instance include time and resources for such an evaluation in their tender offers. The results from conducting evaluation rounds could be very valuable for the client in his or her next project.

4.13.7 Discussion

Table 15 Reuse of Knowledge and Experiences from Previous Projects

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	Inspection of technical solutions used in previous projects has become much easier, and more valuable.	Evaluation rounds are not conducted due to time pressure at the end of a project.	Set aside time for evaluation at the end of BIM projects.	Most clients would benefit from this themselves. The responsibility falls on project participants.
Consulting Engineers	Components are parameter-controlled, and can be reused. Allows for quicker review of projects.	Evaluations usually done after failed projects.	Introduction of final evaluations can help speed up further BIM implementation.	Project management.
BIM Technicians	Better understanding of technical solutions regardless of discipline and project.	No routine for exchange of empirical and tacit knowledge.	House-evaluation rounds, and request written feedback from project participants.	Management of consulting companies and contractor companies.
Architect	Learning potential from making tacit knowledge available to others is huge.	Evaluation by completion is seldom done on a multidisciplinary level, least not w/o payment.	Establish mandatory multidisciplinary evaluation rounds after project completion.	
Project Management - Contractor	Learning of others' mistakes and successes is extremely beneficial.		We should utilize this opportunity better.	Everyone.
Construction Scheduler - Contractor	Approximately 80 % a schedule could have been used in future projects if a BIM project implementation standard was established.	Final evaluations at the end of project are currently completely absent, even though both clients and project participants could benefit enormously.	Establish a standard for how BIM projects should be implemented. Introduce evaluation rounds at the end of every BIM project.	Standard Norge, or the Norwegian Ministry of Finance. Project managements.

The researcher wanted to find out to what degree industry participants are exploiting the opportunity to reuse technical solutions and work from previous projects, and to what degree they're making an effort to learn from their own or others' mistakes and missteps. The former seems to be well exploited, while the latter seems completely absent. This may suggest that reuse of components and technical solutions is done on the participants' own initiative, while the managements of the various parties aren't taking advantage of the gains final evaluations and house-evaluations can offer. It is a known fact that the AEC industry is suffering from having a much lower productivity than other comparable industries like the manufacturing industry. House-evaluations, final evaluations at the end of a project, and benchmarking, as researched by Du et al., may help AEC companies improve their performance in BIM utilization and increase their BIM maturity (Barnes and Davies, 2014, Du et al., 2014).

4.14 Project Handover

4.14.1 Project Management – Project Owner

The model is handed over to the client by project completion, and can be considered documentation for the client's facility management. This should be used as an argument to get clients to choose BIM over traditional methods. The project handover can be much more efficient if changes and facility management documentation have been added consecutively. Suppliers, and facility management software producers claim they're able to link facility management information and BIM models. We attempted this at PMF, but failed due to inadequate software.

4.14.2 Consulting Engineers

Control of, and comparison between the proposed product and the As Built make expectation fulfillment evaluation convenient. Few changes are needed to update the model to As Built state if the model is continuously updated as changes occur. Having an As Built model makes it easier for clients to assess if they're satisfied with the result. The client's intended future use of the model should be stated in the contract agreement to ensure that the model is updated and adjusted for such use. To enrich a model with all facility management documentation requires extra time, but the goal is to have a complete model, and adding such information will be extremely valuable to the client. Such information should be inserted continuously.

4.14.3 BIM Technicians

As Built scanning of the completed product can be compared with the BIM model, but it is only possible to scan the exterior shell of the building. Everything inside the building must be verified through inspection rounds.

BIM models with integrated facility management documentation may in the future become one of the biggest client incentives for choosing BIM. What's missing is a "BIM Facility Management For Dummies"-application that even operations managers with limited BIM knowledge are capable of managing. The application must be extremely easy to use: The model must be enriched with intervals for maintenance, and cleaning instructions, and operations managers must master modeling changes as they occur. Adding facility management documentation to the model is the contractor's responsibility, and must be done in cooperation with suppliers and manufacturers. It is also important to remember that such services cost time and money.

4.14.4 Architect

Using BIM models as facility management documentation can be a huge benefit. Each component must be enriched with information of the manufacturer, and component type. Such enrichment requires extra work, but integrating facility management documentation can be a helpful tool for the client. The utility value of this benefit depends on the client's ability to take advantage of it, and on his or her willingness to pay for the service. A necessary action is development of software that can handle such large quanta of data. Facility management documentation contains large amounts of information that neither computers nor most facility managers will be able to utilize if integrated into the model. Too large files won't increase the utility value, but rather cause more frustration. It is in my opinion more than sufficient enough to link components to some kind of PDF file that contains facility information, or a web link to the manufacturer. One must keep in mind that this requires work that someone has to do, and thus a service someone has to pay for.

4.14.5 Project Management – Contractor

The expectation clarification we had early in PMF made the client aware of what to expect when we handed over the project, the facility management documentation, and the IFC file. It turned out to be a good experience, and we avoided any big discussions in the final phase. We were unable to integrate the facility management documentation in the BIM model, but assessed that such a service can be very beneficial.

4.14.6 Construction Scheduler – Contractor

I have not seen anyone walking around with the model on a tablet during the final inspection, but I can imagine BIM could be useful in such context due to the exceptional visualization. It is important that the model is updated before such an inspection.

4.14.7 Discussion

The earlier mentioned black hole is created due to the fact that most AEC companies only use BIM in the initial and the closing phases of a project, and not during the construction phase (see section 1.1). This suggests that many have experienced that using BIM in project closeouts is beneficial. This question was asked with the intention to find out what these benefits are, and how utilizing BIM in the construction phase may increase these benefits. It can be interpreted, based on the interviewees' answers, that BIM is used in the final stage mostly because clients wish to use the model for their operation management. It can also be interpreted that upgrading the model to As Built, and integrating facility documentation become more complex processes because BIM isn't utilized during the construction phase. The researcher assesses the BIM technicians' suggestion to "develop a 'BIM Facility Management For Dummies'-applications" to be very interesting, and believes that such an application could be very important for the AEC industry's further BIM implementation. Such an application is however not, to the researcher's knowledge, suggested in any previous research.

Table 16 Project Handover

Actors	Benefits	Challenges	Actions	Responsible Party
Project Management - Project Owner	BIM model is handed over to clients for their facility management. The handover can be brief if BIM has been used in all project phases.	Model requires countless updated if not used during construction. Past attempts to link BIM and facility documentation have been unsuccessful due to inadequate software.	Use and update models consecutively during construction. Develop adequate BIM facility management software.	Contractors and others involved in the construction phase. Software producers.
Consulting Engineers	Updating the model to As Built state, and integrating facility management doc in the model is assessed as very valuable to clients.	Client's satisfaction with the model is dependent on a higher level of detail in the model. Client's intended future use not always clear.	Increase the level of detail in models. Client's intended future use of model should be stated in contract agreements.	Contractors or engineers should add information. Client must state future use.
BIM Technicians	Facility documentation integrated in the BIM model is the client's biggest incentive for choosing BIM.	Existing applications are too advanced for operation managers to manage and utilize.	Develop 'BIM Facility Management For Dummies'-application.	First come first served.
Architect	Well-organized to have facility documentation integrated in the BIM model.	File becomes too heavy to work with. Unnecessary if not used later. Clients must pay for the service.	Develop standard for facility documentation integration in model.	Industry participants must agree on method.
Project Management - Contractor	The expectation clarification document resulted in a conflict-free project handover.	Were unable to integrate facility management documentation in BIM model. Appropriate software application was missing.	Develop software for facility documentation integration in models.	Software producers.
Construction Scheduler - Contractor	BIM's exceptional visualization could be beneficial during final inspections.		Bring the model on site during the final inspection via tablets.	Consulting engineers.

5 CONCLUSION

Chapter 5 Conclusion provides a brief summary, and a presentation of the researcher's conclusion and recommendation for future work.

Literature states that there are many benefits associated with using BIM. The theoretical framework for this research is provided in Chapter 2 Theory, and includes BIM benefits and BIM challenges found in recent case study research over the past decade. Many researchers have focused on benefits associated with using BIM in the early project phases. These benefits should also be viewed as beneficial to the construction phase as the construction duration may be shortened, the project costs may be reduced, the project quality may be higher, and the user benefits and profits may be increased as a result from those benefits. A number of technical and process related challenges and obstacles with BIM were found in the literature study. It has however, throughout this research, been the researcher's hope that the benefits exceed the challenges. The research purpose was to answer these research questions:

- *What are the benefits and challenges with using BIM in the construction phase?*
- *What actions are necessary to increase the utility value of BIM in all project phases?*
- *Who should be responsible for implementing the actions?*

The supereminent objective of this research is to try to convince the AEC industry that continuing using BIM in the construction phase after implementing the design phase with BIM can be beneficial. Achieving this goal would help eliminate the earlier described black hole in AEC companies' project processes and implementation methods.

Benefits and Challenges with using BIM in the Construction Phase

The following benefits with continuing using BIM in the construction phase were uncovered through this research's interviews and in the literature reviewed in the literature study:

- The model represents the completed product before construction starts.
- The greatly enhanced visualization offers verification of constructability, more predictability, and a more efficient construction process.
- The newly introduced BIM Coordinator role is responsible for controlling models and checking for collisions.
- Performances can be analyzed, and errors can be detected in BIM models, which result in fewer errors on site and a higher quality project product.
- One shared, updated project model contains every discipline's information, and allows for free flow of information and constant access for project participants, which promotes better communication and collaboration.
- Quantity summation and work activity identification is improved, which is beneficial for activity sequencing and schedule planning.
- Well-implemented BIM projects may experience waste reduction in terms of costs, time, materials, and manpower.
- Inspection of technical solutions used in previous projects is more convenient, and can become more valuable. It can give project participants a greater understanding of other disciplines' work.
- Updating the model to As Built state is a far less comprehensive task.
- The biggest client incentive is the enhanced early visualization of the completed project, which increases their understanding.

These are the challenges the interviewees claim to have experienced when using BIM in the construction phase:

1. BIM Models often lack 4D BIM, 5D BIM, and construction process appropriate detailing due to missing specific requirements in the contractual agreements. A higher level of detail in BIM models is essential in many of the following challenges.
2. Site offices aren't equipped with BIM software and hardware.
3. A need for a new organization of the design phase has arisen due to the implementation of BIM. Contractors enter projects to late to make 4D BIM convenient in traditional contract strategies. Standards for how disciplines should work in BIM are missing.
4. The undetermined ownership of BIM models' content has made project participants fear the exposure of work and installation instructions.
5. The party responsible for modeling in the construction phase is often clarified late.
6. Models must be modeled correctly, but modelers tend to cheat. Modeling correctly entails giving building components correct definitions and properties, and sectioning them into appropriate activity work package sizes and according to logical scheduling zones.
7. Analytical BIM features seem to lack construction intelligence, and do not take the present project phase or contract strategy into account. Setting up their rule sets appears to be quite challenging and time-consuming.
8. Seamless link between BIM and scheduling or budgeting software is missing.
9. Export and import to IFC format, as well as BIM applications' interpretation of IFC files, seems to be some of the most dominate challenges. Use of different modeling software is one of the reasons why a format like IFC is needed.
10. Few clients are currently mandating that BIM be utilized in their projects, which means that many AEC industry participants have limited BIM experience. Public clients should feel some responsibility toward contributing to increase the AEC industry's BIM competence and expand the implementation of BIM.
11. A BIM culture does not exist in the AEC industry. Industry participants lack BIM interest and skills, and willingness to adopt these new tools.
12. Final evaluations at the end of projects are currently completely absent, even though both clients and project participants are likely to profit from them.
13. The interviewees have had bad experiences with linking BIM and facility management documentation due to inadequate software (and hardware as the file size increases).

The researcher assesses challenge 1, 6 and 9 to be the most concerning. Reducing these challenges may diminish the magnitude of some of the other challenges listed above. BIM models should according to the literature reach LOD 400 for BIM to be convenient in the construction phase. The researcher feels that AEC industry participants themselves are responsible for their own training and for making the best of the situation with what they got.
Brad Hardin said that: "It should be stated that BIM in fact does *work* in the [construction] field and that it's often a misconception that although it's not completely intuitive and integrated that it doesn't function at all. There is plenty of room for improvement and smoother interoperability between field systems and tools; however, there is a great opportunity missed by contractors who choose not to utilize this technology and leverage it to some or its full extent on the construction site", (Hardin, 2009). Many of the other challenges require interference from higher hierarchy levels, such as Standard Norge and the Norwegian government, in terms of standardizations.

Challenges related to utilization of 5D BIM are not included in the list above. The reason for this is that none of the interviewees have attempted utilizing 5D BIM. Their answers were mostly assumptions, and should therefore not be considered valid research data. The researcher also had trouble finding documented 5D BIM benefits in the literature study. This is the reason why the researcher has listed further research on this topic under the subchapter 5.1 Future Work.

Necessary Actions to Increase the Utility Value of BIM in all Project Phases

People in the Norwegian AEC industry have stated that we have reached level 3 in Richards and Bew's "BIM Wedge". The researcher disagrees with this statement after researching how well BIM is implemented in the construction phase of construction projects. The reality is that we're somewhere between level 1 and a mild level 2. BIM advocates would like the Norwegian AEC industry to reach a solid level 2, and eventually level 3. In order for this to be possible, certain actions must be implemented. The actions the researcher deemed most important are repeated in Table 17. These actions were proposed by several interviewees, on several occasions during the interviews, and were therefore assessed to be necessary to increase the utility value of BIM in all project phases, including the construction phase.

Table 17 The most important, recommended actions and possible effects and impacts

Actions	Possible Effects and Impacts
Integrate BIM in contract agreements	Increase project participants' trust in BIM.
	Force AEC industry participants to acquire sufficient BIM skills.
	Expand the implementation of BIM industry-wide.
Develop (inter)national standard for BIM implementation	Remove AEC companies' need for trial and fail attempts in order to find best practices for BIM project implementation.
Developing a zoning function in existing modeling software	Align the model to construction phase use.
	Solve most challenges associated with BIM and scheduling.
	Could make schedulers able to estimate exact costs.
Replacing IFC or develop IFC	Increase the frequency of use of analytical features. It would make information exchange more seamless.
Collaboration months	Increase people's BIM willingness, interest, and skills.
	Decrease the cost of BIM project processes.
	Increase the use of BIM in the construction phase.
Standard BIM applications	Decrease people's IFC reliance.
Evaluations and benchmarking	Increase share of reuse.
	Improve project participants' BIM skills and companies' performance in BIM utilization.
	Increase AEC companies' BIM maturity
Develop a 'BIM Facility Management For Dummies'-application	Increase the number of operation managers able to use BIM models for facility and operation management.
	Increase clients' overall understand of and interest for BIM.
	It may even be the incentive that influences more clients to choose to mandate BIM be utilized in their project.

Some less comprehensive, but maybe equally necessary actions that don't require government involvement are: Increase AEC industry participants' level of BIM skills, create a nation-wide culture for BIM, and be willing to utilize available tools.

Party Responsible for Implementing the Actions
The parties responsible for implementing the actions in Table 17 are according to the interviews those named in Table 18.

Table 18 Actions and Responsible Parties

Actions	Responsible Party
Integrate BIM in contract agreements	Project clients.
Develop national (or international) standard for BIM implementation	Standard Norge or the Norwegian Ministry of Finance.
Developing a zoning function in existing modeling software	Modeling software producers.
Replacing IFC or developing IFC	Current or future software producers, and actors similar to buildingSMART.
Collaboration months	Project clients.
Industry standard BIM application	Software producers, taking into account feedback from AEC industry.
Evaluations and benchmarking	Management of consulting companies and contractor companies.
Develop a 'BIM Facility Management For Dummies'-application	First come first served. Current or future software producers.

There were many pointing fingers during the interviews. The consulting engineers and their project and construction managers initially blamed contractors for the poor utilization of BIM in the construction phase. The contractor initially blamed the client and the consulting engineers for not preparing construction phase adequate models. But it turned out that most of the actions the interviewees recommended require intervention from higher powers and outsiders parties. What they really want to see is that the government, buildingSMART and Standard Norge step in to assist the AEC industry in their attempt to implement BIM to its full extent. Continuing using BIM in the construction phase after initiating BIM in preceding project phases is preferable and recommended, as to prevent BIM projects from continuing to be more extensive and expensive than traditional projects. Building Information Modeling definitely has challenges and obstacles that shouldn't be underestimated and that need attention. Some of the necessary actions to increase the present benefits or to reduce or eliminate the perceived challenges are quite severe, and further implementation of BIM needs the government's support. The gains from implementing the actions provided in Table 17 can help companies increase their BIM maturity, and affect more AEC companies to implement BIM, resulting in an advanced AEC industry nation-wide.

5.1 Future Work

Two new possible research areas have been identified, and remain unanswered in this research:

- The benefits and challenges with combining BIM and budget planning and monitoring (i.e. 5D BIM), and the actions necessary to implement in order to make this BIM feature a logical and beneficial next step in AEC companies BIM implementation expansion.

- The overall utility value or the expected savings of cost and time from implementing the construction phase utilizing mainly BIM tools and BIM processes.

BIBLIOGRAPHY

ALARCÓN, L. F., MANDUJANO, M. G. & MOURGUES, C. Analysis of the Implementation of VDC from a Lean Perspective: Literature Review. 21st Annual Conference of the International Group for Lean Construction, 2013 Fortaleza, Brazil. 781-790.

ASLANI, P., GRIFFIS, F. H. & CHIARELLI, L. Building Information Model: The Role and Need of the Constructors. Construction Research Congress 2009: Building a Sustainable Future, 2009. 467-476.

AZHAR, S. 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and the Challenges for the AEC Industry. *Leadership and Management in Engineering,* 11**,** 241-252.

BARNES, P. & DAVIES, N. 2014. *BIM in principle and in practice,* London, ICE Publishing.

BECKER, H. S. 1998. *Tricks of the trade: how to think about your research while you're doing it,* Chicago, Ill., University of Chicago Press.

BIMFORUM. 2013. *Level of Development Specification* [Online]. Available: http://bimforum.org/wp-content/uploads/2013/08/2013-LOD-Specification.pdf [Accessed May 2015].

BRYDE, D., BROQUETAS, M. & VOLM, J. M. 2013. The Project Benefits of Building Information Modelling (BIM). *International Journal of Project Management,* 31**,** 971-980.

CARLSEN, J. 2013. *BIM-prosjektering: de ulike aktørenes oppfatning om effektiv gjennomføring,* Ås, [J. Carlsen].

CHIEN, K.-F., WU, Z.-H. & HUANG, S.-C. 2014. Identifying and Assessing Critical Risk Factors for BIM Projects: Empirical Study. *Automation in Construction,* 45**,** 1-15.

CLARK, F. D., LORENZONI, A. B. & JIMENEZ, M. 1996. *Applied cost engineering,* New York, Marcel Dekker.

DALLAND, O. 2012. *Metode og oppgaveskriving for studenter,* Oslo, Gyldendal akademisk.

DAVE, B., BODDY, S. & KOSKELA, L. Challenges and Opportunities in Implementing Lean and BIM on an Infrastructure Project. 21st Annual Conference of the International Group for Lean Construction, 2013 Fortaleza, Brazil. 741-750.

DOSSICK, C., NEFF, G. & HOMAYOUNI, H. The Realities of Building Information Modeling for Collaboration in the AEC Industry. Construction Research Congress 2009, 2009. 396-405.

DU, J., LUI, R. & ISSA, R. R. A. 2014. BIM Cloud Score: Benchmarking BIM Performance. *Journal of Construction Engineering Management,* 140.

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

EVERETT, E. L. & FURSETH, I. 2012. *Masteroppgaven: hvordan begynne - og fullføre,* Oslo, Universitetsforl.

GHAFAR, M. A., IBRAHIM, R. & SHARI, Z. Embedding Cultural Knowledge in Building Information Modeling (BIM) for Fabrication Efficiency to Reduce Industrialized Construction Waste. Computing in Civil and Building Engineering, 2014 Orlando, Florida, United States. 195-202.

GIEL, B. K. & ISSA, R. R. A. 2013. Return on Investment Analysis of Using Building Information Modeling in Construction. *Journal of Computing in Civil Engineering,* 27**,** 511-521.

HAGELUND, T. O. 2013. *Optimalisering av planlegging av framdrift i byggeprosess ved hjelp av BIM,* Gjøvik, Høgskolen i Gjøvik.
HARDIN, B. 2009. *BIM and construction management: proven tools, methods, and workflows,* Indianapolis, Ind., Wiley Pub.
HARRIS, B. & ALVES, T. D. C. L. 4D Building Information Modeling and Field Operations: An Exploratory Study. 21st Annual Conference of the Internation Group for Lean Construction, 2013 Fortaleza, Brazil. 811-820.
HATTAB, M. A. & HAMZEH, F. Information Flow Comparison Between Traditional and BIM-Based Projects in the Design Phase. 21st Annual Conference of the International Group for Lean Construction, 2013 Fortaleza, Brazil. 761-770.
HAUSCHILD, M. & KARZEL, R. 2011. *Digital processes: planning, design, production,* Basel, Birkhäuser.
HELLUM, M. E. 2014. Gains from Using BIM in the Construction Phase. Trondheim, Norway: NTNU.
HINZE, J. 2012. *Construction planning and scheduling,* Boston, Pearson.
HOWELL, G. 2003. The Last Planner System. *2003 Nova Award Nomination,* Work flow managment.
HUSSEIN, B. 2012a. Forelesningsnotat TPK4115 Prosjektplanlegging og styring: Intro. Trondheim, Norway: NTNU.
HUSSEIN, B. 2012b. Forelesningsnotat TPK4115 Prosjektplanlegging og styring: Scope planning. Trondheim, Norway: NTNU.
HUSSEIN, B. 2012c. Forelesningsnotat TPK4115 Prosjektplanlegging og styring: Success. Trondheim, Norway: NTNU.
JENSEN, P., LARSSON, J., SIMONSSON, P. & OLOFSSON, T. Improving Buildabuility with Platforms and Configurators. 21st Annual Conference of the International Group for Lean Construction, 2013 Fortaleza, Brazil. 771-780.
JOHANNESSEN, A., TUFTE, P. A. & CHRISTOFFERSEN, L. 2010. *Introduksjon til samfunnsvitenskapelig metode,* Oslo, Abstrakt.
JONSSON, J. 1996. *Construction site productivity measurements: selection, application and evaluation of methods and measures,* Luleå, The University.
KENSEK, K. M. 2014. *Building information modeling,* Abingdon ; New York, Routledge.
KHAN, S. & TZORTZOPOULOS, P. Effects of the Interactions Between LPS and BIM on Workflow in Two Building Design Projects. 22nd Annual Conference of the International Group for Lean Construction, 2014 Oslo, Norway. 933-944.
KVALE, S. 1997. *Interview: en introduktion til det kvalitative forskningsinterview,* København, Hans Reitzels Forl.
KYMMELL, W. 2008. *Building information modeling: planning and managing construction projects with 4D CAD and simulations,* New York, McGraw-Hill.
LÆDRE, O. 2009. *Kontraktstrategi for bygg- og anleggsprosjekter,* Trondheim, Tapir akademisk forl.
LÆDRE, O. 2010. Forelesningsnotat 43/10 TBA4202 BM1 Infrastruktur: Kontrakter. Trondheim, Norway: NTNU.
MARADZA, E., WHYTE, J. & LARSEN, G. D. Standardisation of Building Information Modelling in the UK and USA: Challenges and Opportunities. Architectual Engineering Conference 2013, 2013 State College, Pennsylvania, United States. 458-467.
MAYO, G., GIEL, B. & ISSA, R. R. A. BIM Use and Requirements among Building Owners. International Conference on Computing in Civil Engineering, 2012 Clearwater Beach, Florida, United States. 349-356.

MILJØDEPARTEMENTET. 2000. *Fra ord til handling* [Online]. Dokumentarkiv. Available: http://www.regjeringen.no/nb/dokumentarkiv/Regjeringen-Stoltenberg-I/md/Taler-og-artikler-arkivert-individuelt/2000/fra_ord_til_handling.html?id=264395 [Accessed Oct 31 2014].
MOORE, R. 2007. *Selecting the right manufacturing improvement tools: what tool? when?,* Amsterdam, Elsevier.
OSPINA-ALVARADO, A. M. & CASTRO-LACOUTURE, D. Interaction of Processes and Phases in Project Scheduling Using BIM for A/E/C/FM Integration. Construction Research Congress 2010, 2010 Banff, Alberta, Canada. 939-948.
PINTO, J. K. 2013. *Project management: achieving competitive advantage,* Boston, Mass., Pearson.
PMI 2004. *A Guide to the project management body of knowledge: (PMBOK guide),* Newtown Square, Pa., Project Management Institute.
RAMBOLL. 2014. *Nytt nasjonalmuseum* [Online]. Available: http://www.ramboll.no/projects/rno/nasjonalmuseet [Accessed Nov 11 2014].
REGJERINGA. 2012. *Gode bygg for eit betre samfunn* [Online]. Kommunal- og moderniseringsdepartementet. Available: http://www.regjeringen.no/nb/dep/kmd/dok/regpubl/stmeld/2011-2012/meld-st-28-20112012/2/4.html?id=685194 [Accessed Oct 31 2014].
SACKS, R., BARAK, R., BELACIANO, B., GUREVICH, U. & PIKAS, E. 2013. KanBIM Workflow Management System: Prototype implementation and field testing. *Lean Construction Journal*, 19-35.
SACKS, R., KOSKELA, L., DAVE, B. A. & OWEN, R. 2010. Interaction of Lean and Building Information Modeling in Construction. *Journal of Construction Engineering and Management,* 136**,** 968-980.
SAMSET, K. 2008. *Prosjekt i tidligfasen: valg av konsept,* Trondheim, Tapir akademisk forl.
SPITLER, L. E. The Effect of Inter-Team Dynamics on the Constructability of the BIM Model. 22nd Annual Conference of the International Group for Lean Construction, 2014 Oslo, Norway. 957-968.
STATSBYGG. 2014. *Nytt nasjonalmuseum. PNN* [Online]. Available: http://www.statsbygg.no/Prosjekter-og-eiendommer/Byggeprosjekter/Nasjonalmuseum/ [Accessed Nov 12 2014].
SUN, M. & HOWARD, R. 2004. *Understanding I.T. in construction,* London, Spon Press.
TORP, O. 2010. Forelesningsnotat 41/10 TBA4202 BM1 Infrastruktur: Byggeprosessen. Trondheim, Norway: NTNU.
VANDEZANDE, J., READ, P. & KRYGIEL, E. 2011. *Mastering Autodesk Revit architecture 2012,* Indianapolis, IN, Wiley.
WANG, X., ED LOVE, P. & DAVIS, P. R. BIM + AR: A Framework of Bringing BIM to Construction Site. Construction Research Congress 2012: Construction Challenges in a Flat World, 2012 West Lafayette, Indiana, United States. 1175-1181.
WON, J., LEE, G., DOSSICK, C. & MESSNER, J. 2013. Where to Focus for Successful Adoption of Building Information Modeling within Organization. *Journal for Construction Engineering and Management,* 139.
YIN, R. K. 2014. *Case study research: design and methods,* Los Angeles, Calif., SAGE.
ZUPPA, D., ISSA, R. R. A. & SUERMANN, P. C. 2009. BIM's Impact of the Success Measures of Construction Projects. *Computing in Civil Engineering 2009***,** 503-512.
ØSTBY-DEGLUM, E. 2011. Kompendium TBA4127 Prosjekteringsledelse - Teoretisk grunnlag. Trondheim, Norway: NTNU.

APPENDICES

APPENDIX A: Specification of Master Thesis

Problem Description
Many BIM applications have been developed since the concept of BIM was first published, but the AEC industry is an industry reluctant to drastic change, and few are utilizing BIM to its full potential. Participants in the Norwegian AEC industry are currently using BIM actively in the initial and closing phases of projects, but only modestly during the construction phase. This creates a black hole in their project processes, which is the triggering factor for the desire to research the benefits and challenges with using BIM in all project phases, as well as actions necessary to increase the utility value of BIM in all phases. A pilot study including two semi-structured open-ended interviews was carried out to get a holistic view of the benefits and challenges with using BIM. To reduce the challenges and to increase the benefits, three main categories of actions were identified and recommended: Cultural changes, contract revision, and software development.

The transition from traditional implementation methods to BIM based methods will with time be inevitable. The purpose of this research is to (1) seek verification of the already identified necessary actions through further literature review and more interviews, (2) identify more necessary actions, (3) elaborate on the magnitude and significance of the actions, (4) convince the AEC industry that using BIM in all project phases can be beneficial in social, economical and environmental context, and (5) prevent, reduce and eliminate the earlier described black hole in the project processes and implementation methods.

Research Problem
What actions are necessary in order to increase the utility value of BIM in all project phases?

Research Objective
To identify currently experienced benefits and challenges with using BIM in the construction phase, and to identify actions necessary to increase the utility value of BIM in all project phases.

Research Questions
- What are the benefits and challenges with using BIM in the construction phase?
- What actions are necessary to increase the utility value of BIM in all project phases?
- Who should be responsible for implementing the actions?

APPENDIX B: Case Project 1 – New National Museum

Project Facts

The Ministry of Culture represented by Statsbygg, is building a New National Museum for art, architecture, and design at Vestbanen in Oslo, Norway. The new building complex named Forum Artis, will emerge as a cultural profile for Norway, and for Oslo as the nation's capital (Statsbygg, 2014). An illustration of the modeled final project product is shown in Figure 17.

Figure 17 The New National Museum.[15] Illustration: MIR kommunikasjon AS

Rambøll Norge AS is the primary consultant in the disciplines of construction, geotechnical and electrical engineering, plumbing, fire, and acoustics, and holds the role of Engineering Group Coordinator. Rambøll Norge AS is also contributing with special expertise in universal design, lighting planning, security, automation, environment, and traffic. Additional project facts are shown in Table 19 (Statsbygg, 2014).

Table 19 The New National Museum Facts and Roles

Facts	and Roles
Client	Ministry of Culture
Builder	Statsbygg
Architect	Kleihues + Schuwerk Gesellschaft von Architekten mbH
Pre-project Complete	Spring 2012
Development Plan Approved	2013
Construction Start	2014
Status	Detailed design and excavation
Project Completion	Summer 2019
Gross Building Area	Approx. 54 600 m^2
Project Cost	5.327 billion NOK (July 1st 2013)

The New National Museum project (PNN) has a strong focus on environmental requirements related to emissions, energy, materials, and construction solutions, with the goal to build a climate friendly building. The ambitious environmental goals include creating a building that produces less than 50 % of CO^2 emissions compared with traditional reference buildings (Ramboll, 2014).

[15] Illustration is available at: http://www.statsbygg.no/Prosjekter-og-eiendommer/Byggeprosjekter/Nasjonalmuseum/Bilder/

PNN's project model and project scope are shown in Figure 18.

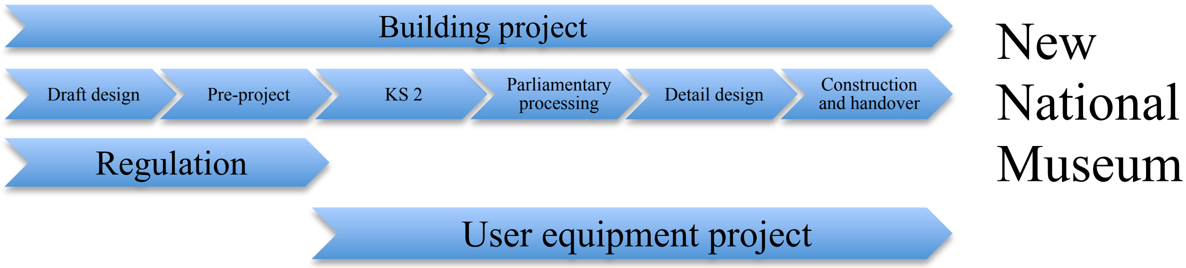

Figure 18 Project Model and Project Scope in PNN

Statsbygg has required use of BIM tools in the implementation of the *Building project* for ongoing project development and implementation, with the intention to reduce construction and operation costs significantly. The project has a general objective to be a reference project concerning use of BIM. The Building Information Model is to be updated continuously until project completion and when the model is handed over to the project owner for facility management, operation, and maintenance.

BIM Goals

A BIM implementation plan has been created for PNN to coordinate and inform all parties involved. These requirements and criteria were introduced in order to achieve the goal of making this a reference project in terms of using BIM:

- BIM processes shall facilitate good communication, coordination, and control of the project, and the visualization of the building geometry shall lead to a better understanding of the project among all parties involved, and contribute to a uniform anchoring of solutions. Furthermore, the models yield the ability to efficiently extract information with a high degree of accuracy.
- The BIM implementation plan should clearly define all processes involving BIM. The document will clarify the level of detail for BIM deliverables in the different phases. The procedures for interdisciplinary collision checks related to the responsibility of monitoring are specified, and an action plan to deal with challenges related to interoperability is created.
- Using BIM in the construction phase will facilitate an effective cooperation between engineering groups and contractors. This applies to both forward planning in the construction phase, planning for the health, safety, and working environment, and digital construction testing.

As the processes of design and documentation change, so does staffing, fundamentally (Vandezande et al., 2011). BIM deliverables must be coordinated and quality assured before sharing, and shall meet requirements imposed by Statsbygg, which demand a BIM Coordinator. The BIM Coordinator's task is not disciplinary responsibility, but technical responsibility for BIM deliverables and their content to be in accordance with Statsbygg's current BIM handbook. The BIM Coordinator is responsible for implementing work processes that support good interaction between design and engineering groups. A Modeling Group has been put together to perform the actual modeling of discipline models, and to participate in interdisciplinary work sessions for interdisciplinary design and planning of work to be executed between meetings. The Engineering Group Coordinator is responsible for coordinating engineering teams, and for making sure that they focus on the right tasks.

APPENDIX C: Case Project 2 – Mesterfjellet skole, Larvik

Project Facts

Mesterfjellet is a primary and lower secondary school (1-10 kl.) in Larvik, Norway. Parts of three schools were replaced by the new school. Although the number of pupils isn't expected to increase, the lack of maintenance over time made it necessary to build a new school. The old school facilities did not meet modern teaching and lecturing methods, and were unable to adapt to new energy requirements with integrated techniques.

Figure 19 Winning design draft named Relativity[16]

CEBRA, Various Architects, and landscape architects Østeng & Bergo designed the project. Various Architects split up during the final design phase, and were replaced by SPINN Architects. The final project design was based on the winning draft named Relativity, which is shown in Figure 19. The completed project product is shown in Figure 20.

Figure 20 Mesterfjellet skole completed. Photo: Trond Joelson[17]

[16] http://www.op.no/jobb/article6125711.ece
[17] http://www.bygg.no/article/1198211

Larvik Kommune Eiendom (LKE) or Larvik City Council, Real Estate Division was the client and project owner. Rambøll Norge AS was responsible for construction management while OPAK had project management. Buer Entreprenør was the main contractor and property developer on the project. Additional project facts for Project Mesterfjellet (PMF) are show in Table 20 below.

Table 20 Mesterfjellet Facts and Roles

Facts	and Roles
Client, Owner and Builder	Larvik City Council, Real Estate Division
Architects	Cebra, SPINN Arkitekter and Various Architects
Landscape Architect	Østeng & Bergo
Property Developer	Buer Entreprenør
Project Type	1-10 grade School
Project Start	March 2012
Project Completion	August 2014
Gross Building Area	Approx. 6 200 m2
Construction Cost	152 million NOK, VAT
Total Project Cost	225 million NOK, VAT

Larvik municipal has focused strongly on energy, and indoor and outdoor environment. The project management focused on both spatial and functional program through active user participation, and energy and environmental goals were specified early in the project. The new school is a low energy building with a hybrid ventilation solution: A combination of both traditional mechanical ventilation systems and motorized opening of façade windows.

BIM Goals

This project did not have a goal to be a BIM reference project, but LKE placed some demands related to BIM use in the construction phase, and to BIM quality:

- All engineering shall be conducted in Open BIM[18]. BIM shall not be used for outdoors plants, roads, or water supply and sewage, but the terrain model shall be included.
- All surfaces shall be placed on space objects.
- BIM shall be utilized for coordination, collision control, and production planning. The BIM model shall be available to the builder's inspection and control at all times during the design process.
- The BIM model can be used after project completion by LKE for future operation and maintenance. The digital original IFC model shall be included in the facility management, operation, maintenance, and development documentation. The model shall contain all technical disciplines, and only include actual used components in terms of size and technical information.
- The main contractors shall allocate their own BIM Coordinator. A BIM handbook with requirements for BIM design must be presented, in writing, to the project owner within two months after signing the contract.

[18] http://www.graphisoft.com/archicad/open_bim/

APPENDIX D: BIM Features Currently Used by the Interviewees

Project Management – Project Owner: The project management uses BIM for visualization and walk-through of buildings, to extract areas and quantities, to look at technical systems, to coordinate, and to verify that there are no conflicts. PNN is suppose to be Statsbygg's reference project within BIM, but the reality is that the architect has no desire to use BIM, and Statsbygg has so far not implemented the project utilizing BIM processes. The result is a traditional design process where the engineering managers deliver a BIM model weekly to the architect instead of continuous sharing. The model received back from the architect is not necessarily updated because they choose to produce paper drawings first, and only update the model once decisions are made, which is a challenge. The consulting engineers use the model for design and engineering by walking through the building room-by-room, and highlighting existing challenges. Collision analyses are however not taken advantage of often enough. The engineering management uses BIM to coordinate the multidisciplinary model. The BIM Coordinator's responsibility is to compile discipline models, and use the multidisciplinary model for engineering management through visual inspections and collision analysis. People in the project administration use BIM too rarely, mostly due to the present contract strategy. Design & Build contracts have become more common over time, which means that the BIM Coordinator role and the Engineering Manager role both lie with the main contractor. The Design Manager has commonly been assigned the BIM Coordinator's responsibility, but this will change as more people become familiar with BIM. The project management of PMF demanded that the BIM Coordinator was not to have any other roles in the project.

Consulting Engineers: Autodesk Revit is used as the main tool, which is a modeling software program. IFC files are used if other software programs than Revit are used, to check that different discipline models are in correspondence. However, export and import of IFC files don't work properly. Solibri and dRofus are used for model analyzing, dimensioning, and quality checks. Statsbygg's demands for building requirements in PNN are inserted into the model using these programs to get correct room temperature, relative humidity, sizes, spaces, airflows, etc. Statsbygg seems most concerned about the 'I' in BIM. They wish to use the model for facility management, operation, and maintenance documentation. Such documentation for the engineering of the building's substructure is minimal, and BIM is therefore used less for such work.

BIM Technicians: BIM Technicians are taught numerous programs and processes. They're taught to manage Revit, ArchiCAD, DDS, MagiCAD, Solibri, etc. They practice collision analyses, quality assurance, and how to implement ICE meetings. ICE meetings or Integrated Concurrent Engineering meetings, are construction meetings where digital methods are used. These can be conducted in a room with two large screens where all disciplines work together to generate a Solibri report. Collisions and errors are reported, and distributed to the responsible disciplines. Revit, ArchiCAD, Solibri, and Navisworks are used for modeling, visualization, extracting and controlling quantities, running collision analyses, and creating implementation plans from the model.

Architect: Graphisoft ArchiCAD is used for designing and modeling, and Solibri Model Viewer is used for coordination with other disciplines' IFC models. ArchiCAD has a function called BIMx, which downloads the exported ArchiCAD model, and makes it possible to view the entire model, but without the option to make adjustments. BIMx can be used in meetings or be given to project clients. We chose to buy ArchiCAD licenses because we felt we got more value for our money. An ArchiCAD license is significantly cheaper than a Revit license, and slightly designer friendlier. Revit is more suitable for engineering. BIM puts restrictions on design, especially compared with traditional design methods. Revit requires decisions to be made much earlier. Decisions that were traditionally made in the pilot design phase or the detail design phase must now be considered in the concept phase. ArchiCAD is more flexible in this context.

Project Management – Contractor: The BIM competence on the contractor side of the AEC industry is very low. Our mother company has hired a resource on BIM, and one of the sister companies have reached out to a BIM expert, but our implementation of BIM is at its earliest stage. We have used Solibri Model Viewer to open IFC files to get a complete overview of what is to be built.

Construction Scheduler – Contractor: Navisworks or something similar is used to read the information available in the model.

Discussion: This question was asked as part of the introduction in the interviews. This question was asked because the answers could give a good indication of how far along the BIM implementation interviewees and their departments have come, as well as throwing light on how important a sufficient export and import format is. Table 21 clearly illustrates the importance of the latter.

Table 21 BIM Features Currently Used by the Interviewees

	Autodesk Revit	Autodesk AutoCAD	Graphisoft ArchiCAD	Solibri Model Checker	Solibri Model Viewer	Autodesk Navisworks	dRofus	ISY G-prog	Microsoft Project	Oracle Primavera P6	IFC
Project Management - Project Owner	x					x			x		x
Consulting Engineers	x			x			x				x
BIM Technicians	x	x	x	x	x	x					x
Architect			x					x			x
Project Management - Contractor					x	x		x	x		x
Construction Scheduler - Contractor						x		x	x	x	x

The BIM technicians seem to be the only ones who are accustomed to most common BIM software programs, which one might say is part of their responsibility as BIM technicians. The fact that the contractor isn't using any Building Information Modeling software programs may indicate a fundamental concern in terms of continuing using BIM in the construction phase. Contractors have the leading roles in the construction phase, and their use of BIM, and their utility value from BIM rely on them having a sufficient level of BIM skills.

APPENDIX E: Current Use of BIM in the Construction Phase

Project Management – Project Owner: BIM is limitedly used in the construction phase. We use BIM to review plans, sections, or 3D representation of rooms, technical facilities, or the project as a whole. The construction phase is divided into periods of 6 to 8 weeks and planned accordingly. We can choose components we are going to produce during the next period, and extract complete order lists and information craftsmen need to execute those activities. BIM has most commonly been used in the design phase, and has become a natural part of design and planning meetings, which are now characterized by interdisciplinary work with IFC and models. These meetings are also conducted during the construction phase, with a new meeting structure: The BIM Coordinator takes control.

Statsbygg has big ambitions of using BIM in the construction phase. We have ambitions and goals of using BIM to communicate solutions among workers on site. BIM gives a better understand of how the building should be built, and a better visualization of what it should look like when finished. BIM is currently actively used for site planning by visualizing different location of cranes and equipment containers in different phases. BIM is going to be used to communicate and ensure interfaces, to clarify interfaces, and to clarify the consequences of changes in engineering solutions. BIM shall also be used actively in planning and execution, which require full detailing, and access to all necessary information. The models meet the level of detail required by Statsbygg in their BIM handbook. It's unclear how many of the contractors have the capacity to follow this up, and use the model actively. The project is currently executing the excavation contracts, so we haven't gotten any impressions of whether the construction contractor wants to use the model or not.
Substantial time was spent figuring out the appropriate level of detail in PMF, but we ended up with a lower level of detail than we wanted to achieve. This was because we believed that neither the project implementation nor the operation afterwards would benefit from further detailing. We were also unable to meet the requirement stating that the model should be part of and integrated with LKE's Management, Operation, Maintenance and Development programme. It will in the long run be of interest to only send out BIM models to tender, so that contractors can cost estimate their services based on that. The 2D drawings and written descriptions still constitute the legal documentation, which makes the implementation of BIM slow on the construction site.

Consulting Engineers: Every discipline models their own models, and submits them to the BIM Coordinator for integration and exporting to IFC. BIM models help consulting engineers anticipate and understand how the building will look when completed. The utilization of BIM is gradually increasing, but the implementation is slow on-site. BIM is used by site office administrations, but the range of use is limited. They use BIM for scanning to measure existing buildings and the site, and for visualization in preparation of site planning and placement of cranes, and site logistics. 2D drawings are classified as the legal documentation, and no specific level of detail is usually demanded as long as 2D drawings are sufficient. The PNN contractors have so far only been granted access to those model parts that correspond to awarded contracts, and not the model of the entire project. BIM kiosks will be placed around site, and tablets will be used for simple visualization. BIM is also going to be used to ensure safety on site. The level of detail in our models is high but not 100 %. The models show all building components' geometry, but it has not been demanded that the models must show the components' interior. Concerning ventilation: Only ventilation ducts, main conduits, and valves are modeled. Suspension systems aren't because we're not required to model them, and the Revit libraries are too incomplete. To include such detailing is time consuming, and we don't prioritize it as it is considered unnecessary, even though it would make models more accurate. The project description and the model should have been linked together, which we tried in the first two contracts, but we experience that the BIM tools were too incomplete. Software producers couldn't promise that their programs would become sufficient enough.

BIM Technicians: Use of BIM in the construction phase depends on the project team's BIM skills and on the appropriateness of the model structure. 2D drawings still constitute the documentation that is sent out on site, even though most large projects today are modeled. Collision analyses are run to get an overview of all errors between disciplines, and these analyses will continue to be carried out weekly in multidisciplinary meetings held throughout the construction phase in PNN. The BIM technician professor believes the blame for people's doubts concerning BIM lies on the way today's architectural education is structured: BIM and BIM methodology are not compulsory courses for either architects or engineers, and the professors therefore disclaim all liability, which is a misuse of state funds. As a result, graduates experience a practice-shock when entering the work life, and are forced to use large public projects for training. Experienced people in the AEC industry claim that if the model is modeled properly, there are no barriers for using BIM in the construction phase. There are ongoing projects now where BIM is brought out on site via BIM kiosks. There is a certain level of skepticism toward them, but this may be a good way of introducing BIM to site workers, along with a gradual transition from drawings to models. Tablets are utilized to control that executed work is done according to drawings and descriptions. Some projects are attempting 4D visualization, like Kunsthøyskolen in Bergen. This project has two goals: To have a paperless construction site, and to use BIM actively on site. Navisworks is used for 4D visualization, which simulates the structure of the building components and their execution sequence. These goals require a very high level of detail, and that the modeling is done in a slightly different way, taking into account how objects are cuts.

The 'BIM or not BIM'-discussion is comparable with the discussion we had in the 80s about whether computers could be as effective a tool as pen and paper for writing. BIM is a force to be reckoned with, and in about half a generation we'll probably be amused by this discussion. The forces against BIM lie with those thinking it's difficult to learn new things, like the professors at the architectural institutes. Those who hope they'll retire before BIM is mandated as a mandatory part of the educational program. The biggest challenge today is to model correctly and not cheat, as work drawings are consequences of the model. The level of detail must be regulated in contract agreements.

Architect: BIM is rarely used on construction sites, which is a shame as architects and engineers spend a lot of time and energy making good 3D models. Models are used for extracting 2D drawings and descriptions. These still constitute the tender documentation and contract agreements, and are the documents craftsmen use. At PMF, we experienced getting phone calls from site workers with questions regarding things they could have easily understood by reviewing the model. We use line weights in floor plans to explain components' elevations, but this is even clearer in 3D. As a complement to 2D drawings, BIM is an excellent tool if used, also on site. However, the model can never be 100 % detailed, so the model is just a representation of information. The model is a simplification, while details are drawn onto 2D sections and floor plans. A BIM model will for instance not be enriched with joints because the file becomes too heavy to work with. Creating a complete model is too time consuming, the software is unable to support it, the file becomes too heavy, and the model becomes unmanageable.

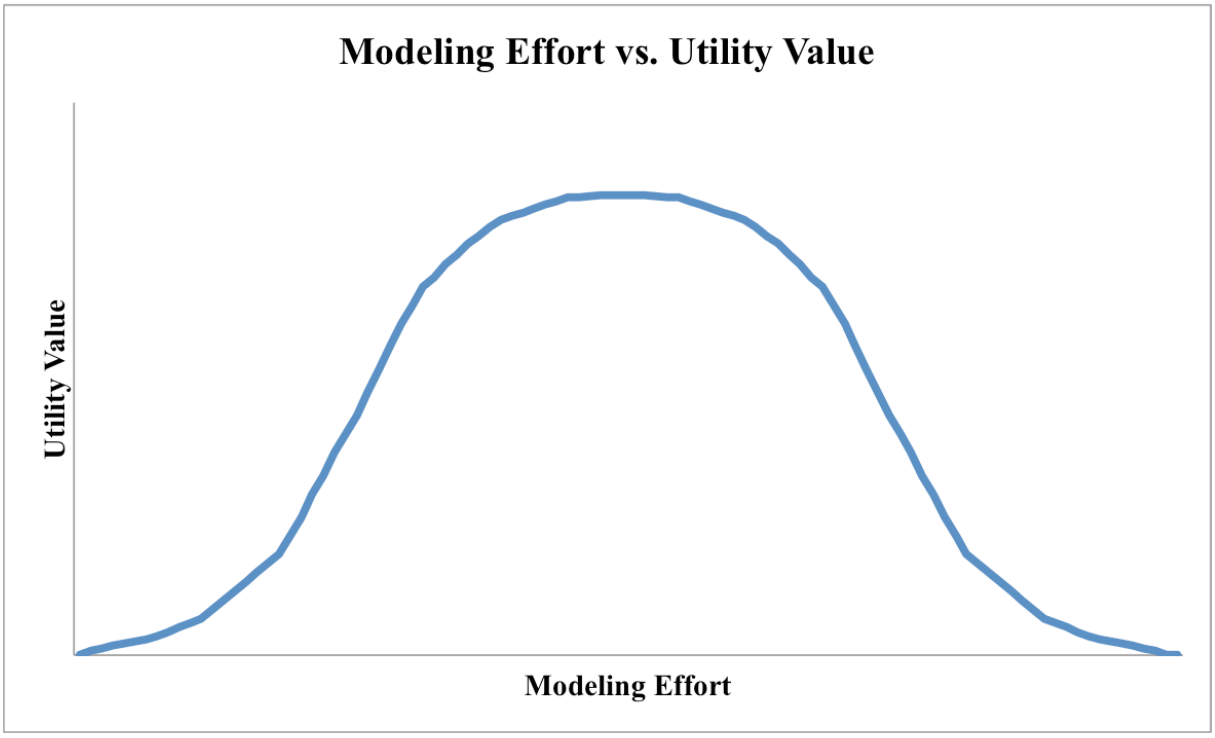

Figure 21 Graph illustrating Modeling Efforts vs. Utility Value

Choosing a sufficient level of detail is a very important design team task. The curve in Figure 21 illustrates how further detailing can result in waste. The goal is to find an optimal level of information in BIM models: The highest level of utility value possible with the least amount of effort. A BIM handbook was developed for PMF with detailing and process requirements: How to work together, and how things should be inserted and modeled in the model.
A complete and fairly detailed BIM model was delivered in PMF, but it is still at a level of abstraction, which is a necessity today.

Project Management – Contractor: BIM is today only used in projects where the client has mandated it. The reason for this is that consulting engineers charge more for their services in a BIM project than in traditional projects. Given that we fail to assess the overall utility value or the cost savings of BIM in the construction phase, we refrain from buying these services to save money, which is a shame. Models were used in the construction phase in PMF for overall visualization of the building. BIM increased our understanding of consulting engineers' chosen solutions, but I still felt that the level of detail was somewhat insufficient. Contractors in the AEC industry have a fairly long way to go before being able to handle BIM efficiently. A big challenge in this project was that some site managers, foremen, and also project managers had too insufficient IT competence to be able to navigate in BIM models. Many of them barely knew how to handle email!

It is in a new ongoing project required that all site managers must have a tablet containing the 3D model available. We begin to recognize the utility value of BIM, but the fear of using it, and the fear of making mistakes are huge obstacles.

Construction Scheduler – Contractor: The BIM model is an information model in the construction phase. BIM is poorly utilized in the construction phase because those who need to understand the model don't have easy access to it. As the construction scheduler I need to understand the composition, and to see the entire project in one model. BIM offers a simple way to visualize that information. The level of detail in the model must be at a blueprint-level.

All details must be included in the model so that it reflects what's to be built. It is important that the model is updated at all times. Traditional 2D drawings' validity is in many projects ranked higher than BIM models in legal context and legal discussions, but these drawings still need to be attached to the model.

Discussion: This question was asked as part of the introduction in the interviews. The intention of asking this question was to find out in what construction phase processes and construction site tasks BIM is currently being utilized. The interviewees all began by confirming that BIM is limitedly used in the construction phase, but they were all able to give examples of tasks or processes where BIM is utilized today. All these viewed collectively make up more areas of use than what the researcher had suspected. The contractor said that BIM is currently only utilized in projects where the client has mandated it, which coincides with two of the most dominant implementation challenges in BIM projects: The missing integration of BIM in contract agreements, and the lack of national or international standards for BIM implementation and BIM processes. The primary reason why BIM models don't have the highest level of detail is because of unspecified requirements set by clients. The secondary reason is, as mentioned by the architect: Creating a complete model is too time consuming, the software is unable to support it, the file becomes too heavy to work with, and the model becomes unmanageable. The three latter challenges suggest that a few important steps for successful implementation of BIM have been skipped (see section 2.12.2).

APPENDIX F: Initial Interview Guide

Presentasjon av intervjuer
Mitt navn er Maria Eriksen Hellum, og jeg er masterstudent ved NTNU på studieretningen bygg- og miljøteknikk med spesialisering innen prosjektledelse. Masteroppgaven, som dette intervjuet er en del av, skal leveres i juni 2015. Temaet til denne studentoppgave ble valgt i samarbeid med Rambøll Sandefjord.

Bakgrunn for intervjuet
Masteroppgaven konsentrerer seg om byggefasen, og overgangen inn i og ut fra byggefasen. Tanken bak denne forskningen er at; Dersom en bygningsinformasjonsmodell kun brukes i prosjekteringsfasen og driftsfasen, men ikke byggefasen, skapes et "sort hull" i gjennomføringen av prosjektet. Flere BIM-fordeler ansees dermed som tapt og å gå til spille. Hensikten med masteroppgaven er å finne ut hvilke fordeler og ulemper bruk av BIM i alle prosjektfaser bringer med seg. Dette skal gjøres ved å se på ulike aktører og rollers oppfatning og erfaring med BIM. Ut fra fordelene og ulempene ønsker jeg også å finne ut hvilke tiltak intervjupersonene mener må iverksettes for å øke nytteverdien av BIM ved å minske ulempene. Problemstillinger:

1) *Hvilke fordeler og ulemper finnes ved bruk av BIM i byggefasen?*
2) *Hvilke tiltak må iverksettes for å øke nytteverdien av BIM i alle prosjektfaser?*
3) *Hvem bør være ansvarlig for oppnåelse og utførelsen av tiltakene?*

Opptak av intervjuet
For å sikre en god samtale og at intervjuet blir gjengitt korrekt vil det bli gjort lydopptak av intervjuet. Lydopptaket vil i etterkant bli transkribert og sendt til intervjupersonen pr epost. Dette gjør det mulig for intervjupersonen utdype dersom ønskelig.

Intervjupersonens utbytte av deltakelse
Intervjupersonene vil til gjengjeld for sin deltakelse få tilgang på den ferdige utgaven av masteroppgaven. Dette vil gi intervjupersonene mulighet til å bruke resultatene internt til forbedring av BIM implementering. Intervjupersonene vil også være med på å bidra til arbeid som kan være med på realiseringen av de hittil uutnyttede BIM-gevinstene.

Spørsmål
Bakgrunn:
- Fortell kort om deg selv og din bakgrunn. (Utdanning, stilling, rolle, karriere, alder)
- Hvordan vil du definere BIM og et BIM-prosjekt?
- Hvilke BIM-funksjoner benytter du og din avdeling/bedrift seg av?
- Hvordan brukes BIM i byggefasen? Hvilke krav stilles til detaljering?
- Hvem har tilgang på modellen i byggefasen? Hvilke andre burde ha tilgang?
- Hvordan er ansvarfordelingen forskjellig i BIM-prosjekter fra tradisjonelle prosjekter?

1) Fordeler(gevinster) og ulemper(mangler/utfordringer) med bruk av BIM i byggefasen:
- Hvilke endringer må gjøres i modellen for å kunne overføre modellen fra prosjekteringsfasen til byggefasen?
- Hva er fordelene og ulempene med BIM i byggefasen med/i forhold til:
  - o Måten ansvaret er fordelt på?
  - o BIMs analytiske funksjoner?
  - o BIMs informasjonsdeling?

- Samarbeid og kommunikasjon med andre aktører på alle nivå?
- Kundesamarbeid og kundetilfredshet?
- Erstatning av papirtegninger på prosjektkontoret? Og ute på byggeplassen?
- Feil og misforståelser i produksjonsgrunnlag?
- Planlegging og oppfølging av fremdrift?
- Planlegging og oppfølging av budsjett?
- Kostnadsendringer? (totale kostnader og cash flow)
- Sløsingsreduksjon? (waste)
- Gjenbruk av kunnskap og erfaring fra tidligere prosjekter?
- Overlevering av prosjektet til prosjekteier?

2) Tiltak som må iverksettes for å øke nytteverdien av BIM i byggefasen:

- For å forenkle overføringen av modellen fra prosjekteringsfasen til byggefasen?
- For å forbedre måten ansvar i BIM-prosjekter er fordelt på?
- For å forbedre BIMs analytiske funksjoner?
- For å forbedre BIMs informasjonsdeling?
- For å forbedre samarbeidet og kommunikasjonen med andre aktører på alle nivå?
- For å forbedre kundesamarbeidet og kundetilfredsheten?
- For å kunne erstatte papirtegninger på prosjektkontoret? Og ute på byggeplassen?
- For å redusere feil og misforståelser i produksjonsgrunnlag?
- For å forbedre planlegging og oppfølging av fremdrift?
- For å forbedre planlegging og oppfølging av budsjett?
- For å redusere konsekvensene av kostnadsendringer? (totale kostnader og cash flow)
- For å redusere sløsing? (waste)
- For å øke nytten av gjenbruk av kunnskap og erfaring fra tidligere prosjekter?
- For å forenkle overlevering av prosjektet til prosjekteier?

3) Hvem bør være ansvarlig for oppnåelse og utførelsen av tiltak tilknyttet:

- Endringer som må gjøres i modellen for å kunne overføre modellen fra prosjekteringsfasen til byggefasen?
- Måten ansvaret er fordelt på?
- BIMs analytiske funksjoner?
- BIMs informasjonsdeling?
- Samarbeid og kommunikasjon med andre aktører på alle nivå?
- Kundesamarbeid og kundetilfredshet?
- Overgangen fra papirtegning til modell på prosjektkontoret? Og ute på byggeplassen?
- Oppfølging av feil og misforståelser i produksjonsgrunnlag?
- Planlegging og oppfølging av fremdrift?
- Planlegging og oppfølging av budsjett?
- Kostnadsendringer? (totale kostnader og cash flow)
- Reduksjon av sløsing? (waste)
- Gjenbruk av kunnskap og erfaring fra tidligere prosjekter?
- Overlevering av prosjektet til prosjekteier?

Avslutning:

- Hva mer kan BIM brukes til i byggefasen?
- Er det noe du ønsker å tilføye som du mener intervjuet ikke har dekket?
- Har du noen kommentarer eller tilbakemeldinger på intervjuet?

APPENDIX G: Revised Interview Guide

Presentasjon av intervjuer
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1) Hvilke fordeler og ulemper finnes ved bruk av BIM i byggefasen?
2) Hvilke tiltak må iverksettes for å øke nytteverdien av BIM i alle prosjektfaser?
3) Hvem bør være ansvarlig for oppnåelse og utførelsen av tiltakene?

Opptak av intervjuet
For å sikre en god samtale og at intervjuet blir gjengitt korrekt vil det bli gjort lydopptak av intervjuet. Lydopptaket vil i etterkant bli transkribert og sendt til intervjupersonen pr epost. Dette gjør det mulig for intervjupersonen utdype dersom ønskelig.

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Intervjupersonene vil til gjengjeld for sin deltakelse få tilgang på den ferdige utgaven av masteroppgaven. Dette vil gi intervjupersonene mulighet til å bruke resultatene internt til forbedring av BIM implementering. Intervjupersonene vil også være med på å bidra til arbeid som kan være med på realiseringen av de hittil uutnyttede BIM-gevinstene.

Spørsmål
Bakgrunn:
- Fortell kort om deg selv og din bakgrunn. (Utdanning, stilling, rolle, karriere, alder)
- Hvordan vil du definere BIM og et BIM-prosjekt?
- Hvilke BIM-funksjoner benytter du og din avdeling/bedrift seg av?
- Hvordan brukes BIM i byggefasen? Hvilke krav stilles til detaljering?
- Hvem har tilgang på modellen i byggefasen? Hvilke andre burde ha tilgang?
- Hvordan er ansvarfordelingen forskjellig i BIM-prosjekter fra tradisjonelle prosjekter?

1) Fordeler og ulemper, 2) Tiltak, og 3) Ansvarsperson/-rolle:
- Hvilke endringer må gjøres i modellen for å kunne overføre modellen fra prosjekteringsfasen til byggefasen?
- Hva er fordelene og ulempene med BIM i byggefasen med/i forhold til:
    - Måten ansvaret er fordelt på?
    - BIMs analytiske funksjoner?
    - BIMs informasjonsdeling?

- Samarbeid og kommunikasjon med andre aktører på alle nivå?
- Kundesamarbeid og kundetilfredshet?
- Erstatning av papirtegninger på prosjektkontoret? Og ute på byggeplassen?
- Feil og misforståelser i produksjonsgrunnlag?
- Planlegging og oppfølging av fremdrift?
- Planlegging og oppfølging av budsjett?
- Kostnadsendringer? (totale kostnader og cash flow)
- Sløsingsreduksjon? (waste)
- Gjenbruk av kunnskap og erfaring fra tidligere prosjekter?
- Overlevering av prosjektet til prosjekteier?

Avslutning:

- Hva mer kan BIM brukes til i byggefasen?
- Er det noe du ønsker å tilføye som du mener intervjuet ikke har dekket?
- Har du noen kommentarer eller tilbakemeldinger på intervjuet?