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Enabling Lean Design with Management of Model Maturity

A Study of Maturity-Based Construction Design
in Norwegian AEC-Projects

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Preface

The following thesis concludes a five-year masters program at the Department of Civil and Environmental Engineering at NTNU. It was conducted with a specialization towards project management within civil engineering and was written during the spring of 2018. The thesis presents a study of current approaches and experiences with maturity-based approaches to construction design management in large Norwegian design build projects.

The assignment was initially based upon the master thesis written by Iver Grytting during the spring of 2017 called *”Use of LoD-Decision Plan in BIM-projects”* with the intent of further developing the LOD-framework presented in his thesis. An introductory study in form of a project report written during the autumn of 2017 revealed that management approaches close to best-practice in the industry commonly utilize lean planning tools such as Last Planner™ and Integrated Concurrent Engineering (ICE). As a result, the study changed direction in order to research how model maturity should be incorporated into these existing practices with implementation strategies based on lean theory.

My guidance councillor Ola Lædre (Associate Professor, dr.ing., Department of Civil and Environmental Engineering, NTNU) deserves acknowledgement for initially leading me onto the topic, in addition to consultations and frequent interruptions of mine in his office. Additionally, my guidance councillor from Skanska Norway, Roar Fosse (Chief Advisor, Operation Excellence) deserves special recognition for providing great sources and inputs on lean construction theory and providing access to relevant case data. Fredrik Svalestuen (PhD Candidate, Department of Civil and Environmental Engineering, NTNU, Involved Planning, Veidekke) deserves mention for academic input and access to case data in Veidekke.

I would also like to thank Glenn Ballard (founding member of the Lean Construction Institute and author of *”The Last Planner System of Production Control”*) for feedback during my time writing the thesis, in addition to the advice given to me during the autumn regarding sound directions for the study.

In addition, I would like to thank my student colleagues Ole Simon Tveiten, Maya Worren Legernæs and Egil Zahl Johansen for feedback and tips during my time writing the thesis.

Lastly, interview participants deserve special recognition for taking time out of their busy schedules to make the study a possibility.

Trondheim, June of 2018

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Summary

Construction design has traditionally been managed with an ad hoc approach due to its reciprocal and iterative nature. The abandoning of sound strategies to management has multiple consequences for the final product, seeing as the work in design is no longer managed in the direction of best possible value creation. This is despite several developments in the AEC-industry over the last decades, such as the Last Planner^{TM} System, Integrated Concurrent Engineering (ICE), Building Information Modeling (BIM) and Level of Development (LOD).

The implementation of Last Planner^{TM} has yielded significant improvements during the production-phase of AEC-projects, but has only seen limited applications in the design phase due to an inability to properly describe the iterative nature of work during design. This thesis proposes the hypothesis that the integration of model maturity can be used to better describe the process in BIM-based workflows, enabling management to employ planning tools like Last Planner^{TM} in design. Each of the aforementioned developments have been exposed to extensive studies and trial implementations on their own, but their use in conjunction with each other has received little to no documentation in the scientific community as of the current time of writing.

The thesis studies two pilot projects utilizing an LOD-based system called Model Maturity Index (MMI) with the intent of uncovering current practices and experiences, in addition to formulating recommendations for sound implementation strategies to maturity-based management in design. The cases were assessed using semi-structured specific interviews with project participants ranging from managers to designers, and a document study of measurements, plans and meeting forms.

In order to establish a theoretical basis for the study, a literature scoping study was conducted in addition to general interviews with specialists in BIM or MMI. The theoretical foundation from these studies was used to define four aspects of maturity-based design management which were used as an explanatory model to asses case implementations and make recommendations. The research questions for the study were formulated as follows:

1. *What are the current approaches to maturity-based construction design management?*
2. *What are the experiences from current approaches to maturity-based construction design management?*
3. *How should maturity-based construction design management be approached?*

Findings from the study indicate that the use of Last Planner^{TM} and ICE are relatively well adopted in these kinds of projects, although some observations may indicate that these tools are still being managed with traditional mindsets. The implementation of maturity-based management were largely met with positive sentiments, citing increased process transparency and inter-disciplinary communication, in addition to greater predictability in planning. In terms of implementation, current approaches typically manage maturity by disciplinary sections of the BIM, although approaches differ in other terms, such as how levels should be specified or how model state should be communicated to designers or external stakeholders during development.

The study concludes with recommendations for management interested in applying maturity-based approaches in their practices, by example how management of larger sections of the BIM improve the ability to describe overall project development when compared to management of maturity on a per-object level. Other examples can be how maturity level specifications related to functional requirements are more in line with lean principles than specifications related to geometrical complexity. In addition, the study highlights the importance of employing standardization and continuous improvement in addition to project-specific flexibility in implementation efforts.

As a part of the study, a scientific paper was written for the International Group for Lean Construction (IGLC). The article was approved for publication and presentation during the it's 26th annual conference in Chennai, India during the summer of 2018, and is attached to the following report.

Sammendrag

Prosjektering har tradisjonelt blitt styrt med ad hoc -tendenser for å imøtekomme det iterative tverrfaglige samarbeidet som skjer i denne fasen. Den påfølgende mangelen på sunne styringsstrategier har flere konsekvenser for det endelige produktet ettersom arbeid ikke lenger styres med hensyn til verdiskapning og prosessoptimering. Dette er til tross for diverse utviklinger i byggindustrien i løpet av de siste tiår, som blant andre Last Planner^{TM}, Integrated Concurrent Engineering (ICE), Bygnings-InformasjonsModellering (BIM) og Level of Development (LOD).

Implementasjoner av Last Planner^{TM} har vist betydelige forbedringer i produksjonsfasen av byggeprosjekter, men har kun blitt brukt i begrensede versjoner i prosjektering på grunn av en manglende evne til å beskrive det iterative arbeidet som skjer i denne fasen. Denne oppgaven presenterer en innledende hypotese om at integrasjon av modenhetsstyring av BIM-modeller kan brukes til å beskrive dette, slik at også prosjektering kan bli styrt med planleggingsverktøy som Last Planner^{TM}. Disse verktøyene har blitt utsatt for utfyllende studier hver for seg, men lite til ingen dokumentasjon av deres samhandling med hverandre eksisterer per skrivende stund.

Oppgaven består av et case-studie av to pilotprosjekter for et LOD-basert system kalt Model Maturity Index (MMI) med hensikt om å avdekke nåværende praksis og erfaringer, i tillegg til å formulere anbefalinger til sunne strategier for bruk av modenhetsstyring i prosjektering. Casene ble undersøkt med semi-strukturerte intervjuer med prosjektdeltakere og et dokumentstudie av målinger, planer og møtedokumenter.

For å etablere et teoretisk grunnlag for studiet ble det utført et litteratur scoping-studie i tillegg til generelle intervjuer med profesjonelle som har god kunnskap om BIM og MMI. Dette teoretiske grunnlaget ble brukt til å formulere fire hovedaspekter for modenhetsstyring av prosjektering, som ble brukt som en forklaringsmodell til å undersøke case-implementasjoner og formulere anbefalinger. Forskningsspørsmålene brukt i studiet var følgende:

1. *Hva er nåværende tilnærminger til modenhets-styring av prosjektering?*
2. *Hvilke erfaringer har man fra nåværende tilnærminger til modenhets-styring av prosjektering?*
3. *Hvordan bør prosjektering bli styrt i henhold til modenhet?*

Funn tyder på at verktøy som Last Planner^{TM} og ICE er relativt utbredt i slike prosjekter, selv om enkelte observasjoner kan tyde på at disse verktøyene fortsatt blir anvendt med tradisjonelle tankesett. Implementasjon av modenhetsstyring ble i stor grad møtt positivt, og virket til å forbedre prosessforståelse og tverrfaglig kommunikasjon, i tillegg til å vise forbedringer i planpålitelighet. Nåværende tilnærminger styrer typisk modenhet basert på større fagmodeller i modellen, men tilnærminger kan variere i andre aspekter, slik som hvordan modenhetsnivåer skal defineres eller kommuniseres under utviklingen av prosjektet.

Oppgaven konkluderer med anbefalinger for ledergrupper interessert i å implementere modenhetsstyring i sine prosjekter. Eksempler på disse anbefalingene inkluderer hvordan styring av modenhet for større fagmodeller forbedrer evnen til å beskrive overordnet prosjektfremgang sammenlignet med modenhetsstyring på objektnivå. Andre eksempler påpeker hvordan definisjon av modenhetsnivåer relatert til funksjonelle krav er mer i tråd med lean prinsipper enn definisjoner relatert til geometrisk kompleksitet. Studiet understreker også fordelene med å bruke standardisering og kontinuerlig forbedring av praksis, samtidig som prosjekt-spesifikk fleksibilitet i tilnærminger til implementasjon ivaretas.

Som en del av studiet ble det skrevet en vitenskapelig artikkel for den Internasjonale Gruppen for Lean Construction (IGLC). Denne artikkelen ble godkjent til publisering og presentasjon i gruppens 26. årlige konferanse i Chennai, India, sommer 2018 og er vedlagt til slutt i oppgaven.

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Abbreviations

AEC	=	Arcitecture Engineering and Construction
BIM	=	Building Information Model(-ing)
LOD	=	Level of Development
LoD	=	Level of Detail
MMI	=	Model Maturity Index
TFV	=	Transformation, Flow, Value
TPS	=	Toyota Production System
PPC	=	Percent Plan Complete
VDC	=	Virtual Design and Construction
CIFE	=	Center for Integrated Facility Engineering
POP	=	Product, Organization, Process
ICE	=	Intergrated Concurrent Engineering
IFC	=	Industry Foundation Classes *(file format in BIM)*

Chapter 1

Introduction

The following chapter will supply the reader with introductory knowledge to the study by explaining the subject background, the research questions and the limitations for the study, in addition to a reading guide for the report.

1.1 Background Information

The construction design phase is a complex and iterative process which requires close collaboration from vastly different people and disciplines in order to achieve its goals. Participants in the design process are often involved in several projects at a time, and are rarely co-located for specific projects. Whereas building construction have workers operating within clearly divisioned teams, only being dependant on communicating with their team leader or colleagues, construction designers have to work across disciplines in addition to having to make smaller decisions or demand such decisions from other disciplines or management.

Such a complicated and dispersed process is hard to properly direct towards actual value creation, and is often managed with an ad hoc approach (Carlos T. Formoso & Liedtke, 1998; Knotten et al., 2017). Although these kinds of approaches may seem like the best option at the time, the moment-to-moment focus decreases efficiency and reliability in planning, increasing cost and creation of waste in the project.

Reasons commonly cited for inefficiency during the design process are often attributed to either rework or waiting due to lack of decisions (Ashford, 1989; Grytting, 2017; Mazlum & Pekericli, 2016; Peter E. D. Love, 2000; Tribelsky & Sacks, 2010). In addition, design-caused defects can be one of the greater reasons for waste during later production stages (Cornick, 1991; Josephson & Hammarlund, 1996).

These reasons for inefficiency can largely be attributed to traditional building design management lacking an optimized flow of resources and information (Lauri Koskela & Leinonen, 2002; Tribelsky & Sacks, 2010).

One of the major developments in building design over the last couple of years has been the introduction of Building Information Modeling (BIM) as an effort to establish a basis for an integrated collaborative design process across disciplines (Jacob & Varghese, 2012). Although BIM is increasingly being put to use in the AEC-industry, new tools are still being managed with a traditional mindset, without the intent of structuring BIM-use in an effort to increase value (Leite et al., 2011).

Another development in the AEC-industry has been the application of philosophies and techniques from the Toyota Production System (TPS), commonly known today as Lean Construction. In contrast to merely pushing orders which management think should be completed, this shift in thinking revolve around eliminating waste by creating a sustainable flow of deliveries towards its destination by pull-based planning from final product specifications (Ballard, 2000a; Moore, 2007).

The Last Planner^{TM} system of production control was created by Glenn Ballard in an effort to create a planning and control system for AEC managers which incorporated these principles (Ballard, 2000a), and has shown improved capabilities and results when compared to traditional systems in building production (Fosse & Ballard, 2016; Knotten et al., 2014).

Last Planner^{TM} has mostly been applied in the building production phase, seeing as tasks during this phase are predefined and have a clear sequence of task to accomplish, making them easy to manage. Some studies have proven a potential for Last Planner^{TM} in building design as well (Fosse & Ballard, 2016; F. R. Hamzeh et al., 2009), although only at smaller scales.

Incorporating Lean Construction principles into current approaches to building design management would in other words be the implementation of Last Planner^{TM} in current BIM-based workflows. The problem with this implementation is the lack of a processual aspect to the BIM, which effectively makes it incompatible with such planning tools.

The concept of Level of Development (LOD) was introduced as a means to formalize the development in a BIM-model (Abou-Ibrahim & Hamzeh, 2016), and could be an alternative to attributing a processual aspect to the BIM, thereby making it compatible with Last Planner^{TM}. However, LOD has yet to be formalized in practice and has thus not been able to fully realize this potential.

LOD has been approached in several ways (Abou-Ibrahim & Hamzeh, 2016; Hooper, 2015; Leite et al., 2011; McPhee, 2013), but little to no documentation regarding LOD as an enabler for using Last Planner^{TM} to manage BIM-based workflows exist as of writing this report.

Recent developments have seen the implementation of Model Maturity Index (MMI), a more process-oriented version of the traditional LOD framework in a couple of Norwegian construction projects. The new MMI-initiative attempts to solve the problems from existing LOD implementations, although it is still a relatively new concept with little adoption or related research.

As a result, researching MMI implementations in relation to the ability to plan and control projects using tools such as Last Planner^{TM} and ICE is an interesting field of study, and one which is relatively undocumented. The following thesis takes aim at doing so, and is structured around the three following research questions:

RQ1: What are the current approaches to maturity-based construction design management?

RQ2: What are the experiences from current approaches to maturity-based construction design management?

and

RQ3: How should maturity-based construction design management be approached?

1.2 Limitations and Scope

The thesis is weighted 30 study points (one semester), and is written by a single author. In addition, the literature research presented here was part of assignments related to two courses during the preceding autumn (*TBA4128 Prosjektledelse, Videregående Kurs* and *TBA4151 Anleggsteknikk, Videregående Kurs*), and the master thesis is based on introductory research conducted as a project report also written during the autumn.

In order to produce any conclusive results within this time-frame, the scope of the assignment has been adjusted accordingly, limiting the study to eleven interviews with a document study of two projects. The choice of the industry's two largest contractors was made on the grounds that these kinds of contractors conduct more extensive, complicated projects, which are more in need of sound approaches to management.

Design build contractors are responsible with managing all project phases, making them more inclined to strive for greater process control and value creation during design. In addition, these contractors also wields greater influence over the project. These aspects naturally leads to the assumption that they would be more inclined to strive for better management practices during design as well as having better means to improve them. It follows that these kinds of contractors would represent approaches close to the current best examples of management during building design, and therefore be among the more interesting types of contractors to study.

In addition to the aforementioned reasons, a turnkey method of delivery results in a less complicated management structure, having only to deal with the contractor as the responsible part of management in the project organization.

The research questions are relatively broad. Having the underlying hypothesis that the integration of Last Planner™, BIM and MMI are a potential way of properly conducting construction design management, the assignment was limited to approaching these specific aspects of design.

The choice of studying one residential project in addition to an infrastructure project was made on the grounds of having a better diversified set of data of MMI implementations in the industry as a whole.

1.3 Reading Guide

The outline of the report has been structured according to NTNU's guidelines for academic writing (Busch, 2014; Institutt for bygg, anlegg og transport, 2017). The report is structured sequentially in the following order.

Part 1:

- **Chapter 1, Introduction**
  Context, description of issues and goals, research questions, limitations and reading guide.

- **Chapter 2, Methodology**
  Analysis of how to answer research questions and descriptions of chosen research methods.

- **Chapter 3, Literature Review**
  Relevant literature found during the literature study.

- **Chapter 4, Results**
  Relevant results from the interviews and document studies.

- **Chapter 5, Discussion**
  Discussion of findings in conjunction with literature.

- **Chapter 6, Conclusion**
  Conclusion answering research questions and suggesting future work on the topic.

Part 2:

- **Scientific article**
  Scientific paper written as a part of the study, published in the proceedings for the 26th annual conference for Lean Construction in Chennai, India.

Part 3:

- **Appendices**
  Interview forms and documentation of the literature study

Chapter 2

Methodology

The following chapter discusses the nature of the research questions and details the research methodology chosen to answer them.

2.1 Research Methods

A research method can be described as the ideas, instruments and models used to conduct sound research (Blumberg et al., 2011). Different methods of research have different strengths and weaknesses, and must therefore be chosen based on what one intends to accomplish while keeping the limitations of the study in mind (Dalland, 2000).

Quantitative and Qualitative Research

Research methods are often described as either qualitative or quantitative. *Quantitative* methods are deductive (testing of theory), empirical and objective approaches based to quantitative data, whereas *qualitative* approaches lean more towards induction (generation of theory), interpretivism (preferencing individuals' interpretations of their social world) and constructionism (viewing social reality as a constantly shifting property of individuals' creations) (Bryman, 2012).

Qualitative research methods include approaches such as in-depth interviews, participant observation and case-studies (Blumberg et al., 2011). These approaches extract large amounts of data from a lower amount of sources, and are as a result often preferred when dealing with smaller or newer fields of study (Samset, 2014; Thagaard, 2013). Although not necessarily more subjective than quantitative approaches, qualitative approaches can in some cases employ the subjective view of the researcher to a greater degree during the study. This requires a greater degree of credibility and transparency on the part of the researcher (Samset, 2014). On the other hand, this subjective filter can prove useful when trying to draw conclusions from experiences (Tjora, 2010).

Quantitative approaches are typically statistical evaluations of large sets of data, drawing conclusions by uncovering correlations related to different variables. When performing quantitative research, it is often more common to extract smaller amounts of data from a larger amount of sources when compared to qualitative approaches (Samset, 2014). These methods are often inherently more reliable and verifiable than qualitative approaches, being less dependant on the researchers interpretation of the relevant data (Thagaard, 2013). However, quantitative approaches are not preferred when dealing with complex phenomena, as the greater quantity of sources could make the amount of available information overwhelming, and thus impossible to draw conclusions from (Busch, 2014).

A qualitative approach was chosen to collect data rather than a quantitative approach, seeing as the the research topic is better explained as a social construct than a set of numbers. In addition, the field of study is relatively new, and is better suited for in-depth evaluations of case examples instead of a broad numeric approach.

Reliability and Validity in Research

The potential soundness of research tools can be expressed as their inherent reliability and validity (Blumberg et al., 2011). *Reliability* is concerned with the accuracy and precision in the relevant research approach and can in practical terms be thought of as the repeatability of its experiments, while *validity* expresses the degree to which the results from the study can be used to accurately answer the research questions (Bryman, 2012).

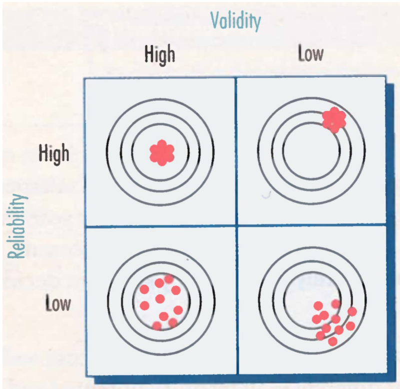


Figure 2.1: Illustration of reliability and validity in research (Blumberg et al., 2011)

Choice of Research Methods

According to Busch (2014), research questions can be classified in one of six ways, in which RQ1 is classified as a *descriptive* question, RQ2 is described as a *problem-identifying* question, and RQ3 is described as a *problem-solving (normative)* question.

RQ1: What are the current approaches to maturity-based construction design management?

Descriptive questions are intended to describe a phenomena, and are usually provided in project works and master theses as an introductory question with the intent of understanding a particular field of study. These kinds of questions does not uncover problems, and are therefore not sufficient for such reports when used on their own.

RQ2: What are the experiences from current approaches to maturity-based construction design management?

Problem- identifying questions are meant to identify challenges or problems, which requires the researcher to find flaws or areas of improvement in the field of study. These questions are usually harder to answer than descriptive ones, as they requires the researcher to have a theoretical understanding of what the best practices would be like. In answering these types of research questions, flaws and areas of improvement are uncovered by contrasting theoretical knowledge to real-world experiences.

RQ3: How should maturity-based construction design management be approached?

Problem-solving (or normative) questions have the purpose of solving a particular problem. These research questions are among the hardest to answer given their need for extensive knowledge in the relevant field of study, and are thus recommended to be used in conjunction with descriptive and problem-identifying research questions (Busch, 2014).

By examining the research questions, it becomes apparent that all three require a study of real-world practices. In addition, theoretical knowledge is required to answer research questions two and three. As a result, a combination of three research methods were chosen, namely a literature scoping study, interviews both general and case-specific, and a document study of said cases.

2.2 Literature Study

A literature scoping study was conducted in order to provide a theoretical foundation for the study.

Methodology

The literature study was based on a previous assignment for courses *TBA4128 Project Management, Advanced Course* and *TBA4151 Construction Engineering, Advanced Course*. The literature study conducted was a scoping study with a uniquely developed framework including research techniques such as citation- and reference-chaining. Literature was acquired directly from the websites of the International Group for Lean Construction (IGLC), as well as Compendex Engineering Village and Scopus. Some books were acquired from the university library.

Arksey & O'Malley (2005) states that literature research falls into one of two methods, scoping studies or systematic reviews. Whereas systematic reviews are traditional specified reviews intended to provide answers for a given topic, scoping studies are broad approaches to mapping out existing pools of literature on given subjects. In general, scoping studies are performed by systematically building information pools of relevant literature, charting the information pool into relevant fields, narrowing down the pool into the most relevant sources and (if necessary) repeating the process until the final literature pool is deemed sufficient for in-depth study. The scoping study framework used in this study is presented in Figure 2.2.

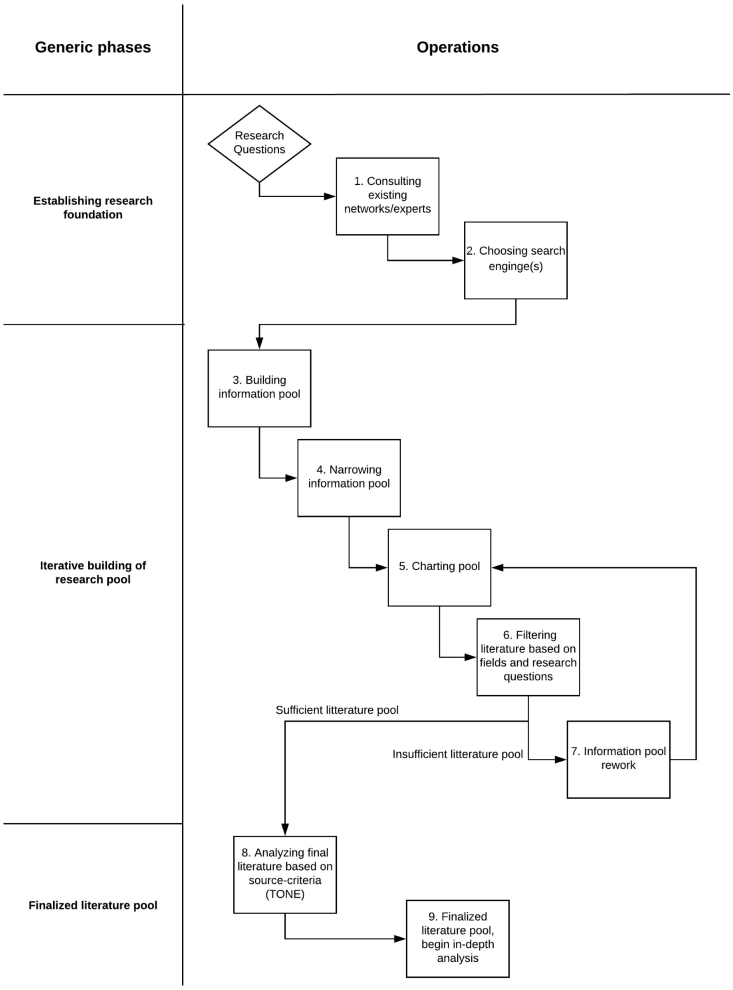


Figure 2.2: Chosen methodology for scoping study, based on recommendations from Arksey & O'Malley (2005); Blumberg et al. (2011).

In scoping studies, using relevant acquired literature is an important part of reworking existing literature pools. Citation-chaining is a relatively effective way of doing this as it mostly produces relevant sources which does not require the literature pool to be reworked a great deal afterwards. The outline of a general framework for performing citation chaining can be described in the following steps (Ellis, 1993):

- Starting. *Identification of a key paper to commence the search.*
- Chaining. *Following up references to this paper and following up book advertisements from the journal consulted.*
- Browsing. *Identifying relevant journal sources.*
- Extracting. *Working through material in relevant sources.*

The opposite of this method would be what is commonly called *Snowballing*, in other words the method of using reference lists in key articles to find new relevant literature (Erasmus University Rotterdam, 2018). This technique is mentioned by, among others, Arksey and O'Malley, although not referred to by this particular name.

In accordance with NTNU's guidelines for acquiring sources, the sources potentially relevant for further study were evaluated in line of the TONE-framework, analyzing the sources based on their credibility, objectivity, accuracy and relevance (The Norwegian University of Science and Technology, NTNU, 2018).

The literature pool was made with the intention of providing articles which could be charted into one of five fields of theory relating to project management, lean construction, BIM, LOD and building design.

The scoping study evaluated 135 potentially relevant sources, ending up with a total of 27 relevant sources, all evaluated according to the TONE-criteria outlined by NTNU. All of these sources were read in order for the researcher to establish an understanding of the relevant literature. Some additional sources were acquired after the scoping study was finished during the continuous discussions with guidance councillors and reference-chaining from read sources.

During the research, the chosen methodology was conducted with one iteration of the information pool (see Figure 2.2, step 7), concluding with the second version of the literature pool which was deemed sufficient for in-depth analysis. For a complete documentation of the literature study, see appendices.

Reason for Use

Due to the researchers initial lack of knowledge regarding the topic, a scoping study was conducted to map the state of existing literature in the relevant field in addition to providing a pool of relevant literature for further study. This literature is not only used to describe ideal practices in relation to RQ2 and RQ3, but also as an introductory source of knowledge for the researcher, ensuring that interviews could be formulated with greater validity prior to being conducted.

Critique

The scoping study yielded a sizable pool of relevant studies, but the method was time-consuming and yielded a lot lower efficiency in producing relevant articles when compared to other methods such as citation- or reference-chaining, both of which received less prioritization in the framework. In addition, the researchers initial lack of understanding the field of study proved quite impactful, having some articles being excluded in early iterations of the research pool included in later iterations once the researcher had gained a greater understanding of what the sources were concerned with.

The literature study is thoroughly documented, providing the reader with 50+ pages of appendices including literature in every iteration of every research pool, with all searches made documented. The search-engines used are all available for any member of an educational facility, and the final results used in this report is of high relevance to the research topic, ensuring validity. However, it should be mentioned that the study relies on subjective evaluations from the researcher based on, at times, limited information. The review process was also quite cumbersome and tiring, further emphasizing the issues with incorporating a subjective evaluation. However, the study maintains a high level of reliability due to thorough documentation as presented in appendices.

2.3 Interviews

General interviews of five professionals proficient in either BIM, MMI or project management in general was conducted.

- Tom Paulsen, Head of EBA's (Norwegian Contractors Association) BIM group
- Karianne Skrindo, Design manager, Veidekke
- Peder Bogsti, BIM-coordinator, Skanska
- Kristian Balke, Head of BIM-department, Skanska
- Håkon Fløisbonn, BIM-advisor and author of the MMI framework, Skanska

In addition, seven case-related, specific interviews were conducted with practitioners from two relevant cases. Firstly E6: Arnkvern-Moelv, a 24km long Class A road project, part of the international E-road network. The project is conducted by Veidekke Entreprenør AS, and was won in a bidding contest for 2043 millNOK. The project is reportedly employing somewhere around 30 designers on a full-time basis.

- Tom Paulsen, Project manager, Veidekke
- Terje Glad, Group leader BIM and geomatics, Sweco
- Nina Rognlien, Landscaping architect, Sweco
- - Anonymized designer -

And secondly, Tiedemannsbyen, an apartment complex of five, six-storey buildings. The project is owned by Skanska Norway, and was conducted for roughly 430 millNOK. The project employed around 14 full-time designers.

- Jan Billing, Senior design manager, Skanska
- Gina Dahlen, Design manager and BIM-coordinator, Skanska
- Kitty Aarseth, Architect, TAG Arkitekter

Methodology

All interviews conducted were semi-structured, in other words having a pre-written interview guide of questions which the interviewer could deviate from if necessary (Blumberg et al., 2011). All interviews were recorded and transcribed, the transcript of which later verified by the interviewee as representative of their views. The interview guide remained relatively unchanged throughout the study, although deviations in which questions were asked occurred due to the nature of the semi-structured interviewing. See appendices for the interview guide. Four of the interviews were conducted in situ, while the rest were conducted over the telephone.

Reason for Use

Interviews are often used during qualitative research, as the flexible and dynamic style enables the researcher to capture aspects which are hard to quantify (Bryman, 2012). As specified in Chapter 2.1, an understanding of real world practices is vital to answering all of the given research questions, and case-related interviews are a great achieving this.

Veidekke Entreprenør and Skanska Norway are relatively similar companies, both being among the largest design build contractors in the industry, both having a pronounced focus on Lean Construction philosophies, and both allegedly employing Last Planner^{TM} and ICE to a high degree in their projects. Cases inspected employ MMI during design, although none of the participants in either case had any prior knowledge of the system. Thus, these cases provide a valid insight into new adoption of MMI in construction design, all the while having a foundation to compare these newer managment approaches to traditional practices.

Critique

The main strength of the qualitative interview is the ability to study a specific phenomena thoroughly, which makes it a great fit for researching this particular field of study. The interviewees makes up a balanced group of both experts in the field (developers) as well as project managers and designers (users). By choosing first time users who had no prior experience of using the system, the the study also has a great foundation of contrasting new practices to traditional approaches.

Although one might think interviewing over the telephone might be less desirable, Bryman (2012) cites that subjects interviewed over telephone are more likely to give accurate answers and to be honest, feeling further removed from whatever consequences that might follow their answers. On the flip-side, the sources also cites that these kinds of interviews makes it harder for the interviewer to observe non-vocal responses in their subject. This is not a problem in this particular case seeing as the the subject matter does not revolve around sensitive material in need of such observations.

On the other hand, the results uncovered in the case interviews does present an issue when generalizing the findings to a greater scope. Both contractors are publicly traded, and are therefore incentivised to present the best possible practice when being met by researchers. In order to preserve validity in the findings, case related interviews were studied in conjunction with general interviews and a document study.

Interviewees were chosen either based on their professional pedigree (general interviews) or practical experience (specific interviews) in the field of study. The semi-structured interview style allows for directly questioning the topic of interest. As a result, one could argue that the research method possesses high validity.

In terms of reliability however, the interviews are highly unpredictable and likely to lack in repeatability. Both the interviewer and the interviewee are subjective beings, whom might act differently under different circumstances. Several factors could influence the answers given in an interview, by example, the interviewer could unknowingly ask leading questions, catch the interviewee in a bad mood, or fail to correctly interpret answers. In order to ensure reliability in the research, all interviews were recorded and transcribed, the transcript of which can be produced if other researchers are interested in studying the same results. Although the transcript is not a word-for-word copy of the original interview, but rather condensed into a more direct summary of relevant questions and answers, reliability in research is maintained by the fact that they are all post-approved by interviewees as representative of their views.

2.4 Document Study

A document study of presentations, meeting forms, project plans and technical data from both cases was conducted to support the findings in the interviews.

Methodology

Relevant company presentations were considered when investigating the generalizability of the findings. Meeting forms, project plans and technical data from cases were inspected prior to interviews, in search of interesting aspects for further inquiry. These documents were also consulted post interviews, in attempts to validate (or disprove) statements made by interviewees.

Assessed documents were as follows:

General documents

- Various company presentations from Skanska as a part of participation in the CIFE-certification program.
- Excerpts from Skanska 's guidelines for MMI.
- Collision metrics and plans from Powerhouse Kjørbo (Skanska)
- Presentations from Veidekke regarding recent developments in guidelines concerning the Involved Planning initiative.
- Examples of ICE meeting forms, project schedules and evaluation of root causes in Veidekke from ZEB Flexible Lab.
- Guidelines for definition and application of MMI, written by Gunnar Skeie (Kruse Smith) and Håkon Fløisbonn (Skanska).

E6: Arnkvern-Moelv

- Meeting forms, project plans, visualization charts for state of maturity.

Tiedemannsbyen

- Meeting forms, project plans, collision metrics.

Reason for Use

A document study is relatively simple to conduct, and can provide great context when used in conjunction with other research methods.

Critique

The documents are easily understood and investigated, thus acquiring high reliability. However, the documents often included large amounts of irrelevant data, decreasing validity.

2.5 Scientific Article

A scientific paper was written as a part of the master thesis, intended for publication in the proceedings for the 26th annual conference of the International Group for Lean Construction in Chennai, India during the summer of 2018.

The paper had four authors;

1. Andreas Nøklebye, MSc, Student, Department of Civil and Environmental Engineering, NTNU
2. Roar Fosse, Chief Advisor, Operational Excellence, Skanska Norway
3. Fredrik Svalestuen, PhD Candidate, NTNU / developer of the Involved Planning initiative, Veidekke
4. Ola Lædre, Associate Professor, dr.ing., Department of Civil and Environmental Engineering, NTNU

The idea of writing and submitting the paper can be credited to Ola Lædre, who provided inputs on proper structural and practical guidelines for both the research as well as the paper itself. Roar Fosse and Fredrik Svalestuen served advisory roles in the study, providing access to suitable cases in both their respective companies, in addition to professional insights and directions for the study. Research and writing was in large part conducted by the lead author.

The article was written alongside the master thesis during the spring of 2018, and does to a certain extent follow the same structure. However, being limited to only ten pages, the paper is written with a conceptual approach, and only presents key findings from the study.

The article was approved by two independent reviewers and were published in the proceedings for the conference during the summer of 2018. In addition, said paper and the study documented in the following thesis were presented during the conference itself.

Chapter 3

Literature Review

The following chapters detail relevant findings from the literature study.

3.1 Fundamentals of Planning and Control

Planning and control are in many cases two sides of the same coin and are sometimes both referred to as planning, although the terms are more easily explained when separated.

Planning can be described as the act of establishing an order of work related to job scope, sequence, requirements, resources etc. in order to increase the efficiency of future work (Moore, 2007). Control on the other hand, can be described as the managing of work, actors and deliveries according to the predefined plan in an effort to identify negative variances and initiate corrective measures if needed (Ballard, 2000a; Moore, 2007). The succeeding theories, theoretical developments and tools have all been developed with the intention of achieving these goals.

Planning should not be confused with scheduling, which is related to the priority and timing of work (Moore, 2007), although most plans typically produce a schedule as a by-product.

3.2 Construction Design

Construction design refers to the creative process of realizing ideas, goals and user requirements of a future construction as a set with proposed technical solutions. The design process is highly iterative, and involves sharing and working with incomplete information, as well as working with different disciplines and people who are often involved in several projects at a time.

Project Phase Structure

The design phase is often divided into several minor phases. The phases usually describe certain developments of a building and are often expressed differently from company to company. A study of different Norwegian companies and their project phase-structure can be seen in Figure 3.1 below.

Although the phases are not discrete seeing as multiple phases overlap from company to company, the work, relevant disciplines and thus relevant design approaches differ from phase to phase. Understanding project phases is in other words necessary for understanding the development of work in a project, which is essential to understand and eventually implement tools in order to achieve a greater ability in planning and control.

The problem with approaching design phases as one-dimensional phases is the lacking understanding of the underlying process of iterative work, or the exchanging information back and fourth between designers.

Actors	Phases							
Neste steg (Bygg 21)	1 - Strategic definition	2 - Programming and concept development	3 - Pre-project development	4 - Detailing	5 - Production and deliverance	6 - Handover	7 - Use	8 - Discontinuation
Arkitektfaglig ytelsesbeskrivelse	Evaluation	Sketch-project-phase	Pre-project-phase	Detailing-phase	Execution phase		Operations-phase	
Statsbygg	Initializing / study	Programming / Ascertain	Pre-project / Develop	Detailing / Planning	Building / Execute	Building / Finalize	Warrant / Managing	
RIF		Programming	Designing		Production	Handover / warrant-time	Operations, management and maintenance	
Statens Vegvesen	NTP strategic evaluation	Concept-evaluation	Pre-project	Detailing-plan / regulation planning	Building Plan		Operations, management and maintenance	
Jernbaneverket	NTP strategic evaluation	Concept-evaluation	Technical main plan / municipality planning	Technical main plan / regulatory planning	Building planning / byggemelding	Production / Handover	Operations, management and maintenance	
SamBIM	Programming		Design		Production		Operations	

Figure 3.1: Official project phases in significant Norwegian actors (Grytting (2017), translated from Norwegian

Process Logic and Iterations

The design process is highly uncertain and requires iterations in order for designers and clients to better understand each other and what they are working towards (Abou-Ibrahim & Hamzeh, 2016; Demir & Theis, 2016). Iterative processes can be divided into positive and negative iterations, positive being value-creating and negative being waste-generating (Ballard, 2000b).

These iterations can be related to several different types of process logic describing how different designers and disciplines are dependant on each other. Sequential logic describes a process where deliveries flow from one designer to the next and reflective logic describes an interdependent relationship between designers. Previous studies (Knotten et al., 2014) highlight the importance of knowing the traits of each process logic, and having the ability to adjust management style accordingly.

These types of logic can also be further described in four different types of process logic as seen in Figure 3.2.

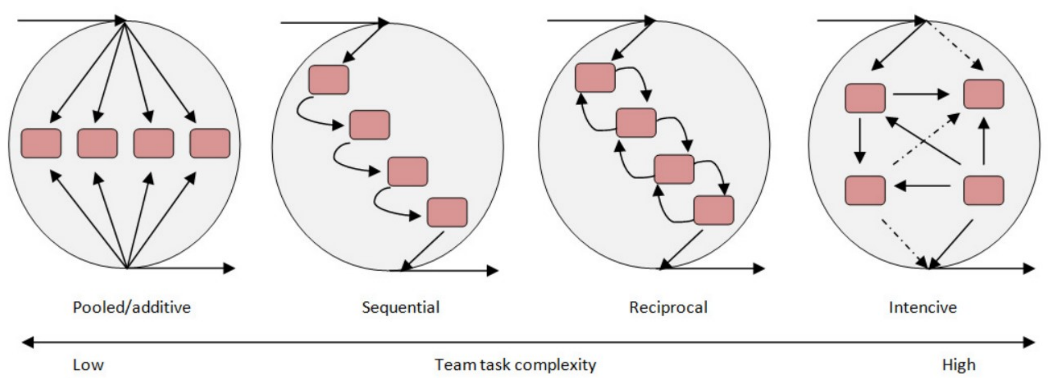


Figure 3.2: Different types of dependencies between tasks, Andersen 2011, rendered by Knotten et al. (2014)

As we are about to see when explaining the tenets of Lean Construction, understanding and properly managing different types of processes in order to achieve better flow in projects are essential in order to increase efficiency. These processes are easy to explain in theory, but practical application of their properties would require correct implementation into relevant project phases (as seen in Figure 3.1) without making a system too complicated to use. As for construction design, no theoretical examples of achieving this were uncovered during the literature review or the general interviews.

3.3 Lean Construction

Lean Construction is the collective term used to describe the application of Lean Production principles in AEC-projects, and can be described in many ways. The following chapters describe the necessary lean principles to understanding currently used lean planning tools, appropriate applications of information technologies and theory regarding ideal projects.

During the downtime after the second world war, Japanese manufacturers struggled to make business profitable, having to operate with relatively few resources. Through a focus of eliminating all wasteful work in a healthy manner, Toyota pulled through and became one of the largest car manufacturers today (Liker & Meier, 2006). Studies of Toyota's philosophies and practices formulated what is known today as Lean Manufacturing, which over the last decades has been transferred into what the AEC-industry know as Lean Construction.

The 4P-model shown in Figure 3.3 represents the framework of lean thinking, ranging from the philosophy at the foundation to problem solving and specific tools at the top.

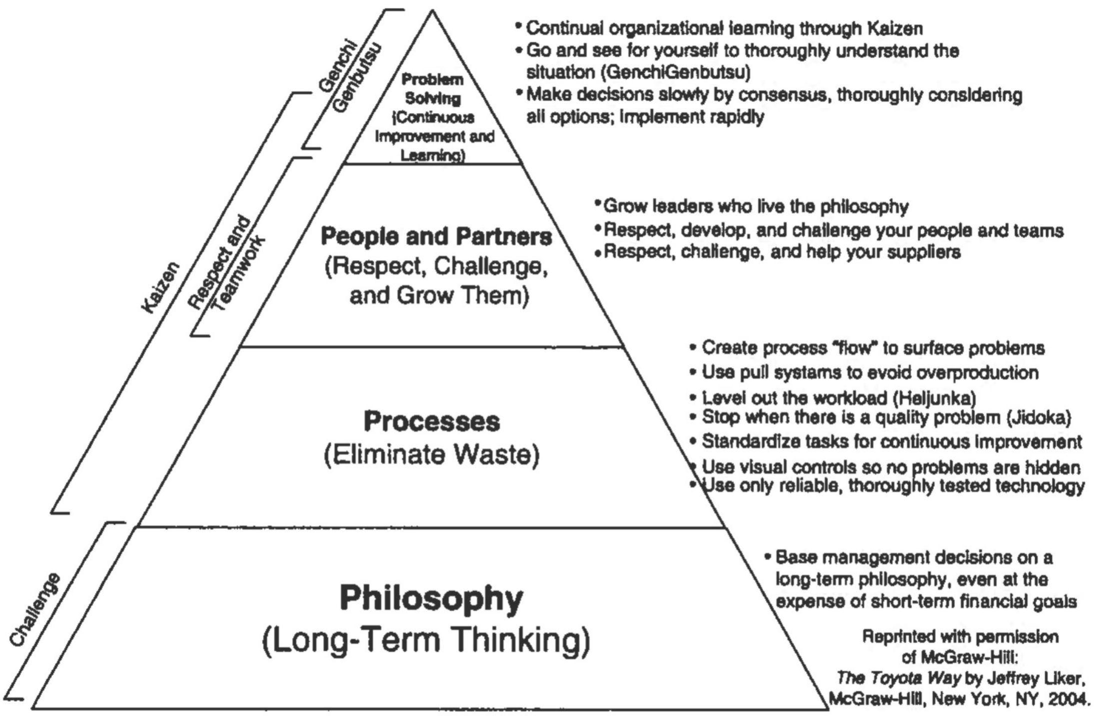


Figure 3.3: The 4P-model of the Toyota Way (Moore, 2007)

Waste

Waste can be described as all invested resources which does not lead to increased value in the final product. Waste can take many forms in construction projects, whether it be excess amount of materials, inactive workers or time and effort spent on failed concepts which are later changed or discarded.

In Lean Construction theory, the concept of waste is a way of specifically referring to anything which does not lead to increased efficiency or effectiveness.

TFV Theory

The TFV (Transformation-Flow-Value) theory was developed by Lauri Koskela in an effort to establish an easier framework of understanding lean philosophies. The theory states states that projects can be understood in three ways (Ballard, 2000a):

1. A set of **Transformations** of objects, converting inputs to outputs.
2. A **Flow** of information and resources which enables new transformations to happen.
3. A **Value** creating process which defines and meets customer requirements

Koskela et al. (2007) uses this model to explain how traditional management has mostly been interested in explaining which *transformations* that need to happen, that is, the specific tasks that need to be completed. In doing so, project managers may only be interested in whether or not their subordinates are working actively, rather than asking themselves whether or not those activities *flow* downstream in an efficient manner in order to create *value* in the project.

The TFV theory is effectively a model of explaining lean principles by introducing new aspects to previous understandings of project management. A traditional project described only by a set of transformations are impossible to troubleshoot or improve if approached with a traditional mindset, as it is only by acknowledging the other aspects of what the project truly is that it can be optimized in its entirety.

Push vs Pull

The major principle for reducing waste by achieving better flow and value are pull-actuation of deliveries. The principle can be illustrated by envisioning a production line sending deliveries between stations which performs transformations, producing new deliveries to send further downstream which eventually results in the production of a finished product.

A traditional manufacturing system which is not lean would instruct stations to *push* as many deliveries onto the next station as they could manage in order to increase production and thereby efficiency. These systems are considerably waste-generating, seeing as some stations are likely to produce more deliveries than necessary.

By restructuring the manufacturing system to only exchange deliveries from one station to another when the station supposed to be receiving the delivery requests it, overproduction is minimized, and a leaner flow of deliveries towards value creation is accomplished.

The balance of push (what management or owners want to accomplish with a task) and pull (what has to be done in order to complete the task) is essential to lean management, and is reflected in many techniques and tools developed with lean philosophies in mind.

Inventory

A good way of illustrating the shift in mindset from traditional transformation-based understandings of manufacturing is with inventory sizes.

Traditional management systems might view large inventories as a good thing, seeing as the increased amount of available resources reduces the volatility in up-time for the production system. However, when viewing the production system not only by its transformations, but also by the flow of deliveries towards value creation, the large inventories paint a completely different picture.

The reasoning for having large inventories in the first place is to accommodate for uneven supply from upstream stations, lack of reliability in production cycles and so on, which by definition means that the system are not optimized to its full potential.

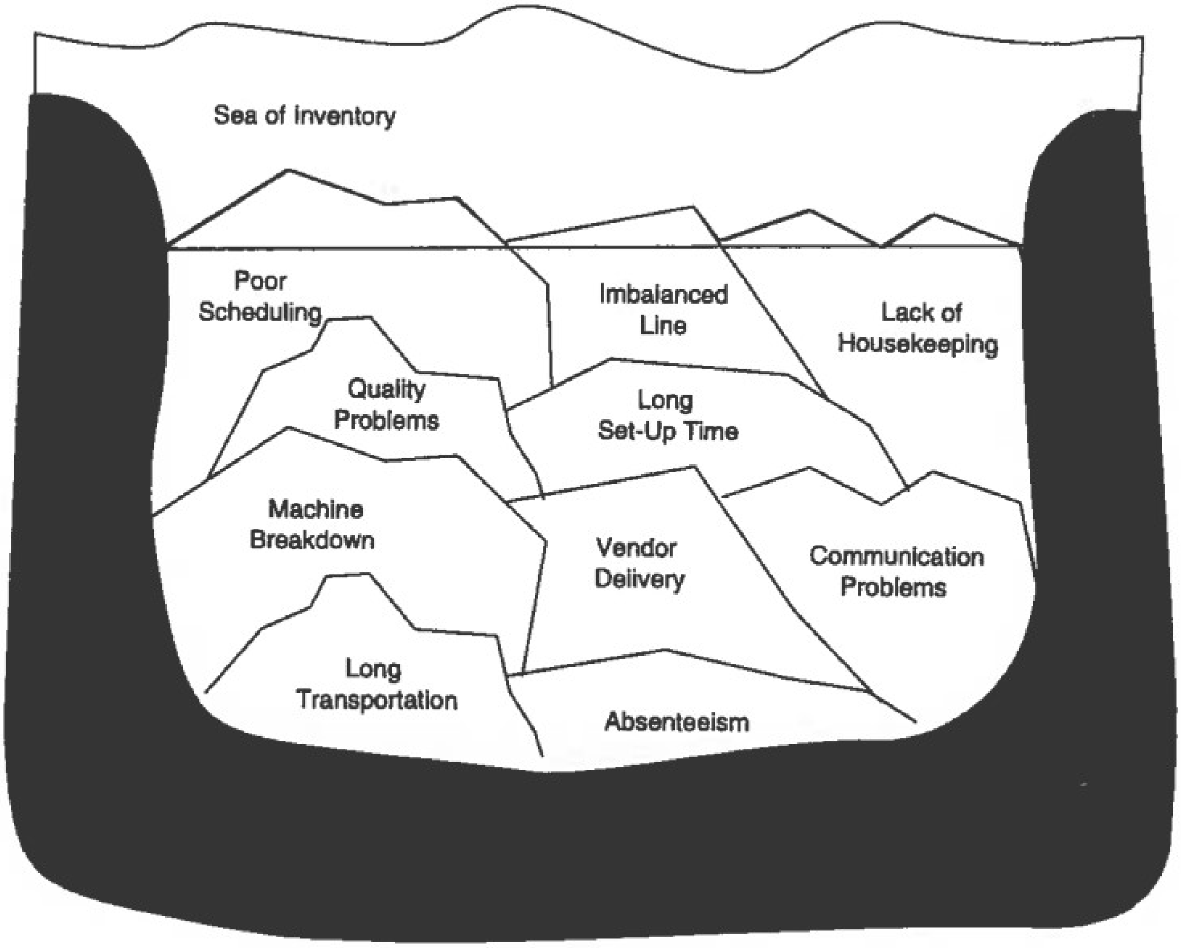


Figure 3.4: An illustration of how large inventories (sea) hide problems (rocks) (Moore, 2007).

Figure 3.4 illustrates how inventory hides problems existing elsewhere in the production line. In order to adjust the production line to become more lean, the problems (rocks) have to be removed in order to lower the inventory size (sea), thus reducing waste from unnecessary overproduction.

One-Piece Flow

In traditional production systems, like the one explained in the chapter about push vs pull, stations are encouraged to maximize production, resulting in an uneven flow of deliveries towards value creation. The principle of one-piece flow refers to the process of leveling the overall activity in a production system to meet (or slightly fall below) its daily required output (takt time) and utilizing pull planning throughout the entire production chain. In doing so, the activity is more equally distributed across the production chain, and waste is eliminated.

Production lines are defined by having a product which moves through a process of stations, which in this regard is the completely opposite of construction, where it is the process that moves through the product. In order to operate with one-piece flow in construction projects, one must understand the construction development as a continuous flow of operations moving through the construction with equal exertion at any area of operation. This principle can be visualized with a train with wagons of different subcontractors moving throughout the building, as illustrated in figure 3.5.

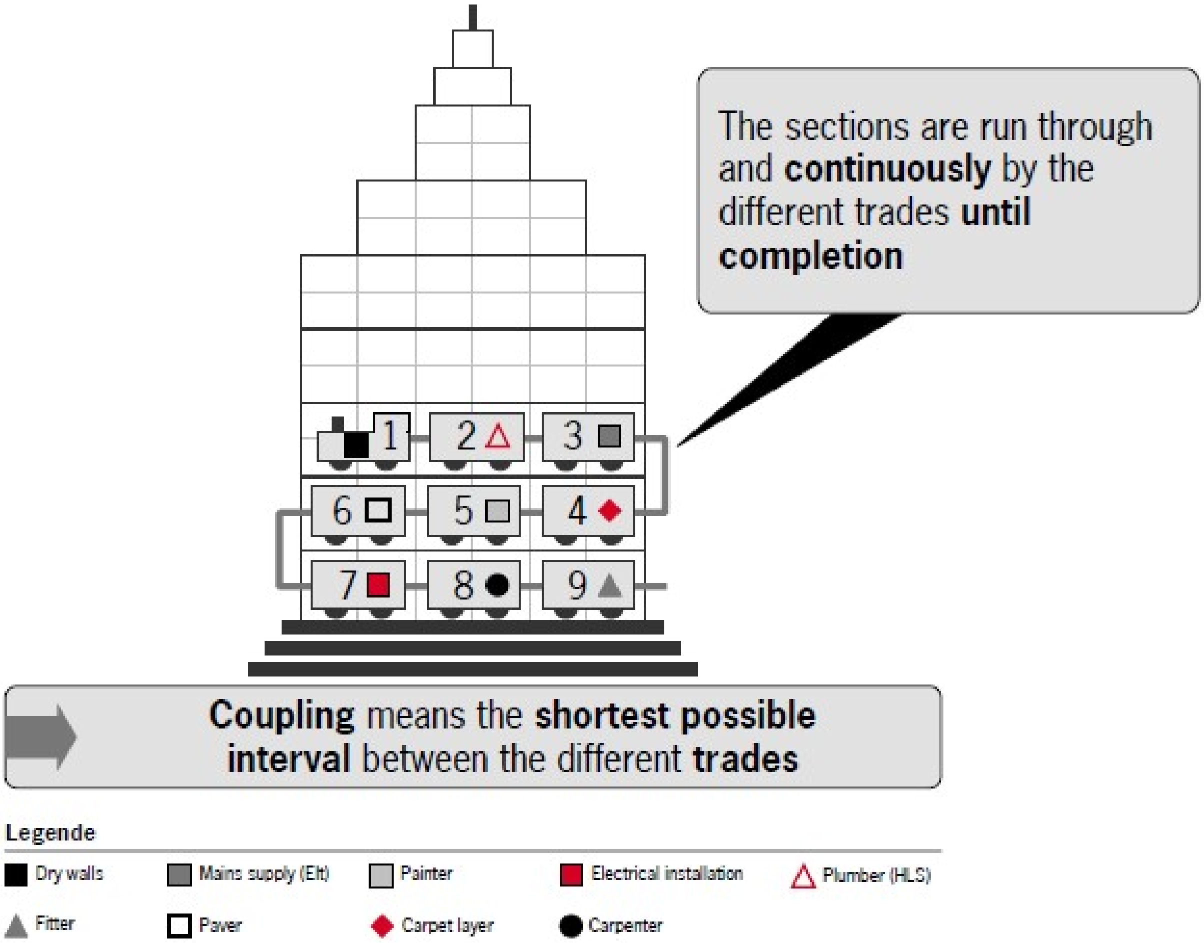


Figure 3.5: One-piece flow of operations in construction projects.

Standardization and Continuous Improvement

As a result of only trying to do work which will release future work, lean manufacturing systems have small inventories, and thus require low variance in deliveries in order to minimize volatility. This is achieved by reducing cycle times, leveling flow over the entire production chain and increasing flexibility.

Managers wanting to implement lean strategies often strive to implement these aspects directly, without consulting the 4P-model (see Figure 3.3) which illustrates that in order to use specific tools or optimizing processes, a long term philosophy of continuous improvement must be present to organically drive the organization forward. Moore (2007) makes a point of this approach being closer to anorexic than lean.

Rather than implementing radical new changes, the ideal lean manufacturing system starts with a philosophy of focusing on smaller improvements day-by-day, which eventually seeps into all sub-processes and operations, dynamically adjusting the production system towards its lowest point of entropy.

This continual improvement is made possible by standardization, which at any time reflect the current best, easiest and safest way of performing a task (Moore, 2007). Not only does standardization preserve the current best for all workers, but it provides a framework for measuring performance, reliability in returns, easy diagnostics and a foundation to continuously improve upon (Liker & Meier, 2006).

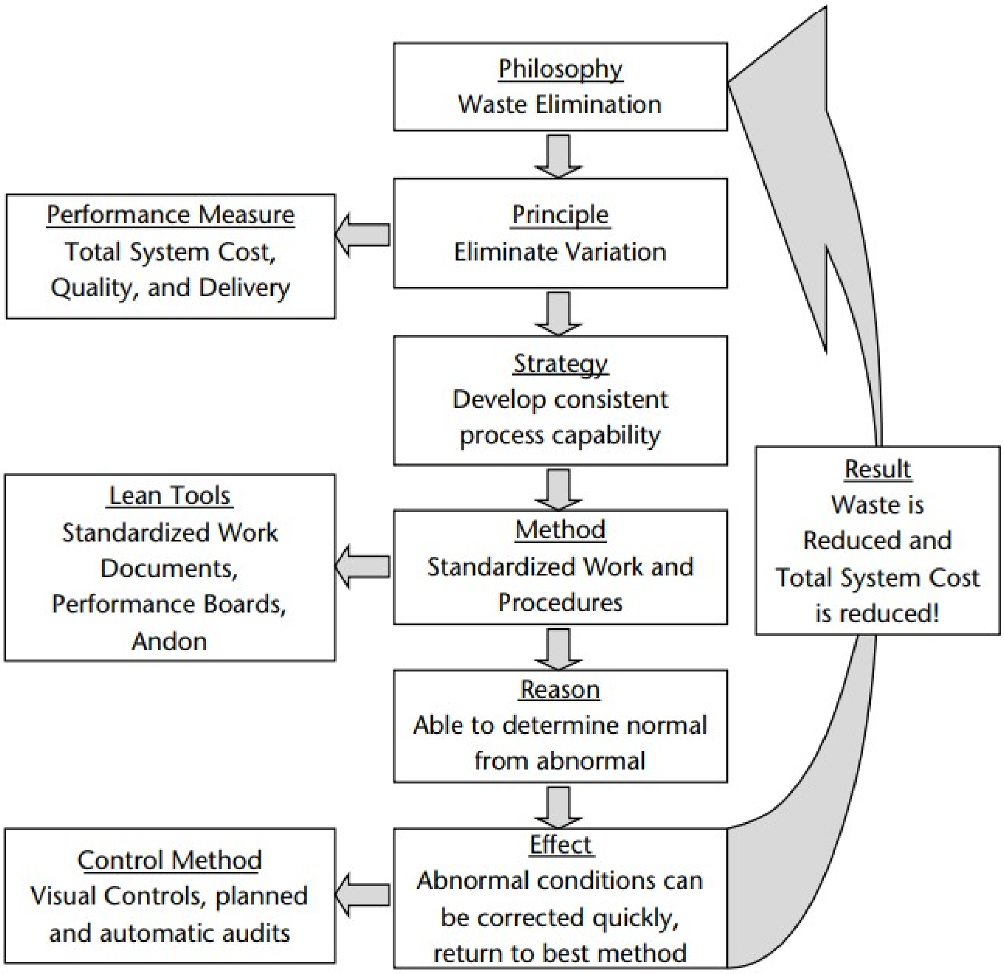


Figure 3.6: Model for continuous improvement through standardization (Liker & Meier, 2006).

In other words, in order to successfully plan and control construction design, there has to be an established, standardized framework for managing this phase.

Set-Based Design

One of the primary differentiators of design and production is the fact that iterations in design can be both positive and negative (Ballard, 2000b). As such, managing building design according to lean principles becomes a matter of reducing negative iterations while keeping the positive ones. The Toyota design approach (Set-Based Design) starts with mapping available design space and functional requirements for an object, then using input from different disciplines to narrow down the amount of available concepts, eventually converging towards a finalized design (Allen Ward & Sobek, 1995).

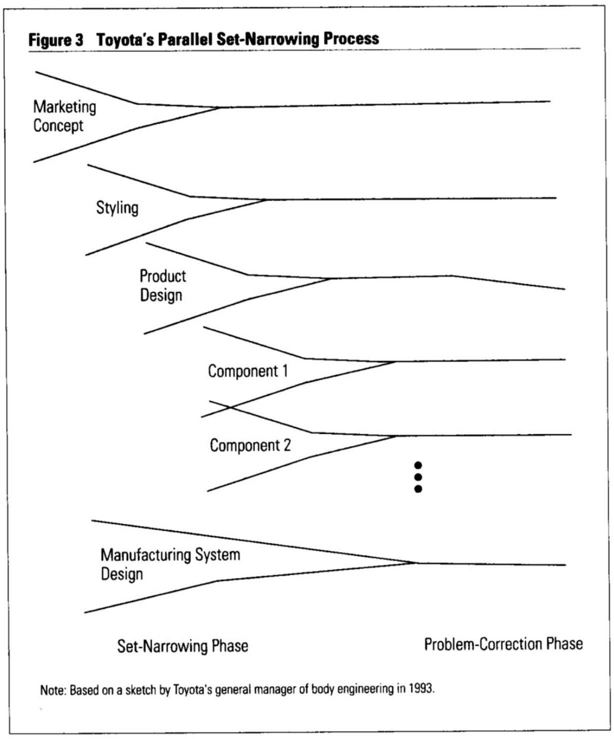


Figure 3.7: Illustration of the Set-Based Design principle (Allen Ward & Sobek, 1995) as a chart of time on the horizontal axis and possible designs on the vertical axis.

By determining the boundaries within which work will be conducted, workflow iterations are more likely to be positive, and thus value-creating for the project. This approach is contrasted to traditional practices, which are illustrated as "Point-Based Design" (See Figure 3.8).

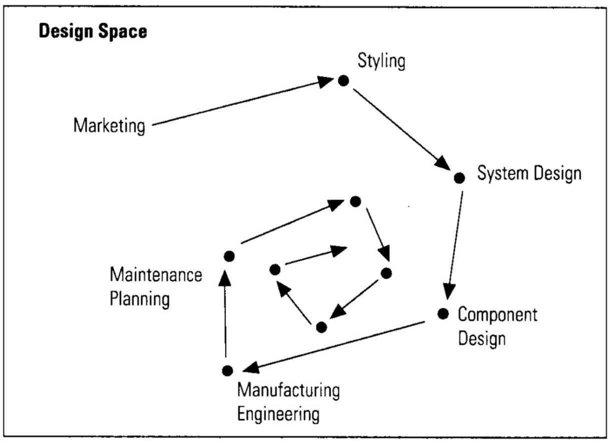


Figure 3.8: Illustration of Point-Based Design (Allen Ward & Sobek, 1995).

Last Planner^{TM} System

The Last Planner^{TM} System of production control is a philosophy as well as a set of rules, procedures and tools (Ballard, 2000a). The system is built on the principle of pulling requirements from the end product back throughout all the necessary tasks over the entire project lifespan. In order to successfully represent the requirements for all future tasks, the system highlights the importance of including all relevant project participants when planning. The system gets its name from starting with the final tasks in mind and the final people responsible for completing those tasks, that is, the *last planners*.

At a theoretical level, what separates Last Planner^{TM} from traditional planning tools is the addition of what *CAN* be done when deciding whether or not to execute work, rather than just what *SHOULD* be done. While traditional management would consider what one *SHOULD* do to be the same as what one *WILL* do, managers using Last Planner^{TM} considered what *CAN* be done simultaneously to determine what *WILL* happen. This way, the manager avoids the snare of *pushing* impossible plans on workers, thereby increasing reliability and effectiveness in planning.

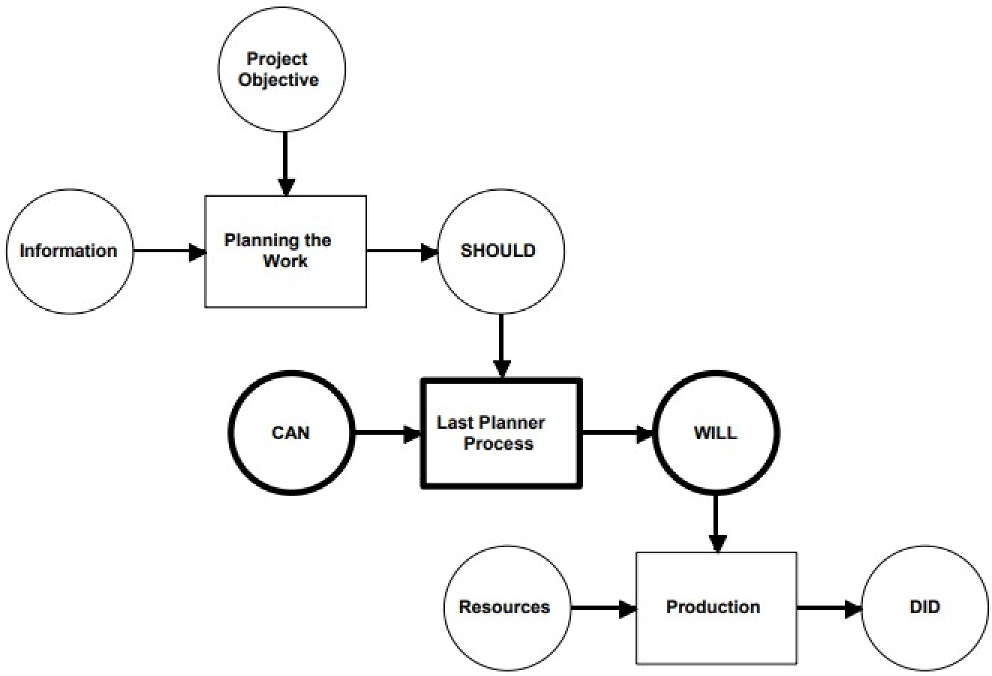


Figure 3.9: The theoretical shift in thinking when using Last Planner^{TM} (Ballard, 2000a).

Fosse & Ballard (2016) describes Last Planner^{TM} as a set of four components:

- **Planning**: Creating pull-planning sessions which involve participants representing all future work in the project, increasing reliability in the plan and ownership among team participants.
- **Lookahead**: Focus of making future tasks ready in order to react proactively to changes in the schedule. Using sound criteria for activities to ensure reliability.
- **Checking**: Tracking Percent Plan Complete (PPC) and root causes for failed commitments in order to measure progress according to plan.
- **Learning**: Analyzing PPC and root causes in order to learn from trends and previous mistakes.

Although Last Planner™ exist in many forms as of today, the system proposed by Ballard (2000a) present four individual, interdependent plans, which form the basis for most implementations of the framework.

- **Master Schedule** (*SHOULD*): A set of milestones covering the entire project.
- **Phase Scheduling** (*WILL*): A more detailed, collaboratively made pull-based schedule, which is dynamically adjusted throughout the planning phase.
- **Lookahead Planning** (*CAN*): A list of activities that need to happen over the next six weeks, a focus is continually being put on making future task ready (makeready-planning).
- **Weekly Work Plan** (*DID*): Detailed set of production tasks for the next week or two, depending on the project. PPC is measured and discussed among designers.

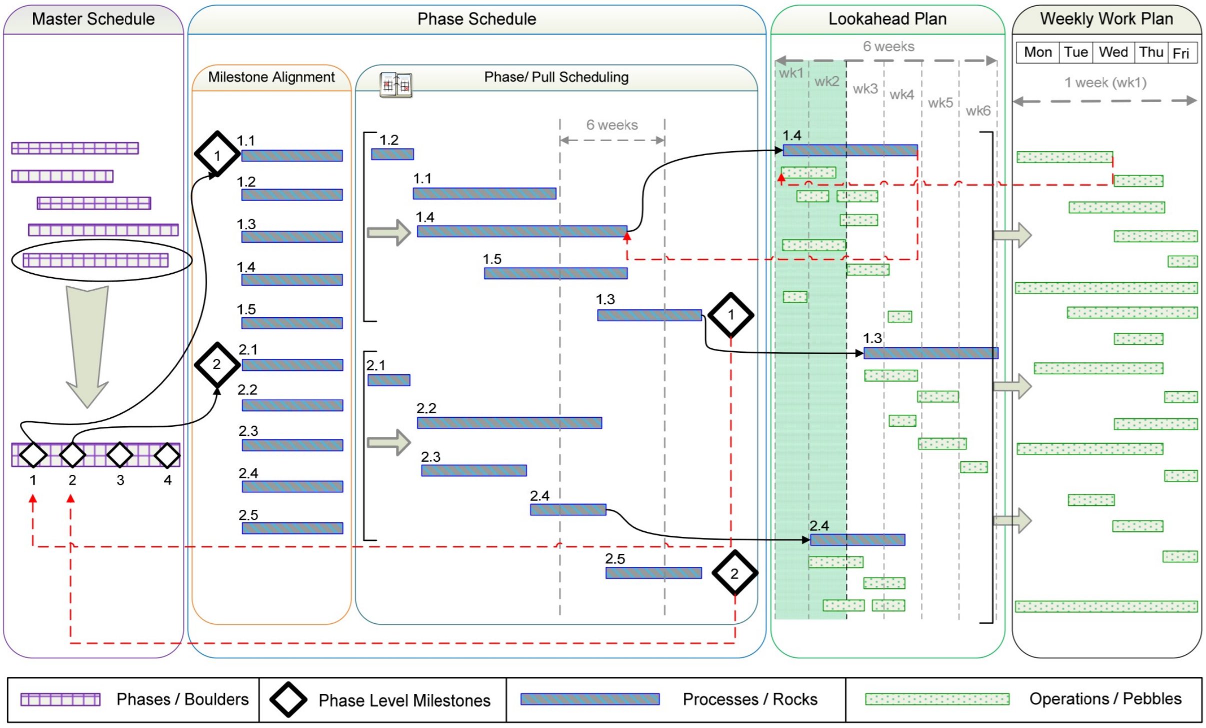


Figure 3.10: The four plans of the Last Planner™ System (F. Hamzeh, 2009).

When implemented correctly during production, the Last Planner™ System has shown significant improvement in performance, citing increased process transparency, work scheduling, learning, process control and completion rates (Fosse & Ballard, 2016).

Traditionally, Last Planner™ has not seen significant implementations in construction design (Fosse & Ballard, 2016), often as a result of the complicated iterative processes associated with this project phase (F. R. Hamzeh et al., 2009), or in other words *the inability to properly describe them*.

Percent Plan Complete

Percent Plan Complete (PPC) is simply put the percentage of tasks completed compared to the number of tasks that were expected to be completed over a certain span of time. The metric is quite simple, and comprises the foundation for a lot of progress-based measurements used in controlling projects today.

Although practical in its simplicity, PPC does have weaknesses as it only measures performance quantitatively and according to a to a predefined plan. A project with a less ambitious plan would thus have higher PPC than a project which completed the same amount of work with a more ambitious plan.

VDC and ICE

Virtual Design and Construction (VDC) is an approach to managing AEC projects according to lean principles by integration of information technologies (Kunz & Fischer, 2012). The approach highlight the importance of using visualization and new ways of communication in order to make the complexities of multi-disciplinary projects more manageable. VDC addresses the gradual implementation of these tools in project organizations using the Maturity Model, defining three stages of implementation (Kunz & Fischer, 2012).

- **Visualization and Metrics**: Project teams use 3D-models and graphical representations to represent product, organization, construction operations and process.
- **Integration (computer based)**: Projects develop computer-based automated methods of exchanging data among disparate modeling and analysis applications reliably.
- **Automation**: Projects use automated methods to perform routine design tasks or to help sub-assemblies in a factory.

VDC expresses the need for proper integration of the product, organization and process (POP) for projects to achieve higher stages of implementation. The management of these three aspects of projects are referred to as the POP-model, which serves as the fundamental principle to understanding VDC. The POP-model can be viewed as the integration and interaction of the social, technological and processual aspects in design.

Another important aspect to VDC is to bring different stakeholders together, as they all have specific business objectives which can provide complementary perspectives during project design (Kunz & Fischer, 2012). As a result of this, CIFE recommends using Integrated Concurrent Engineering (ICE) as an integral part of VDC.

The ICE-methodology was created during the 90's by the Jet Propulsion Laboratories (NASA) in order to develop multi-disciplinary project models quickly and effectively. The methodology revolves around highly structured, often day-long weekly meetings with all relevant designers, were everyone involved are required to participate and solve a given task within the end of the meeting. In AEC-projects, these meetings are typically exercised with large touch-screens in meeting rooms commonly referred to as ”big rooms”.

ICE has shown effectiveness when used in the AEC-industry (Kunz & Fischer, 2012). In relation to the POP-model, one could make the argument that ICE provides a sound approach to the management of the organization in the project.

3.4 Building Information Modeling

A Building Information Model (BIM) is a digital representation of the building to be (Reinhardt & Bedrick, 2017), as well as a technological tool and framework for designers (Sacks et al., 2010). In current approaches to AEC-projects, BIM enables inter-disciplinary collaboration and communication by providing a common design platform for all disciplines. BIM could be used to refer both to the model itself or to the practice of using information technologies in design, in which case referenced to as "Building Information Modeling".

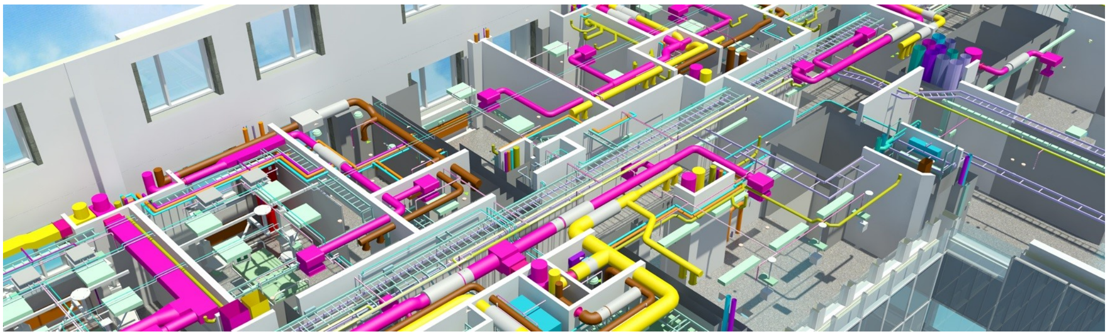


Figure 3.11: Building Information Model as used in building design (BIMCrunch, 2014).

The BIM can contain information as properties of modeled elements. Certain pieces of information are sometimes referred to as the six dimensions for modeled elements, the first three being spacial dimensions, the fourth being time of construction during the production phase, the fifth being cost of elements and the sixth being lifecycle-cost of elements. These practices are what is commonly referred to as 4D-, 5D-, or 6D-modelling.

Work in BIM can be performed in several programs (Tekna, Revit, Novapoint or similar), but work is usually exported to a universal file format (.IFC) in order to coordinate different disciplinary models.

The potential from using BIM becomes apparent when viewing it in relation to the POP-model. When used correctly, BIM enables all designers, managers and owners to have direct access to the product, making the product the foundation for all design works. In this regard, differences to traditional approaches are quite pronounced, in which design work consists as a sum of exchanging drawings and select pieces of information.

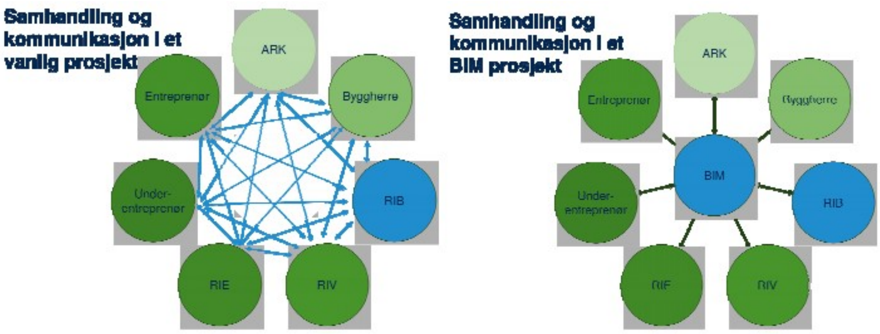


Figure 3.12: Integrated BIM in building design, from InnovasjonNorge, rendered by Lunn (2011).

One could also make an argument for BIM as an enabler of better inter-disciplinary communication, improving the flow in multi-disciplinary design. However, BIM is still merely a tool without any processual aspects to it when considered on its own, much like how a sequence of bolts to be fastened is not a property of the wrench used to carry out the work. In other words, what construction design management lack in order to manage BIM according to lean principles is a processual aspect describing its development.

3.5 Level of Development and Model Maturity Index

”Level of Development” (LOD) is a broad term with varying definitions. A suitable description of LOD in relation to the study is that of a formalized description of model development in BIM (Abou-Ibrahim & Hamzeh, 2016), or in other words a measure of the degree to which designers can rely on information from the model (McPhee, 2013). This term is often confused with ”Level of Detail”, the differences of which are described below.

- **Level of Detail (LoD)**: The amount of information associated with a specific element in BIM.
- **Level of Development (LOD)**: The reliability of the information associated with a specific element in BIM.

”Level of Detail” can be described as how much information a designer includes in a production drawing or how specific a design manager wants to be regarding meeting schedules.

As to the ability to describe the progress and state of a BIM-model in order to associate design work to plans, it is the reliability (maturity) of the model which is interesting in relation to sound management approaches, not the amount of information present. As such, this report researches LOD (as a short for ”Level of Development”), not LoD (as a short for ”Level of Detail”). BIMForum (2017) states the following definitions of LOD stages:

- **LOD100**: Graphical representation in the model as a symbol or a generic object.
- **LOD200**: Graphical representation in the model as a generic object with approximate quantities, size, shape, location and orientation.
- **LOD300**: Graphical representation in the model as a specific object with quantities, size, shape, location and orientation.
- **LOD350**: Graphical representation in the model as a specific object with quantities, size, shape, location, orientation and interfaces with other building systems.
- **LOD400**: Graphical representation in the model as a specific object with quantities, size, shape, location and orientation with detailing, fabrication, assembly, and installation information.
- **LOD500**: A field verified representation in terms of size, shape, location, quantity and orientation.

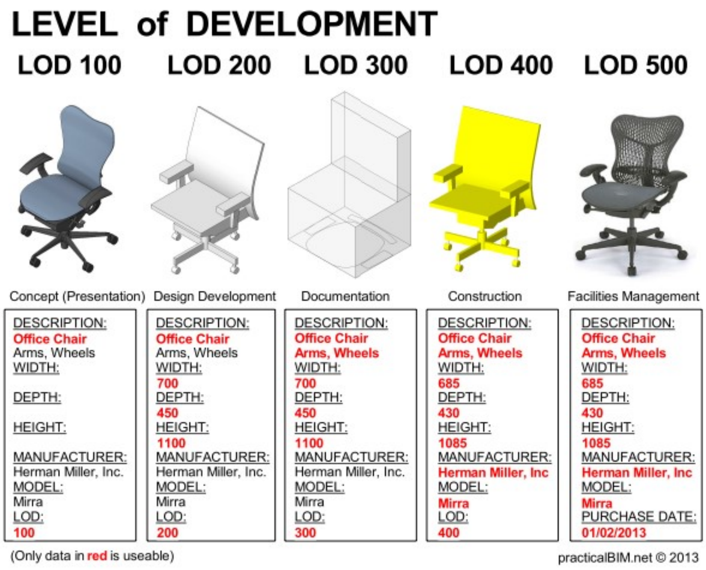


Figure 3.13: Practical example of the LOD-development of a chair (McPhee, 2013)

Although the intent of LOD is to formalize and standardize building design, variations in definitions and terms used indicate that this goal has yet to be accomplished. Findings from studies of actual implementations support this impression (Hooper, 2015).

Some practitioners choose to describe the reliability of their BIM-model using the term Maturity Model Index (MMI) instead of LOD. No literature regarding this term was found, yet industry professionals described these terms as effectively meaning the same thing, although the MMI-framework is more concerned with the process of design development rather than geometrical specifications.

Although it is possible to do on a per-object-level, it is often more practical to manage LOD-levels by sections confined to certain locations, building systems, or combinations of these. The relative size of these sections ultimately determines the degree of specificity to which LOD will be managed in the project. This means that the model development must be understood as a combination of two different types of processes. Firstly, the process of developing a specific section from an idea towards a production ready design. Secondly, the process of interactions and inter-dependencies between sections as they develop, influencing the design space and functional requirements of each other as they do so. In addition, as the function of LOD is to express the fitness of the information in the model, an accurate way of communicating the model state to designers needs to be implemented in projects.

In summary, findings from the literature review indicate that successful design management by lean principles can be achieved by proper implementation of Last Planner^{TM} with BIM according to VDC principles. The findings also indicate that for this to be a possibility, there must exist a processual aspect to the development in the BIM, and that implementation of model maturity in the form of LOD or MMI could solve this issue. Lastly, we can formulate four aspects of maturity-based design management from the challenges in application as specified above, namely *the specification of maturity levels*, *the degree of model disaggregation*, *the communication of model maturity* and *the responsibility for assigning maturity levels*. Theoretical approaches to these aspects can be formulated from theory as follows:

- **Specification of Maturity Levels**
  Requirements for an object achieving a certain maturity should be related to the make-ready of future tasks. Being unrelated to the volume of detail, levels should specify the necessary information for model progression towards value creation.

- **Degree of Model Disaggregation**
  The disaggregation of the BIM into sections should be done in such a way that the amount of information within one section remains comprehensible for all designers, at the same time ensuring that all project participants are enabled to understand the overall development of sections.

- **Communication of Model Maturity**
  The method of communicating the maturity levels of the different parts of the model should enable designers to know the fitness of the information they are working with, without being needlessly complicated to manage.

- **Responsibility for Assigning Maturity**
  In keeping with principles from Last Planner, having the designers declare the maturity of their own work increases their ownership to tasks and responsibilities.

Chapter 4

Results

The following chapter details findings from the interviews and the document study relevant to the research questions. The findings has been sorted into the sub-divisions of (1) Design Phases, (2) Planning and Control, (3) BIM-coordination and (4) Maturity in order to discuss the research questions in a more systematic format. It should be noted that the chosen assortment of findings is only intended as a practical approach to presentation and discussion, as many findings have relevancy to more than one of said sub-divisions.

4.1 Current Approaches to Design Management

The following chapter details findings relevant to RQ1.

Current Approaches to Design Phases

Interviewees from Veidekke presented the following phases for design:

1. **Sketch- and pre-project** (also known as development-phase): Setting up a model, starting initial assessments and concept development.
2. **Detailing-phase**: BIM development towards production drawings.

Skanska represents their design process in relation to the maturity (MMI) of their BIM-model. Throughout the interview, the practitioners referred to the design process using two phases.

1. **Early-phase**: MMI100 - MMI200. Early concept design intended to produce a BIM-model sufficient for cost-calculations (MMI250).
2. **Detailing**: MMI250 - MMI400. Development of BIM-model towards production drawings. Detailing and designing the finalized building, incorporating other disciplines.

Current Approaches to Planning and Control

Both contractors use customized versions of the Last Planner^{TM} methodology for planning and control in the cases assessed in this study. In addition, the contractors utilize collaborative and involved planning (ICE) using pull-based techniques planning backwards from the desired final product. In Skanska, the weekly (or bi-weekly) work plan are incorporated into the lookahead plan, lowering the amount of plans from four to three.

The approach in Veidekke also differs slightly, combining master and phase schedules and using different approaches to construction versus design. The construction plan is pretty similar to the original proposition of the Last Planner™ System, consisting of lookahead- and weekly work plans, although the planning methodology for design has seen some changes. Much like in Skanska, the lookahead plan has been incorporated into the weekly work plan to a certain extent, although referred to as the ”Dialog Matrix”. In addition to the plans from the Last Planner™ System, a smaller plan called the ”Question Matrix” was presented in Skanska, consisting of a smaller matrix where newer, smaller problems would be noted every week.

Beskrivelse	Ansvar	Medvirkende	Beskjed til	Ja	Nei	Uaktuell	Årsak: Prosjekteringsgrunnlaget er ikke ferdig	Forventninger og krav er ikke ivaretatt	Mangel på dialog for å avklare problemet	Mangel på beslutninger	Feil metode/verktøy	Mangel på mannskap (kapasitet og kompetanse)	Kommentar
Har drift/NTNU Campusservice fått med alle nødvendige avklaringar mot sentral drift av VVS?	BH	BH v/Trond			x								
SHA-risikovurdering, foreløpig SHA-plan	BH		VD		x								
Avklare avfallsrom (eksternt bygg)	BH		VD,ARK										
Skjema til rammesøknad	BH		ARK		x		x						
ARK/IARK													
Rammesøknad	ARK		BH, VD		x							x	Leveres 21/11??
Vindusskjema	ARK		VD		x							x	
Oppdatert trappeskjema revideres etter innspill fra BH	ARK		VD	x									
Tegne inn porter ifm adkomst plan 3	ARK		VD	x									
Oppdatere gulv- og himlingsplaner ift grunnlag fra brann og akustikk	ARK		VD	x									
Dørliste kompletters ihht lyd- og brannrapport	ARK		VD		x							x	
Plassering solavskjerming i vindu	ARK		VD		x								
RIB													
Dekkeoppbygging				x									
Automatikk													
Komplett beskrivelse og pris	RIAuto		VD		x								Kom 24/11
Bemanningsplan	RIAuto		VD										
RIE													
Komplett beskrivelse og pris	RIE		VD		x							x	Sykdom
Bemanningsplan	RIE		VD										
RIV													
Komplett beskrivelse og pris	RIV		VD		x								Pris kom 27/11. Beskrivelse 24/11
Bemanningsplan	RIV		VD										
RIEnergi													
Funksjonsbeskrivelse RIEn	RIEn		VD	x									
Energiberegninger	RIEn		VD		x								
Energitiltaksliste	RIEn		VD		x								
ITB													
Avtale om solidarisk ansvar for TUE	ITB		VD		x								
Notat/beskrivelse for plan for igangkjøring og prøvedrift	ITB		VD	x									
Oversikt over hva VD må prise ift tekniske fag	ITB		VD	x									

Figure 4.1: Example of standardized meeting forms used in Veidekke (from ”ZEB Flexible Lab”, conducted in cooperation with NTNU)

ICE -sessions are utilized in both companies. While Skanska and Veidekke uses PPC in their projects, PPC was seemingly not used by Sweco in E6: Arnkvern-Moelv. In this case, PPC was replaced by monthly subjective evaluations of design progress made by designers in addition to expressing the MMI development of the model in a chart. Otherwise, PPC is typically measured with standardized meeting forms requiring failed tasks to be assigned to one of the standardized root causes.

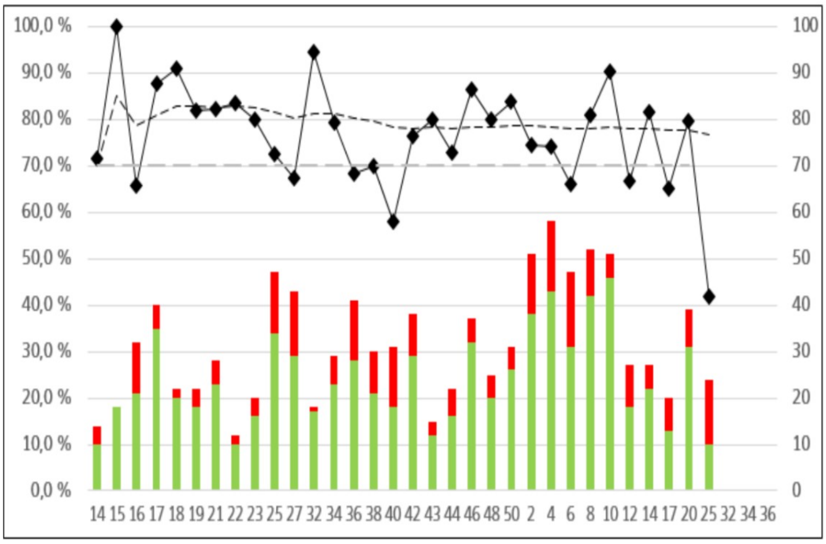


Figure 4.2: PPC charts from Tiedemannsbyen. PPC represented in line-graphs and the number of tasks represented by bars (green being accomplished, red being unaccomplished).

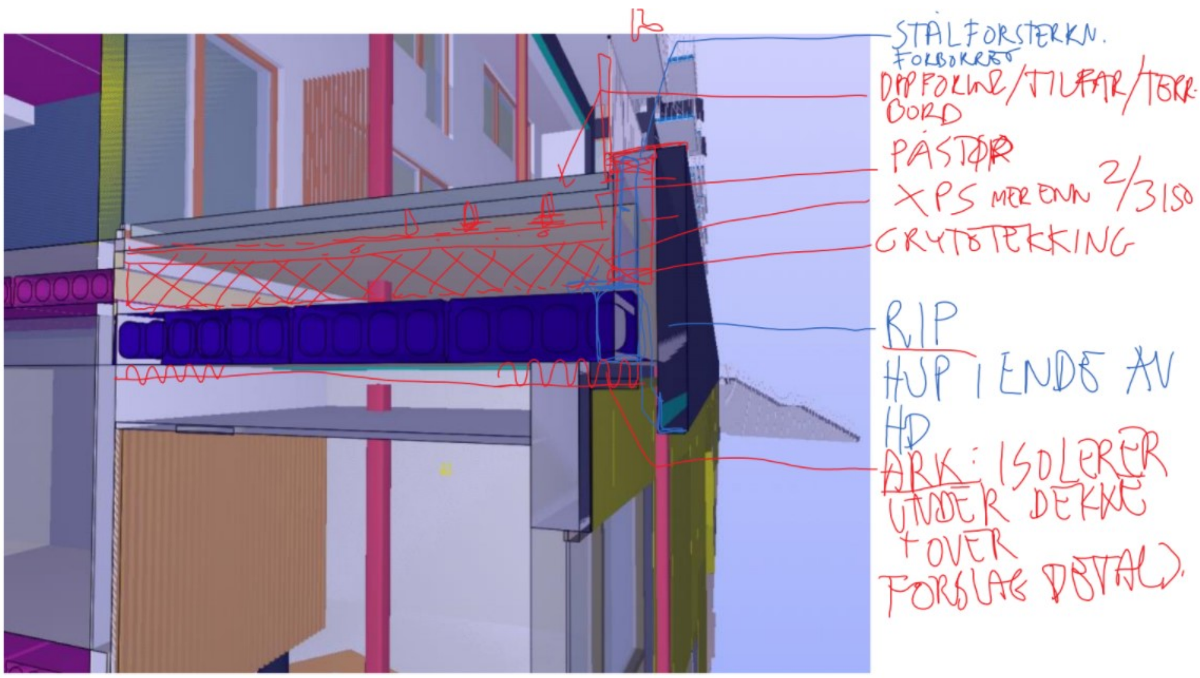


Figure 4.3: Notes taken during ICE-session in Skanska, using Microsoft OneNote to sketch over screenshots taken from Solibri

Both contractors evaluate root causes for uncompleted tasks based on criteria for sound activities. Sound activities as used in Veidekke are listed below (although these were not used in E6: Arnkvern-Moelv).

1. Dependant for other designs to be completed
2. Expectations and goals are not met
3. Lack of communication
4. Lack of decisions
5. Wrong method/tools
6. Lack of manpower (capacity and/or competence)

Management in Skanska uses a bit more options for root causes.

1. Unclear task description
2. Insufficient manpower
3. Insufficient competence
4. Insufficient tools
5. Underestimated scope
6. Preceding tasks incomplete
7. Public process (external applications not validated in time)
8. Insufficient inter-disciplinary participation
9. Priority given to other tasks
10. Insufficient information

In relation to maturity, Skanska represents MMI-milestones as deliveries in Last Planner^{TM} (see Figure 4.4).

Figure 4.4: MMI-deliveries sorted into Last Planner

Interviewees from both contractors reported that the pre-project/early-phase would typically lack significantly in structure when compared to the detailing phase. In addition, the project organization would often only include architects and structural engineers during the first phase of design.

Current Approaches to coordination in BIM

All interviewed practitioners reported a complete shift in BIM-use over the last couple of years, increasingly being viewed as a fundamental part of construction design. In the words of the BIM-coordinators from Skanska, this increased integration could be expressed by the fact that it was no longer a matter of whether or not you would use BIM, but a matter of whether you would use 4D-, 5D- or 6D-modelling. Practitioners from both contractors report using BIM in pre-project/early-phase, although to a lesser extent than in detailing. Despite increased adoption however, some interviewees made a point of the fact that some consulting firms still charge extra for using BIM in contracts, seemingly not viewing it as an integral component to design just yet.

Management in Tiedemannsbyen used BIM functionality to track maturity indirectly, generating weekly charts of the number of clashes within the model, both within each discipline and in-between different disciplines. These charts serve to provide insight into the the model progression during design development for all designers.

In E6: Arnkvern-Moelv, and reportedly in other infrastructure projects, the concept of BIM is not as widely used as in building projects. Although in essence 3D-modelling, the models developed in these projects using NovaPoint and Autodesk Civil 3D reportedly possesses less information when compared to building information models in residential or commercial building projects. In comparison, designers in Tiedemannsbyen employ modelling software like Revit, Tekla, and MagiCAD, in addition to Solibri for viewing the model.

Current Approaches to Maturity

The contractors utilize more or less the same MMI framework in the two cases, although the approaches differ in minor ways. The MMI framework was developed by Håkon Fløisbonn (Skanksa Norway) and Gunnar Skeie (Kruse Smith) with the opinion that traditional LOD frameworks employed too much focus on the graphical detail of objects in the BIM. This, they argued, was a problem seeing as this approach did not effectively translate into eventual value creation in the design process (see TFV Theory in Chapter 3.3). In addition, BIM software includes large libraries of placeholder elements, detailed to a level comparable to finalized designs, effectively refuting the idea that the amount of detail is any indication of an object's fitness for use.

Specification of Maturity Levels

The MMI framework uses the same six levels as in the general LOD framework (see Chapter 3.5). The general framework also addresses the process and associated information to an object in addition to its geometrical properties as used in LOD.

	100	200	300	350	400	500
	Idea	**Refined idea**	**Ready for inter-disciplinary control**	**Inter-disciplinary controlled**	**Production-ready**	**As built**
Process	Object represented as a sketch	Object is further developed from an idea, and treated as a preliminary solution	Object controlled for conflicts with other object within own discipline. All objects with inter-disciplinary relevance represented.	Object inter-disciplinary controlled, no remaining inter-disciplinary conflicts	Object verified by design team and ready for construction	Object confirmed built
Geometry	No requirements, object is to be considered as a sketch no matter the potential detailing at this stage.	Generic representation with approximate shape, size, location and orientation.	Object is represented as a specifc system with correct size, shape, location and orientation.	Object is represented as a specific system with correct size, shape, location and orientation.	Object is represented as a specific system with correct size, shape, location and orientation, with detailed execution of construction.	Object corresponds to its real-life counterpart in terms of size, shape, location and orientation.
Information	No requirements.	Object contains suggestions to materials and modeling requirements.	Object contains correct information in relation to materials and modeling requirements.	Object contains correct information in relation to materials and modeling requirements.	Object contains all relevant production information in relation to modeling requirements.	Object contains relevant information from its real-life counterpart. Information regarding installation present.

Figure 4.5: General MMI-framework, as specified by Gunnar Skeie and Håkon Fløisbonn (translated from Norwegian)

Although the aforementioned framework may seem complicated, it should be noted that the definitions used here are only meant to establish MMI as a concept. In practical approaches, MMI-levels are often used with more open and leniant formulations. For example, whereas LOD200 is specified as a *"Graphical representation in the model as a generic object with approximate quantities, size, shape,location and orientation"*, MMI200 is achieved in projects by *"producing a finalized concept ready for further detailing"*. This approach was chosen partly to ease implementation, as its authors wanted the implementation of MMI to be "free" for management to implement in their projects.

In Skanska, MMI-levels are closely related the general MMI framework, with the addition of a 250-level. This level is intended as a tool for cost calculation, only being separated from the 200-level by having elements with associated cost. Having taken inspiration from the principles of one-piece flow in construction, the MMI-approach in Skanska is thought to be a continuous development cycling through the different sections of the building, therefore illustrated as a wheel (see Figure 4.6).

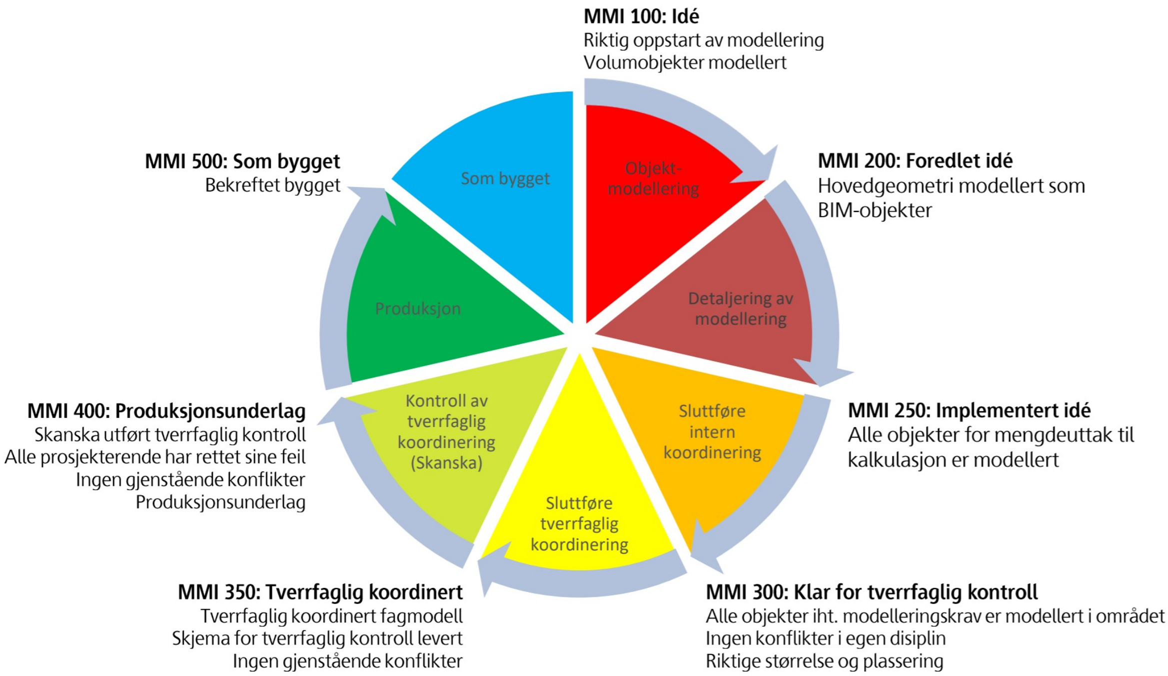
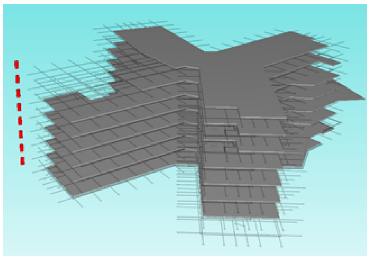


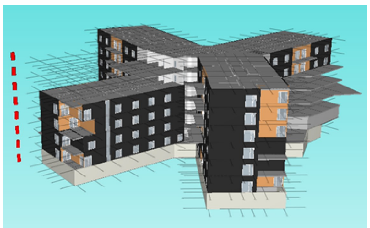
Figure 4.6: Model Maturity Index (MMI) as used in Skanska

In addition to the MMI-levels stated above, managers from Tiedemannsbyen admitted to informally use an additional level referred to as ”MMI425”, where production-ready drawings would have been checked with production personnel for validation as constructable. Graphical examples of maturity taken from Tiedemannsbyen are presented below:



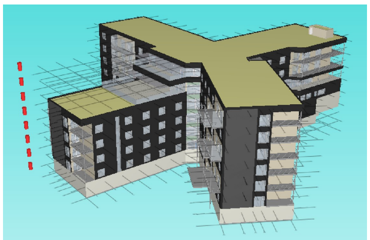
MMI100: Idea

Coordinated IFC, correctly established model, axis and coordinates.



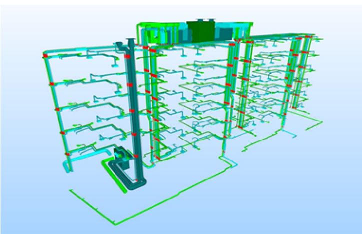
MMI200: Refined Idea

Proposed solution before detailing, main geometry modeled as BIM-objects.



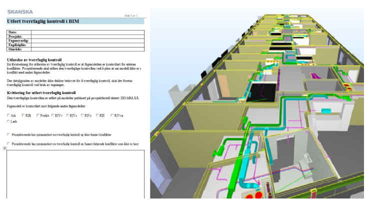
MMI250: Implemented Idea

Proposed solution ready for cost calculation, all objects necessary for measurements modeled.



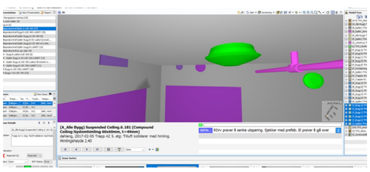
MMI300: Ready for interdisciplinary control

Finalized model without any relevant collisions within own discipline, all relevant objects for the particular discipline has been modeled. As one of the practitioners put it; ”A communication tool for designers to declare their particular work ready for collision-checking with other disciplines”.



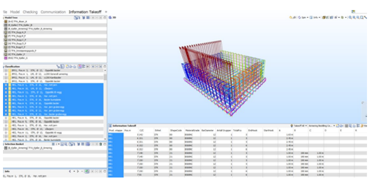
MMI350: Interdisciplinary coordinated

Finalized model without any relevant collisions within or across disciplines, no remaining conflicts. Whereas the previous level were presented as a tool for communication, the 350-level is used more as a distinct property of the model.



MMI400: Production-ready

All potential conflicts resolved, model ready for the creation of production drawings and plans.



MMI500: As built

Modeled as built.

In E6 Arnkvern-Moelv, maturity level specifications were formulated more openly when compared to Skanska's approach in Tiedemannsbyen, although it should be noted that this approach has taken further measures in describing the process between each level.

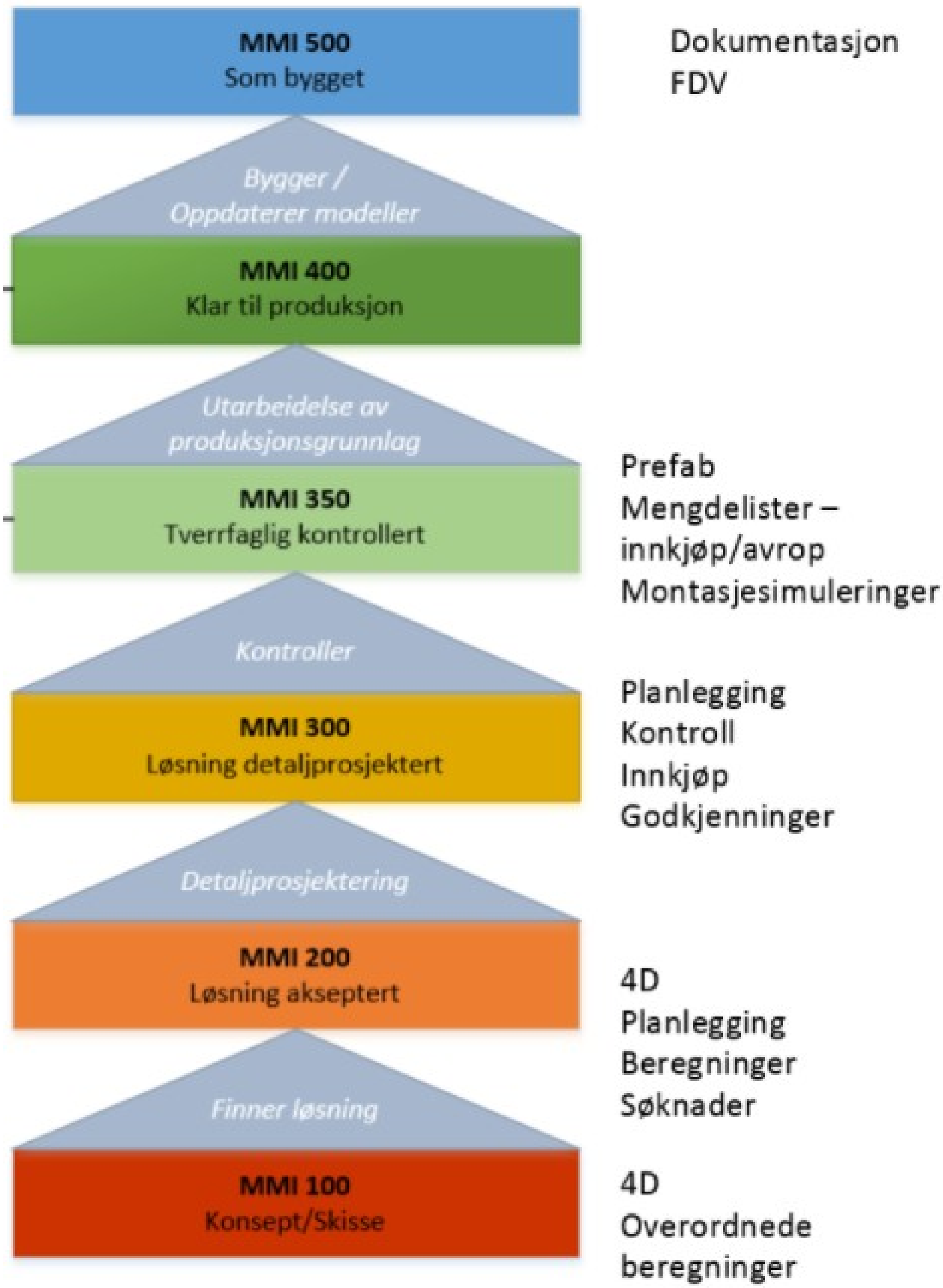


Figure 4.7: MMI definitions as used in E6: Arnkvern-Moelv

This decreased specificity in levels also comes as a result of management employing more discipline-specific requirements for maturity. By example, the construction discipline might be required to have the concept model for a bridge be approved by local municipalities in order for the model to achieve 200-status.

Degree of Model Disaggregation

Both cases separate the BIM into rather large sections, and manage each disciplinary model within these sections. In Tiedemannsbyen, sections represented each building step during the production, making one section for each building and each basement, making up ten sections in total.

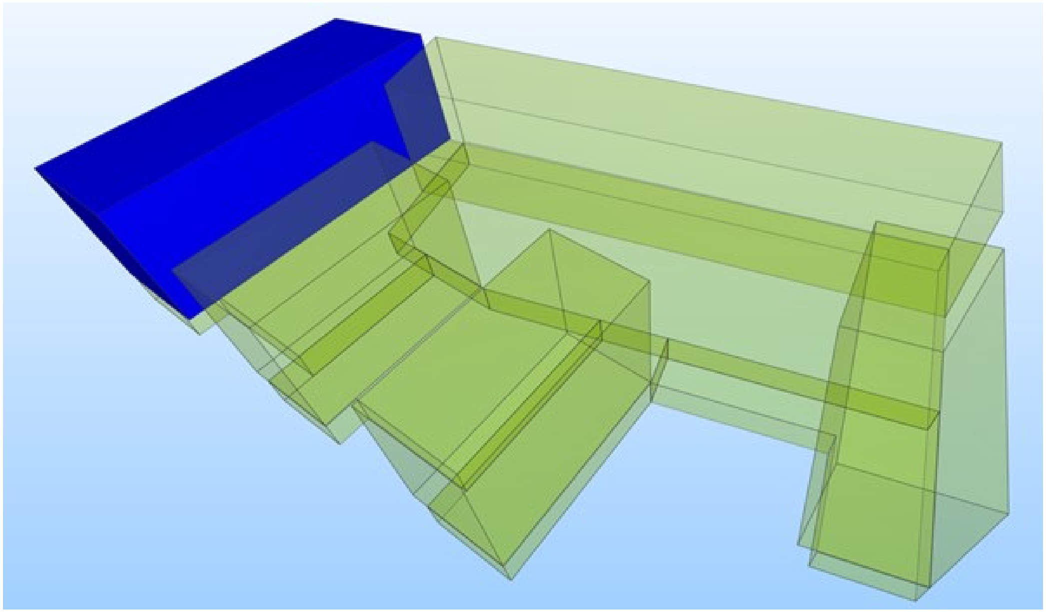


Figure 4.8: Example of a BIM section, Tiedemannsbyen

Although these section might seem big, it is important to mention that floor layouts and specifications are often repeatable in apartment projects, making it easier for designers to operate within larger sections.

Section sizes were similarly large in E6: Arnkvern-Moelv, breaking up the road into a total of 19 sections. Sections were divided based on the their complexity, using smaller sections around bridges, intersection or similar.

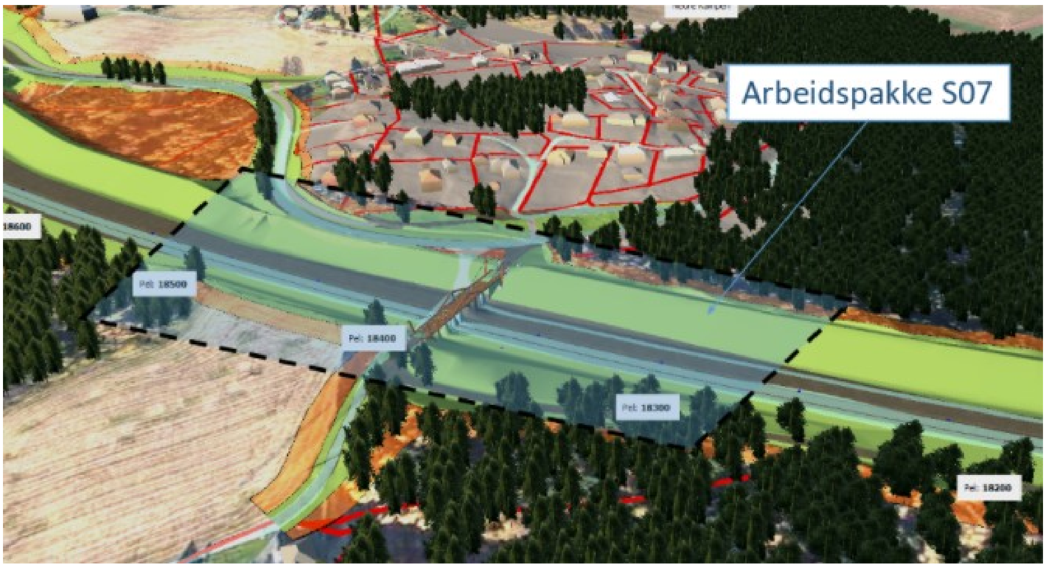


Figure 4.9: Example of a BIM section, E6: Arnkvern-Moelv

MMI was in both cases managed as an attribute for each disciplinary model within each of these sections.

Communication of Model Maturity

Skanska does not employ any particular tools to communicate MMI states to designers. The rationale for doing so was the argument that the MMI-deliveries were clearly laid out in the plans, the fact that designers would get regular updates from weekly ICE-sessions, in addition to the fact that model progression was brought up weekly with charts of trends in clashes. In E6: Arnkvern-Moelv however, management took an active approach to communicate model state to designers, making a 3D visualization in Revit as seen in Figure 4.10. In this chart, each MMI level corresponding to a section (on the horizontal axis) or discipline (on the vertical axis) is represented by a coloured bar, making it easy for any designer to understand the fitness of the information from other disciplines. In the example below, one can for instance observe that section 12 (S12) is more or less ready for inter-disciplinary control, while sections like S3 needs disciplinary controlled models from the water and drainage -systems (VA) and construction (KONSTR) disciplines in order to do the same (the landscaping architect (LARK) are significantly dependant on other disciplines, and are likely adjusted after said disciplines when they have been controlled).

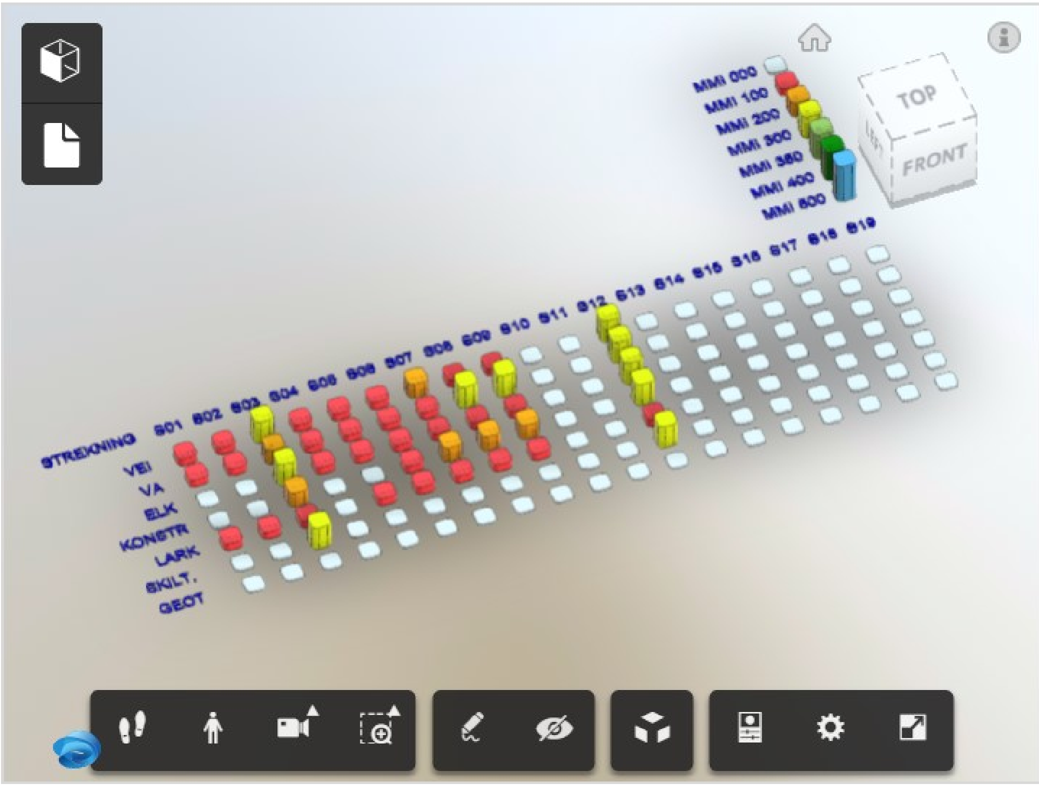


Figure 4.10: 3D Chart for visualizing model state, E6: Arnkvern-Moelv

Responsibility for Assigning Maturity

Both cases employed a certain degree of control when declaring different parts of the model at a certain MMI-level. In Skanska, the project employs a BIM-coordinator who validates disciplinary models when declared ready by designers for each level in detailing.

In E6: Arnkvern-Moelv, the design organization was quite large, consisting of large teams for each of the main disciplines illustrated in Figure 4.10, mostly ranging from five to ten designers per discipline. Assigning maturity is the responsibility of each disciplinary group leader, except for the MMI350-level, which required inter-disciplinary control. In these cases, the responsibility for declaring certain parts of the model at certain stages of maturity was with the BIM-coordinator or the design manager.

4.2 Experiences from Current Approaches

The following chapter details findings relevant to RQ2.

Experiences with Design Phases

Interviewees reported that although phases in design did have ambiguous definitions, most stated that there was a common understanding of what the phases were, those being the two phases presented in Chapter 4.1.

However, both the separation of the stages and the work associated with phases was unclear, and lacked formalized conception between industry actors. In addition, the work assigned to different phases would often vary depending on type of project or contract.

The use of MMI as intermediate milestones (or phases) in design was however considered a great benefit by project participants, not only providing better description of relevant work for each phase, but also a clearer separation between stages.

In Skanska, the use of MMI250 as a definite separation between the early-phase and the detailing phase proved especially useful according to interviewees.

Experiences with Planning and Control

Both teams reported great prior experiences with Last Planner^{TM} and ICE. As described by participants, traditional approaches without this would typically revolve around big meetings having the project manager listing up deadlines and checking progress with designers. When faced with a missed deadline, milestones would be moved further into the future and planning predictability would have been lost, without any inquiry into the root cause of the issue. With these new tools however, the entire team was active in discussing project development, and systems were in place not only to measure productivity, but also to uncover the underlying reasons for deviations from the plan. However, some difficulties were still present in case projects, namely:

- The necessity of proactive management in engaging designers correctly in their tasks.
- Difficulties in planning design due to the uncertainties of what the end product would be like.

In addition, the organizational structure and project development in E6: Arnkvern-Moelv did not seem optimal according to project participants. The design organization was almost entirely made up of designers from one external design firm, being managed by a ”lead designer” which was in direct communication with the design manager representing the contractor. These were both changed in favour of new representatives during the spring of 2018, citing poor communication as the reason for new management.

In general, there was a greater reported sentiment among E6: Arnkvern-Moelv designers that management resembled traditional ad hoc approaches without predictability in planning. In addition, unclear roles and responsibilities were mentioned. Whether or not this was directly tied to the change in management is not clear.

The designers did however praise the turnkey method of delivery, in contrast to the general contracts they were accustomed to in other infrastructure projects, citing increased communication and decreased self-interest among stakeholders.

Although adoption of new frameworks in Tiedemannsbyen was slow in the beginning, the team reported a clear learning-effect, increasing productivity over the coming weeks. The design organization was described as typical, which can be referenced to previous statements regarding MMI-implementations being ”free” and effortless to implement.

Management in Tiedemannsbyen spoke quite fondly of the design team, stating that the team had ”positive actors” who were enthusiastic for implementation and proved vital to implementation efforts.In addition, they also stated that in their opinion, this team would have likely worked well using most management approaches.

In general, project participants did not express a tendency to miss deadlines, although some MMI-milestones were moved on occasions. However, this reportedly occurred to a far lesser extent than in traditional approaches.

One of the BIM-coordinators from Skanska (who where not involved in Tiedemannsbyen) did admit to putting somewhat sizable buffers (2-3 weeks) in between MMI350 and MMI400 on a regular basis, which he reported to be adequate in most situations. Moving milestones as a result of incorrect planning happened rarely according to the practitioners.

Experiences with coordination in BIM

All participants reported active use of BIM as an integrated tool in their projects, although they expressed that BIM was harder to employ / less employed during the pre-project / early-phase of design than in later phases.

There was also mentioned examples of cost-calculators using BIM on their own, modeling up missing data instead of merely requesting models as deliveries from BIM-coordinators. The same BIM-coordinators explicitly used the word ”integrated” when referring to the use of BIM in their company.

In Tiedemannsbyen, trends in the number of model clashes were recorded on a weekly basis. In presenting this for the design team, existing clash-detection functionality in the BIM software were used to tally up the total number of clashes in the model, which was graphed for each ICE-session. These metrics would include clashes on a per-discipline and inter-disciplinary level, highlighting which disciplinary models produce the highest number of clashes.

Performance was initially sub-par, having the team missing all relevant deadlines for the first of the five buildings (see Figure 4.11).

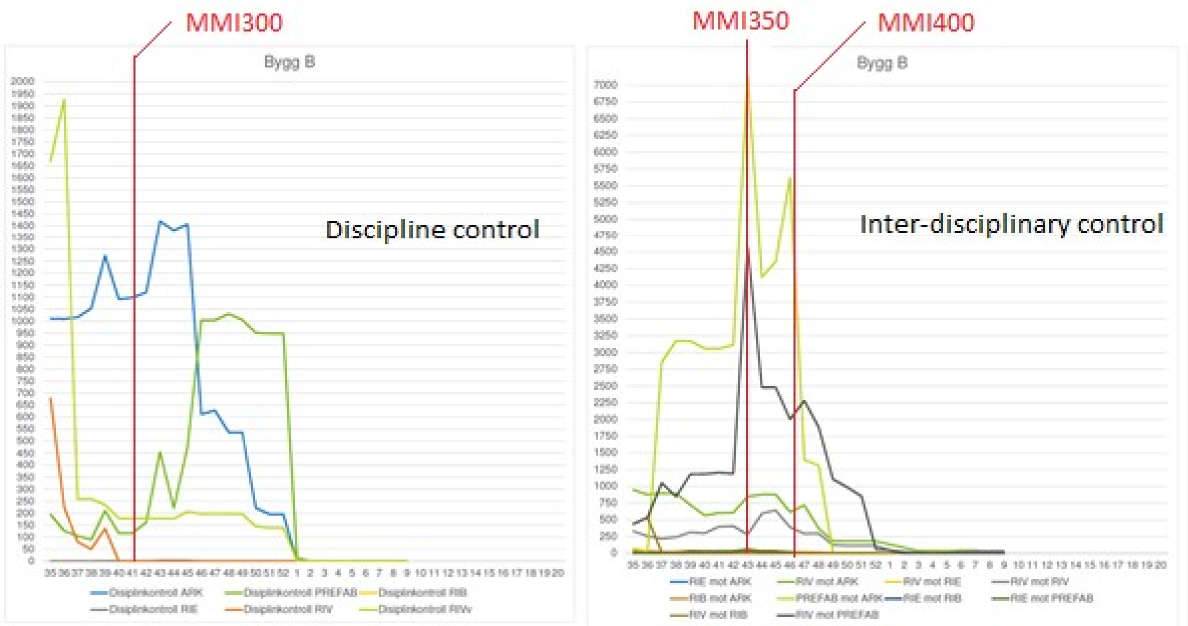


Figure 4.11: Trends in clashes, Building B, Tiedemannsbyen

Although the team was unable to meet its deadlines for the first section, efficiency and reliability in meeting deadlines grew as the designers were increasingly exposed to the framework. Four months later, during the design of the third building, the model matured sufficiently in time for the team to meet their deadlines (see Figure 4.12).

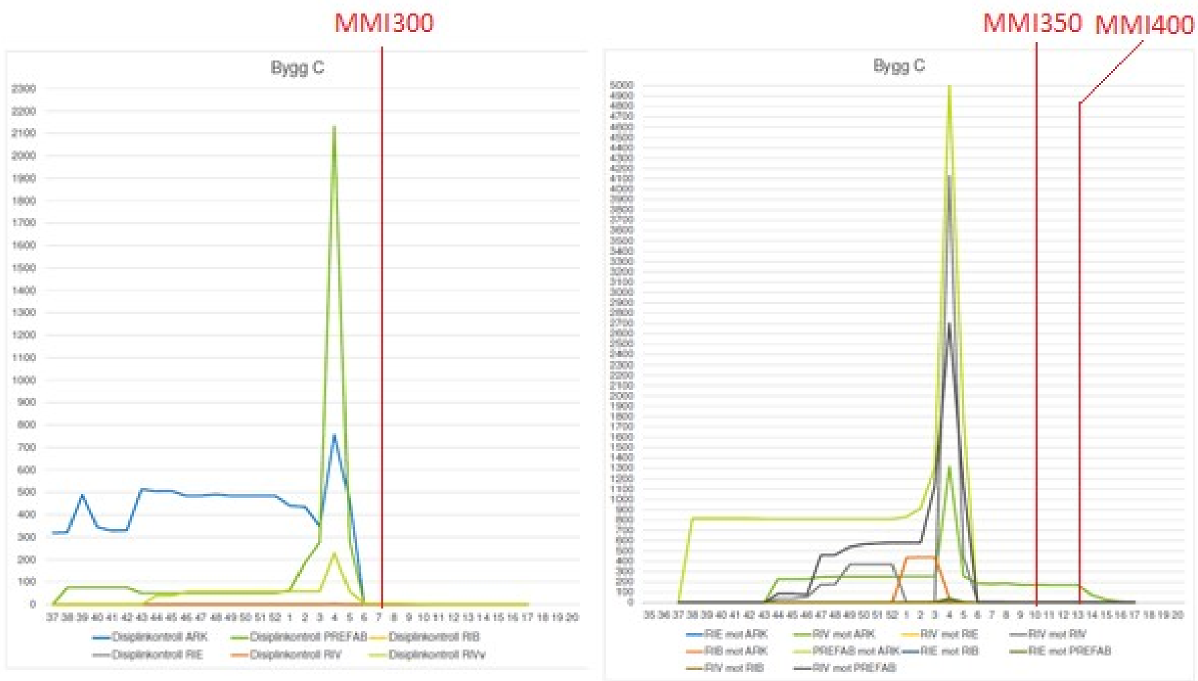


Figure 4.12: Trends in clashes, Building C, Tiedemannsbyen

It should be noted that Figures 4.11 and 4.12 reflect the total number of clashes in the BIM, including several cases of objects clashing with no relevance to constructability. However, the trends from these automated weekly charts can provide great value in making project development transparent for all designers.

Some shortcomings of BIM use were uncovered by the interviews however, namely varying degrees of competence among designers, in addition to a number of minor issues with software. Examples of these issues were designers working in different units or datums, or having difficulties loading files due to server-side errors or faults regarding naming conventions. Other than explicit problems, responses also cited that work in BIM often involved unnecessary technicalities which ideally should have been programmed into the BIM.

Experiences with Maturity

Responses from both cases were largely favourable towards the implementation of the MMI-frameworks. A number of effects was observed:

- Greater ability to share incomplete information.
- Less rework.
- Greater insight into project development for the design team.
- Greater ability to understand the fitness of the information in the models from other disciplines.
- The system was voluntarily adopted by designers.

- The framework were on some occasions described as a fundamental necessity in design, stating comments like *"prior to using this, we were more akin to headless chicken running around aimlessly"*.
- Designers becoming more proactive.
- Greater ability to express project development and fitness of the information in the BIM to external stakeholders.
- Designers now possessed a (self-reported) "language" to describe project work and development.

In general, participants acknowledged that the framework was not finalized, and expressed an understanding for the fact that it needed ongoing exposure in order to mature.

Contrary to this, there where several observations of cultural inertia in adoption. In E6: Arnkvern-Moelv, one instance of rework was made as a result of personnel from the construction team failing to provide sufficient information at an earlier MMI-stage. In Tiedemannsbyen, the initial lack of adherence to MMI-deadlines as seen in Figures 4.11 and 4.12 are another example of this.

In addition, one interesting observation regarding maturity came from the landscaping architect from E6: Arnkvern-Moelv. The landscaping discipline is quite small in terms of complexity, and usually has to adjust itself to the other major disciplines. During the interview, the architect noted that for her discipline, MMI levels did not rise gradually (having a comparable amount of work within each MMI level), but rather slowly towards the 200-level and rapidly up from there. This skewed distribution of work was apparently as a result of her dependency on the other disciplines. While working on her models, she would in most cases be close to finished, waiting for the models from the major disciplines to mature (see "LARK" Figure 4.10). Only when the other disciplines had developed a certain maturity could hers do the same, which often resulted in a quick process once this threshold had been reached.

Although having done little work in the later stages, the models would greatly increase in maturity. The significance of this observation in particular is the fact that inter-dependencies between disciplines can result in the maturity of one discipline largely being a product of the maturity of other disciplines.

Specification of Maturity Levels

The response from participants regarding the maturity levels themselves was somewhat mixed. Although largely being received as sufficient, some designers expressed a desire for more detailed specifications. The levels used in the cases (see Chapter 4.1) was open by design in order to ease implementation, which in effect required designers to make subjective interpretations and assessments when evaluating the maturity of their work, leading to confusion and a lack of common understanding of the requirements for deliveries.

On the other hand, the focus on functional requirements rather than graphical detailing was well received by all participants, in addition to the approach of tailoring requirements by discipline.

Lastly, it should be mentioned that in Tiedemannsbyen (and seemingly in building projects in Skanska as a whole), there lacked a precedence for using the levels prior to MMI250 in an orderly fashion. Although the framework for levels 250-400 seemed a lot more defined and thorough than their counterparts in E6: Arnkvern-Moelv, the levels for the early-phase was seemingly neglected in comparison. In E6: Arnkvern-Moelv however, the approach was more consistent in focus over all MMI-levels.

Degree of Model Disaggregation

The response from project participants were generally favourable towards the use of large sections, citing it as a contributing factor to increased understanding of overall project development. Participants did however stress that the complexity often varied between different parts of the model, and that it might be favourable for management in some occasions to make smaller sections for complex areas such as technical rooms or similar. The separation according to building steps in production was reportedly useful for production personnel to relate to when assessing the finalized model.

Communication of Model Maturity

All participants stated that they did not have any particular problems with keeping track of model progression.

Responsibility for Assigning Maturity

Although having the designers assign maturity themselves did increase ownership of the system among them, there were several reported instances of designers having submitted models which did not live up to the intended maturity. As such, third-party oversight in the form of BIM-coordinators proved necessary.

4.3 Improvements of Current Approaches

The following chapter details findings relevant to RQ3. Readers should note that due the the research question's nature of being a problem-solving type of question (see Chapter 2.1), it does not lend itself well to the format of presenting relevant data found in the study. Seeing as the answer to such a question revolves a lot around theory in conjunction with findings from other research questions, it is a lot more suited for the discussion-format in Chapter 5. Nevertheless, some interesting observations with relation to the research question has been categorized accordingly.

Improvements of Design Phases

Several participants noted the positive effects of incorporating MMI into the existing phases. Some expressed the positive effects of replacing the existing two phases with the more frequent and intermediate milestones from MMI, while others pointed out the increased clarity in definitions of work when doing so.

Improvements of Planning and Control

The integration of MMI-deliveries into plans (see Figure 4.4) proved a successful effort of integrating product development into planning.

In E6: Arnkvern-Moelv, where the overall plan for the project had been made mostly by the design manager from Veidekke (who were only in contact with one representative from the design organization), existing plans were deviated from during the design-works, adopting an ad hoc approach in large parts of the organization.

BIM-coordinators from Skanska whom were not affiliated with Tiedemannsbyen, but often responsible for integrating MMI into Skanska's projects, cited that they commonly used buffers in the scope of two-three weeks when planning for MMI deliveries. According to the BIM-coordinators, these buffers typically accommodated for the designers' lack of experience with the framework.

In general, the most commonly cited reason for a designer to be unable to meet project deadlines was either due to lack of resources or the task being more comprehensive than previously thought.

Improvements of coordination in BIM

The use of BIM was largely received as positive, although frequent reports of minor inconveniences was reported. These inconveniences provided increasingly negative effects when combined with a varying degree of competence in BIM by designers. In fact, many of the participants emphasized the opinion that most of the problems with using BIM came from the people using it rather than the software itself. In summary, most of the areas of improvement in relation to the use of BIM in design was related to usability rather than lacking functionality.

Improvements of Maturity

In general, the responses to the MMI-framework was positive, although there existed a broad consensus for the opinion that the framework needed further refinements from experiences.

Specification of Maturity Levels

The specification of maturity levels was one of the greatest areas of improvement in the system. Several designers stated that they would prefer MMI-levels to be concise, and more in the form of a checklist. In fact, checklists were employed by the BIM-coordinators when assessing MMI350-submissions. Varying responses were made in regards to standardization of these levels. Some practitioners advocated for flexibility in definitions, stating that these levels should be specified by participants during the initialization of the project. This argument in particular raises the question of whether or not formalization of practice is necessary for establishing a common understanding of the framework.

Degree of Model Disaggregation

Although management of maturity in large sections weas generally favoured over object-level management of MMI by case practitioners, the developers of the system were split on the issue. Some favoured large sections in the short term in order to ease implementation efforts, with the intent of moving towards a more object-based framework in the future. The reasoning for doing so is to integrate the maturity of an object as a property in the BIM, with the intent of enabling the BIM to be more transparent and understandable for external stakeholders. One argument proposed against this is the opinion that this would be hard to do in practice, seeing as designers would likely batch several of their modeled elements and assign maturity to them all at once anyway.

One aspect that was largely agreed upon however, was the project specific autonomy in separating sections according to their needs, varying section sizes according to their complexity.

Communication of Model Maturity

As mentioned just above, the responses were mixed regarding the approach of managing maturity as properties of elements in the BIM. There was however positive sentiment expressed for the 3D-visualization as used in E6: Arnkvern-Moelv (see Figure 4.10), although the design team in Tiedemannsbyen did not seem to have any issues working without it.

Responsibility for Assigning Maturity

As previously mentioned, third party validation did prove necessary in these early stages of implementation, although most respondents argued that a perfect implementation of the framework would lack the need for it, possibly having automated validations of maturity worked into the BIM itself.

Chapter 5

Discussion

The following chapter uses established literature to discuss findings from interviews and document studies according to the research questions. The same sub-divisions as in Chapter 4 has been used in order to preserve consistency in presentation.

5.1 Current Approaches to Design Management

The following chapter discusses findings relevant to RQ1.

Current Approaches to Design Phases

Although described using different terminology, practitioners from both contractors referenced two main phases of design. These phases are separated by the acknowledgement of the model as a chosen concept for further development.

- **Concept-phase**: Concept development ending with a choice of concept.
- **Detailing**: The development of chosen concept into a production-ready model.

These phases line up rather well with other big Norwegian AEC-companies (see Figure 3.1). The concept-phase and detailing-phase in these companies are most likely referring to the phases explained by (example) Neste steg (Bygg 21) as ”3 - Pre-project development” and ”4 - Detailing”, a view which was shared by many other companies in the study conducted by Grytting (2017).

Current Approaches to Planning and Control

Both contractors use applied versions of Last Planner^{TM} in the cases. Although some might interpret the deviation from the original versions of these frameworks as inadequate attempts at implementation, it is important to consider that implementation of Lean Construction principles does not start with the tools in mind, but rather the philosophy for why one would want the tools in the first place (see Figure 3.3). Both companies have (to a certain extent) merged the weekly work plan with the lookahead plan for design, which makes sense considering the fact that design management only have to deal with one team of designers. Contrast this to construction, where a larger number of different teams have to work on different types of tasks at the same time, and the reasons for having these plans separated becomes clear.

ICE is also implemented in these projects, with standardized meeting forms gradually changing as newer and better methods are proposed. A clear focus on communication and process transparency is documented in both contractors.

The concept-phase showed the least amount of structure in terms of planning and control, with a reduced use of BIM and MMI as well as a having the distinction between the phases varying from project to project, sometimes lacking discreteness in separation of phases.

In regards to control, approaches deviated somewhat. Although PPC is a common method of control in projects in both Skanska and Veidekke, this approach was not being utilized in the design organization internal to Sweco in E6: Arnkvern-Moelv. In Sweco, the common approach (although they too were using Last Planner^{TM} on a regular basis) was for the designers to make monthly subjective assessments on their progress. This practice was used in E6: Arnkvern-Moelv, in combination with frequent updates of model state (Figure 4.10).

Although formulated somewhat differently, the root causes used to determine the reason for missing a deadline was largely the same in both contractors.

In Skanska, model maturity is integrated into into planning by using MMI-milestones as deliveries in Last Planner^{TM}, further integrating model progress into project development.

Current Approaches to coordination in BIM

Both companies report active use of BIM in their projects. In relation to the VDC maturity model, both contractors use 3D models and graphical representations to represent the product, organization and process, and can as such be said to have achieved the first stage of implementation. In addition, some examples of computer based integration of practices were discovered, by example the automated weekly charting of model clashes in Tiedemannsbyen. These practices can be viewed as signs of the second stage of implementation in the maturity model, seeing as the requirements for reaching this stage is for projects to ”develop computer-based automated methods of exchanging data among disparate modeling and analysis applications reliably”.

Although BIM was reportedly employed less during the concept-phase, comments made by all the practitioners still describe BIM as a central development tool during this phase, however lacking in strict planning and control the phase (or use of BIM) might be.

The generation of weekly charts of clashes in the model is a great example of utilizing BIM to integrate the product with process and organization, by making the continued development of model maturity transparent to the entire project organization.

Lastly, the case studies uncovered a sizable difference between use of BIM in building and infrastructure projects. The general sentiment was that although fairly established 3D-modeling efforts had been made in infrastructure projects, BIM-use in building projects had come further in its integration in terms of information associated with the model.

Current Approaches to Maturity

Regarding the general MMI-framework (see Figure 4.5), a parallel can be made to lean construction using the TFV theory. As opposed to the LOD framework only emphasizing change in geometry (transformations), additional dimensions such as process (flow) and information (value) are introduced to better understand model development. As promoted by the authors of the general framework, the implementation of MMI differed slightly from the original framework in both cases.

Specification of Maturity Levels

	General MMI-framework	E6: Arnkvern-Moelv	Tiedemannsbyen
MMI100	Sketch without requirements to geometry or information	Concept/sketch.	Coordinated IFC, correctly established model, axis and coordinates.
MMI200	Preliminary solution with approximate geometric properties and information	Solution accepted as chosen concept.	Proposed solution before detailing, main geometry modeled as BIM-objects.
MMI250	-	-	Proposed solution ready for cost calcuation, all objects neccesary for measurements modeled.
MMI300	Specific system in regards to geometry and information, disciplinary coordinated.	Part detailed.	Finalized model without any relevant collisions within relevant discipline, all relevant objects for the particular discipline has been modeled.
MMI350	Specific system in regards to geometry and information, inter-disciplinary coordinated.	Inter-disciplinary controlled.	Finalized model without any relevant collisions within or across disciplines, no remaining conflicts
MMI400	Specific system in regards to necessary geometry and information for production.	Ready for production.	All potential conflicts resolved, model ready for creating production drawings and plans.
MMI425	-	-	Verified as constructable by production crew.
MMI500	As built.	As built.	As built.

Figure 5.1: Comparison of MMI levels from cases

When comparing the MMI-levels from the cases (Figure 5.1), the increased specificity in the levels used in Tiedemannsbyen becomes apparent. However, it should be noted that in practice, the maturity levels used in E6: Arnkvern-Moelv were specified per discipline, hence the more open definitions cited in Figures 4.7 and 5.1.

The levels utilized in both cases distinguish themselves from traditional LOD-frameworks in that they are all formulated as functional requirements for objects rather than specified amounts of detail or geometric properties.

Degree of Model Disaggregation

Management in both cases opted to manage relatively large sections of the BIM (as illustrated in Figures 4.8 and 4.9). In Tiedemannsbyen, sections reflected building steps in construction. Sections were large, although management of maturity was accomplished as a result of the repeatability of design between floors. In E6: Arnkvern-Moelv, sections varied in size, having been chosen with equal distribution of complexity within each section in mind.

Communication of Model Maturity

Two different approaches to communicating model state to designers were chosen in the cases. In E6: Arnkvern-Moelv, an automated 3D-chart was made in Revit (see Figure 4.10), while in Tiedemannsbyen, charts tracking trends related to disciplinary and inter-disciplinary clashes were discussed on a weekly basis (see Figures 4.11 and 4.12).

Responsibility for Assigning Maturity

Both cases utilized third-party evaluations of maturity for the MMI350-level, and in Skanska additionally in MMI300 and MMI400. Otherwise, the designers reported the maturity of their own work. In the case of E6: Arnkvern-Moelv, discipline group leaders were responsible for assigning maturity for their respective teams due to the size of the design organization.

5.2 Experiences from Current Approaches

The following chapter discusses findings relevant to RQ2.

Experiences with Design Phases

Although there seemed to exist somewhat of a common understanding of design phases in the cases, phase definitions were reported to vary from project to project, in addition to being somewhat ambiguous, especially in regards to the distinction between phases. The variation in contracts used are likely to be an issue in regards to clearly defining project phases, seeing as contracts dictate varying degrees of stakeholder involvement in the different stages of design. As a result, the concept phase was especially demanding to define clearly, seeing as the contract dictated whether or not the design build contractor would own the project at this stage.

In general, the research committed in this study indicates a lack of a uniform model of explaining design development which could be applied in any project.

The inclusion of MMI was largely favoured by designers as a solution to this, providing a clear understanding of project process by integration of the product development in the BIM.

Experiences with Planning and Control

In general, using Last Planner™ and ICE in planning was greatly preferred when compared to traditional practices by project participants, citing increased transparency and communication in addition to showing increased performance and compliance to milestones as a result of this. The customized approaches in both companies based on standardization and continuous improvement were also well received, and certainly inspired by lean principles.

On the other hand, the use of the master schedule in E6: Arnkvern-Moelv was not as successful. This had reportedly been made without much input from designers, due to the large size and complexity of the design organization in addition to designers hesitating to make assessments and inputs to the plan due to their lack of familiarity with the new MMI-framework. This should not have occurred seeing as the authors of the framework intended it to be ”free” for management to implement, making as little changes to designer tasks as possible. After all, the MMI-framework was not intended to change the work the designers was responsible for carrying out, but rather assign a processual aspect to existing work. As a result of not having received inputs from-, and provided ownership to all stakeholders in the project (which are vital elements to planning with Last Planner™, see Chapter 3.3), planning predictability decreased as ad hoc approaches were adopted. However, the relative size and complexity of E6: Arnkvern-Moelv should not be understated, being an ambitious scene for implementation of the framework.

Although not commonly used in infrastructure projects, the participants from E6: Arnkvern-Moelv was quick to point out the positive benefits of using a turnkey method of delivery, increasing positive relations between disciplines. One could argue that the better alignment of stakeholder interest is the reason for this, not rewarding individual actors for individual tasks, but the project organization as a whole based on their collective output. Additionally, it should be pointed out that due to the decreased distance between stakeholders, implementation of new approaches such as MMI are easier for management to direct.

Results from cases also highlight the personality and culture among designers as an impactful aspect to implementation. A proactive approach from management to activate designers correctly in their projects still proved necessary in Tiedemannsbyen, and in E6: Arnkvern-Moelv, there was a general sentiment that more oversight from management was necessary.

BIM-coordinators from Skanska reported using buffers in their plans, which tended to work well in enabling designers to meet deadlines. A parallel can be made between buffers in plans and inventories in production lines (see Chapter 3.3), suggesting that these buffers are hiding the designers' inability to meet plan requirements, implying that improvements in planning are still to be made. One of the reasons for this could be the uncertainties regarding the finished product, as mentioned previously.

The ambiguity surrounding the concept-phase was also a point commonly made by interview participants. Comments indicated a lack of properly using MMI to its full extent, as well as only using BIM to a limited degree and expressing somewhat unclear and varied distinctions between the concept- and detailing-phase. The relative low number of involved designers and stakeholders was used as a reason for not managing this phase too thoroughly. This reasoning can be interpreted as a lean approach to the issue, by not complicating that which does not have to be too complicated. On the other hand, it might also be reminiscent of the ad hoc approach traditional design management has been struggling with in the past. In addition, it should be mentioned that this phase is distinguished from detailing by the very fact that it is less defined and open for experimentation. Knotten et al. (2014) highlights the importance for management to know when to administer strict guidelines and when to allow for greater flexibility. Still, according to the POP-model, the concept-phase should be describable in terms of product, organization and process, the last of which seems to be somewhat lacking in current approaches.

Experiences with coordination in BIM

The trend of including BIM to an increasing degree in both companies over the last years suggest success in its use. The interviews and documents also highlight how BIM serves as the backbone for much of the communication during work and meetings throughout detailing. The example of graphing collisions in order to increase the transparency of the actual work done during building design are testaments to its increased use as a more complete framework for integrating product with organization (and process using MMI). The study does however highlight several areas of improvement, although most of these are related to the designers abilities (or rather, lack there of). These results might serve as a reminder that design management is, despite technological innovations, still a discipline in managing people.

Experiences with Maturity

Initial responses to implementation of MMI were largely positive in both cases, citing a large number of positive benefits (Chapter 4.2). Many of the perceived benefits cited by interview participants correlate nicely with effects one would presume to gain by having a greater ability to relate design development to project phases (stated as the initial desirable function of planning systems in Chapter 3.2). Other observed effects can mostly be described as a greater ability to communicate across disciplines, which can be regarded as a side-effect of the increased ability to describe project work and development.

Both systems were fairly simplistic in their approach, participants citing increased experience as necessary for further development. This approach correlates nicely with the the lean principles of standardization and continuous improvement for implementation of new tools. According to the interviews, the designers did adopt the new frameworks instead of reverting to old practices, indicating success in implementation.

One factor for success discovered in the cases was the flexibility for management only to implement functionality beneficial specifically to the relevant project. In E6: Arnkvern-Moelv by example, tracking trends of clashes in the model as done in Tiedemannsbyen would likely be superfluous given the fact that infrastructure-projects are not as hampered by small geometrical tolerances and disciplinary intersections as building projects are. Conversely, given the significant lesser amount of individual sections in the BIM, 3D charts for visualization as in E6: Arnkvern-Moelv was not essential for the designers (although these might have been beneficial in communicating project development externally).

Lastly, one of the major factors hindering implementation was cultural inertia in adoption. Examples of this are plenty, for instance the trends in clashes in Tiedemannsbyen or the case of the production personnel failing to participate in early decisions.

Specification of Maturity Levels

Of the four aspects of maturity in design presented in this thesis, the specification of maturity levels was the one considered to have the greatest area of improvement. The lack of clarity in specifications reportedly resulted in designers having to make subjective assessments regarding what they were supposed to deliver, which is a huge detriment to establishing a common understanding of the framework. In general, there seems to be a need for increased clarity in requirements for deliveries.

On the other hand, the approach given in E6: Arnkvern-Moelv to clarify these requirements per discipline aids greatly in providing each designer with a specialized set of task him/her must complete, although this approach is certainly a lot more substantial, and requires greater investment into the framework.

The MMI-approach of tailoring specifications to functional requirements rather than specifically geometrical properties was positively received. This approach can be associated to the lean principles of pulling, making implementation focused on project needs rather than the technical possibilities of tools.

The decreased focus on earlier MMI stages in Tiedemannsbyen rather than E6: Arnkvern-Moelv can largely be attributed to the contract form and calculation methods. In infrastructure projects, calculations are made external to the BIM. As such, bids are won before any modeling starts, and the entire design organization are present from the start of concept development. In contrast, building projects perform cost calculation based on conceptual models in the BIM, making it hard to establish the entire design organization early on, seeing as there might still be a possibility that the bid will be lost.

Degree of Model Disaggregation

Experiences from using large sections were positive. In practice, it would be hard to represent overall project development in plans if maturity was managed on an object-level in the model. This aspect can also be understood in terms of pulling, as previous unsuccessful attempts at implementation of LOD often has employed an object-level approach, which can be interpreted as pushing needless functionality without considering which solutions would bring value to the project.

Communication of Model Maturity

None of the participants expressed a lack of understanding the current state of the model, a finding which illustrates the significance of visual aids for designers. Visual communication is an important aspect of Last Planner^{TM}, ICE, and VDC, and the chosen methods of communicating model state in both projects can be seen as great examples of this.

Responsibility for Assigning Maturity

As it is a vital point of Last Planner^{TM} to include all project participants and make them submit their own assignments in order to increase their ownership to the tasks they are responsible for completing, one could hypothesize that the ideal approach to declaring maturity would be the same. This was however disproved in practice, seeing as the lack of understanding among designers as to what they were supposed to deliver ended up with them mistakenly declaring maturity of models that were not ready. One could make the argument that this is only a result of the lacking specificity and common understanding of MMI levels in this early stage of implementation. Nevertheless, third party oversight from BIM-coordinators proved necessary in both cases.

5.3 Improvements of Current Approaches

The following chapter discusses findings relevant to RQ3.

Improvements of Design Phases

As discussed in Chapter 3, design phases should be used to efficiently and accurately describe design work and development at any point. The two existing phases does so to a certain degree, separating concept-work and detailing in order to distinguish the more volatile and uncertain initial project development from the more structured and complex design process which ensues when a concept has been approved. However, the system is not flawless, the shortcomings of which are fairly well documented earlier in this study.

The solution to these issues, as presented in the study, is the integration of model development into planning using MMI. When using the system, planners cited an increased understanding of project development, both as a result of the more granular definition of work as a result of a greater number of smaller phases, but also due to the clear distinctions between phases. These aspect fits nicely with VDC concepts, integrating the process of product development into existing organizations.

Improvements of Planning and Control

The use of Last Planner^{TM} and ICE are established to a high degree in both companies, and although having benefited greatly from this, areas of improvement are still evident in both cases. In E6: Arnkvern-Moelv, one can make the argument that management have seemingly only paid attention to the overall project plan, effectively using it as a project schedule from traditional approaches. The missed opportunity to integrate project participants into planning could imply a lack of knowledge of lean principles and proper integration of Last Planner^{TM}.

In regards to project control, PPC is highly desirable compared to subjective progress estimation, seeing as subjective assessments decrease formalization of practice and are inherently less reliable than quantitative measurements. In addition, the integration of root causes when measuring PPC serves as a foundation for troubleshooting and continuous improvement.

The buffers used in planning might indicate a failure to integrate designers into planning as well, seeing as the designers seemingly needed to fail initially in order to understand what they were supposed to deliver. This view can be illustrated further by the fact that lack of resources or underestimating the volume of work was the most frequently mentioned reason for late deliveries in design. Although buffers might be used introductory as a means of easing implementation, root causes for missing deadlines should be employed extensively to cut these short.

In addition, in the case of projects starting concept development prior to having won bids, management approaches in the concept-phase was significantly less structured than in detailing, resembling an ad hoc style and lacking the inclusion of designers other than architects and structural engineering. This could as previously mentioned be integral to the design development, seeing as the concept-phase necessitates greater freedom and flexibility during development. However, the concept phase of development should ideally still have a clear structure, seeing as it would provide increased efficiency in development even though bids potentially could be lost. During the initialization of projects, there still exist introductory work such as budgeting, analyzing major risks, establishing stakeholder requirements, and so on, all of which could be incorporated into a standardized methodology for this phase. By example, incorporating decision-making approaches for concept developments such as *Choosing by Advantages (CBA*, developed by the Lean Construction Institute as a standardized framework for incorporating subjective values into decision-making processes) as a milestone for achieving MMI200 (or MMI180 if so preferred) could yield significant returns for management in the future.

A positive observation in both contractors was the focus on standardization and continuous improvement of their practices, being meeting forms or planning tools. The adjustments made to the implementations of Last Planner™ are seemingly results of this, and are encouraged from a theoretical point of view.

The study does also point out the impact of a personal and cultural aspects on implementation success. When implementing new frameworks desired by management, one should consider the team composition in order to maximize proficiency and openness to new practices, making the implementation case a good example for less exited practitioners to follow.

Improvements of coordination in BIM

The use of BIM had reportedly been to an increasing degree in both companies, going from being a specific tool to a platform for the entire design process. Current implementations of BIM have proven quite complicated however, using a multiple of different programs and practices, leading to several issues stagnating progress. As a result, the proper implementation and use of BIM in projects is essentially its own discipline, as represented by the BIM-coordinator.

In general, the shortcomings of using BIM in construction projects as of today mostly come as a result of poor usability or failure of management to properly address common pitfalls in its use.

Ideally, use of BIM would be completely automated and fully understood by all its users, negating the need for BIM-coordination as its own discipline. This aspect can once again be tied to the VDC maturity model, stating ”automated methods to perform routine design tasks” as a part of the final stage of implementation.

Improvements of Maturity

The study has shown the potential for MMI as a tool for planning and communication throughout design, providing increased understanding of project development by integration of model state into planning.

Specification of Maturity Levels

One could argue for the success of functional requirements with the lean principles of pulling, stating that the minimal amount of work necessary should be pulled only when it will allow for future tasks to be made ready. By using functional requirements in specifying maturity deliveries, designers are not only encouraged to facilitate for downstream work, but are also granted increased freedom when doing so. Traditional LOD-approaches using geometric fidelity as a measure of fitness of the information fail at this, seeing as it encourages focus on the task itself, not its relevance to the overall project process.

The clarity in MMI-levels was found to be lacking, making the framework less consistent and understandable. In order to ease implementation, levels should be clear and easily understood by everyone. Although this aspect should be an area of focus for future implementations, some good examples of MMI-levels done right was uncovered in the cases. Examples being inter-disciplinary controlled MMI300 (no relevant clashes within own model) or MMI200 for a bridge (construction discipline in E6: Arnkvern-Moelv) being having the concept approved by local municipalities. These examples are great seeing as they have clear distinctions for whether or not a level has been reached, are easily understood and can be formulated in short terms.

Having personalized definitions per discipline makes the process of providing clear functional requirements easier, although a generalized understanding of levels between all actors are still necessary.

Lastly, the degree to which maturity levels should be specified is a point of contention. On one hand, one might argue that formalization is needed in order to achieve common understanding among project participants, but the project-specific autonomy in tailoring implementation approaches was hailed as a factor for success, and could be argued to be more in line with lean principles of pulling needs. In addition, the round-table discussions regarding the specification of maturity levels was cited to be an important learning experience for the designers in Tiedemannsbyen. The approach given in E6: Arnkvern-Moelv might give an indication of the proper direction to the approach of standardizing levels, having standardized, open specifications to increase general understanding, all the while using these levels as a foundation to formulate more specific requirements per discipline per project.

Degree of Model Disaggregation

The use of large sections was discovered to be an enabler of early implementation. Practitioners largely agreed that overall project development was easy to understand. The choice of section size must naturally be adjusted on a per-project level, although a simple suggestion to make from the results of this study would be to make sections as large as possible as long as all designers can keep track of the complexity within each section of the model individually. It should also be mentioned that section size should not be determined by physical dimensions, but rather the complexity of the information within each section.

Whether or not MMI should be managed at a more granular level in the future is a different question all together. In general, opinions uncovered in this study seems to depend on whether or not one is concerned with describing the overall development of the model or the current state of the model at any point. Arguments made in favour of the management of object-level specificity was often made in relation to the latter, stating that this would be far easier with a BIM capable of rejecting or approving maturity submissions automatically, storing maturity as properties of elements in the IFC and visualizing maturity on a per-object level with colors or similar. This way, any production personnel could open the BIM on their own and get a direct read of the current state of any object they would construct that day.

As previously mentioned, the ability to express model development using this system would likely be impaired if doing so. When using larger sections, management can more easily illustrate dependencies between sections and disciplines within each section, thus having an easier time to manage the process. Keeping track of maturity on a per-object level would require management to have a detailed knowledge of elements within each section. One might also argue that the overall interactions and dependencies between disciplines are better expressed in this format.

In addition, the practical usability of object-level tagging in future BIM software is unknown at best and would be hard to integrate with external or qualitative requirements to achieving a maturity level. As an example, a BIM that could automatically verify whether or not a model conforms to stakeholder preferences or municipal guidelines are far from being deployed in the industry as of the current time of writing. However, there are important arguments to be made here for new possibilities in the communication of model maturity, as discussed below.

Communication of Model Maturity

In terms of early adoption, one could make the argument that no significant measures of communicating model state is needed if the design organization is relatively small. If the organization is larger in size however, the increased complexity would likely require at least efforts as shown in E6: Arnkvern-Moelv. These relatively simple undertakings are hugely beneficial in the example above with production personnel checking out drawings from the model, although lacking somewhat in nuance when compared to the concept of communicating the model maturity directly from the model itself. It should be mentioned that storing model maturity as a property in the IFC could be done even while managing maturity with larger sections, although the ensuing complications in doing so is unknown to the researcher at the time of writing.

In new implementations of maturity in projects with comparable proficiency in utilizing BIM as the contractors in these cases, the easiest recommendation to make is the use of 3D-charts for communicating model state to designers and external stakeholders, although generation of charts of clash-trends as in Tiedemannsbyen could be beneficial for designers as long as they are working with a comparably lower amount of sections at a time.

Responsibility for Assigning Maturity

The aspect of responsibility for assigning maturity is closely correlated to the success of the specification of maturity levels, seeing as better defined levels would lead to greater accuracy in submissions, requiring less external control. In addition, future BIM functionality might include automated maturity verification when submitting work to a certain maturity, which would be examples fully matured implementation of BIM in relation to the VDC maturity model. These functionalities are however not met in the short term, and would require all maturity levels to expressed quantitatively for the BIM to perform validations. The latter aforementioned aspect might provide problems when validating levels prior to 300 for example. It should also be mentioned that some deliveries might require specific knowledge to different disciplines to validate, making it hard for a BIM-coordinator to suggest improvements for design aspects not directly related to modelling. As such, the importance of correctly defining maturity level specifications during project initialization are further emphasized. One solution to reduce faults in deliveries other than using a BIM coordinator for levels 300-350 could be to utilize other technical professionals during 100-250, or production personnel during 400.

Chapter 6

Conclusion

The following chapter answers the chosen research questions, as well as suggesting future work on the topic.

The findings in this study are based on two pilot projects in their respective industry. In terms of generalizability, BIM-practitioners from Skanska (who were not affiliated with Tiedemannsbyen) reports using the MMI-framework to a certain extent in all their current residential projects, with implementations similar to the one used in Tiedemannsbyen. In Veidekke, no projects other than E6: Arnkvern-Moelv was found to be using MMI at the time of writing. As such, the approach documented in this study might not be as relevant to future projects conducted by the contractor. In terms of contrasting new findings to traditional practices, most of the interviewees had several years of prior experience from such projects in multiple companies, suggesting that the study has good reliability and validity in generalizing these findings to a broader scope.

6.1 Current Approaches to Design Management

The following chapter will answer the research question

RQ1: What are the current approaches to maturity-based construction design management?

In traditional means, design development was expressed using two phases, that being the concept-phase and detailing. In the pilot projects, MMI-stages has to a certain degree been incorporated into these phases, using levels up to MMI200/250 to describe concept development and later levels to describe detailing development.

Both contractors utilize modified versions of Last Planner^{TM} to a high degree, merging the weekly work plan with the lookahead plan, and using ICE-sessions with PPC and evaluation of root causes to control project development. Examples of standardization and continuous improvement of these practices are evident in both companies. In some cases, PPC was not used in favor of subjective assessments of completion rate. MMI levels are incorporated into planning as deliveries per discipline. In general, management approaches are more strict and structured in detailing than during concept development.

BIM is increasingly being implemented in current projects, seeing increased adoption and functionality allowing for greater transparency in product development during design. However, findings suggest that integrated use of BIM has been developed to a further extent in building projects than they have been in infrastructure projects.

MMI implementations largely use the generalized framework proposed by Fløisbonn and Skeie, with some exceptions. In E6: Arnkvern-Moelv, general MMI-levels have been simplified in order to make discipline-specific requirements, and management in Tiedemannsbyen added two additional levels, MMI250 and MMI425. Otherwise, both implementations utilize the same LOD-levels with functional requirements instead of geometrical properties, third party control in detailing, and the management of MMI per discipline for large sections rather than individual objects. Strategies to communicate model state and development differ in both companies, although both were found to employ highly visual approaches. In Tiedemannsbyen, weekly trends for the total number of clashes per discipline in the model were discussed among the designers in its relation to MMI-levels, while management in E6: Arnkvern-Moelv utilized a 3D-chart for keeping track of maturity for each discipline per section for the entire project.

6.2 Experiences from Current Approaches

The following chapter will answer the research question

RQ2: What are the experiences from current approaches to maturity-based construction design management?

The traditional phases, although having a general understanding among industry professionals of what they meant, was reported to be vague and offered limited ability to clearly describe design development. These phases were found to lack clear descriptions of the work conducted within them and clear separations between phases. In addition, these phases were reportedly subject to change depending on type of project or contract. According to practitioners, the inclusion of MMI in projects helped in all these aspects, allowing product development to be better integrated into the design process.

The use of Last Planner^{TM} and ICE was reported to be beneficial to all practitioners, although some findings might indicate that these new tools might be managed with a lack of understanding of how to properly apply them, thereby managing new tools with traditional mindsets. Results also highlight positive sentiments towards the design build contract form in comparison to general contracts, having better alignment of designer interests and inter-disciplinary communication. The importance of interpersonal aspects was made further evident in findings suggesting that good teams were a factor for success in adoption, and the fact that the greatest obstacle to implementation was cultural inertia among designers. Findings also highlight the fact that management frequently employed week-long buffers in planning, and the fact that the concept-phase was notoriously harder for management to conduct with an orderly and sound approach.

Experiences from using BIM was generally positive when compared to traditional drawing-based approaches, serving as a means to realize product integration into project development. BIM-based coordination are however not finalized in current practices, reporting several occasions of needless waste during design as a result of the combination of inadequate knowledge from designers and the lack of fool-proof procedures in the software.

The use of MMI has reportedly increased communication and understanding of project development by attributing a process to the product development in the BIM. Factors for success in implementation was attributed to a simplistic approach and project-specific flexibility in implementation. Functional and discipline-specific specifications for maturity levels was received positively, and correlates with expectations from lean theory regarding the concept of pulling. However, the specification of levels lacked clarity, decreasing the common understanding of what deliveries included, thus making the desired formalization of practice harder to achieve. Experiences from managing MMI per discipline for large sections was received positively, citing an increased ability to express overall project development in the BIM. Visual approaches to communicating model state was reportedly beneficial in both projects. Lastly, as a result of incomplete understanding of MMI-levels among designers, third party oversight in the form of BIM-coordinators were proven necessary when assigning maturity to certain parts of the model.

6.3 Improvements of Current Approaches

The following chapter will answer the research question

RQ3: How should maturity-based construction design management be approached?

The current approach to design phases were found to have several limitations. The study emphasizes the positive aspects of understanding design development in conjunction with product development by using MMI.

In terms of tools for planning and control, methods like Last Planner^{TM} and ICE (with PPC) are reportedly great at increasing value generation in projects by eliminating needless work, but only if managed with sufficient understanding of the proper implementation of these tools. In accordance with lean theory, approaches to planning and control should be standardized in companies, allowing for continuous improvements of practices. Using buffers could be compared to having large inventories, not addressing root causes for late deliveries. However, when implementing new tools, one could argue that using buffers provide a valuable learning experiences for new designers, as long as a foundation for measuring project progress and root causes are utilized to minimize these buffers over time. Management are encouraged to seek more standardized approaches during concept development, such as the inclusion of tools for project initialization such as CBA. In addition, the study highlights the importance of personal and cultural aspects in project organizations, suggesting that management should strive to have a team composition of hard-working, open-minded individuals when implementing new tools in order to increase the potential for successful adoption.

In terms of BIM, most of the shortcomings documented in the study was related to usability, not necessarily functionality. As a result, management are encouraged to preemptively address issues that may arise from poor procedures for work or poor interfaces between disciplines.

The studies highlight significant positive results from utilizing maturity in design as a means to describe project progress with integration of product development. Based on lean theory and findings from case implementations, the study presents the following recommendations for management when implementing model maturity in construction design:

- **Specification of Maturity Levels**
  Levels should be stated as functional requirements, ideally per-discipline. Requirements for achieving a certain maturity should be clear and easily understood by all project participants, ideally formulated as quantitatively as possible (like checklists or binary completion statements). Using adapted approaches from the existing MMI framework is advisable, as it has to a certain degree been adopted in some companies and thus has greater potential for formalization across designers in the industry, although experimentation according to specific project needs with standardization and continuous improvement is necessary.

- **Degree of Model Disaggregation**
  Models should be segregated based on equally distributing the potential complexity between sections. Put simply for new implementations, these sections should be kept large, while still small enough for designers to comprehend the amount of information within each section.

- **Communication of Model Maturity**
  The chosen approach should be visual, striking the balance of accompanying project needs according to scale and the degree to which designers are to work in different sections simultaneously, in addition to the investment into making the communication tools. For example, the weekly clash trends as used in Tiedemannsbyen and 3D-MMI-charts as used in E6: Arnkvern-Moelv provided good results in their respective projects, but due to differences in project characteristics and scope, implementation would likely have been poor if practices were to be swapped between the cases.

- **Responsibility for Assigning Maturity**
  Third party validation has been shown to be advisable in the cases, although having the designers submitting designs for valuation is advisable to keep ownership to tasks. Recommended third party validators of maturity submissions are as follows:

  1. MMI100-MMI250: Designers, design lead, project owners.
  2. MMI300-MMI350: BIM-coordinators.
  3. MMI400-MMI500: Production staff.

  Management should however be notified that the designers' reliability in declaring maturity correctly is highly dependant of having correctly specified requirements for maturity levels. As such, management are encouraged to continuously observe the development of these specifications alongside the potentially decreasing number of rejected maturity deliveries, with the intent of eliminating third-party validations when no longer necessary.

Lastly, the importance of simplicity in implementation efforts should be mentioned, which can be referred to the statements from the authors of the MMI-framework regarding MMI as ”free” for management to implement in projects. After all, the designers should not be made to carry out new types of work, but rather be better able to assign a processual context to the work they have always been doing. In conclusion, one could make the argument that previous implementations of LOD have failed due to their focus on implementing complicated new standards for work, *pushing* needless functionality on projects, rather than *pulling* project needs for a systematic understanding of design development.

6.4 Future Work

The study was limited to the two largest design build contractors in the Norwegian AEC-industry at the time of writing, with the hypothesis that these would present approaches closest to industry best-practice. As such, the current approaches to maturity-based management in smaller design build contractors (as well as whether or not maturity-based approaches to design are beneficial for smaller projects) is an area of interest for further research. In addition, the study was limited to contracts employing a turnkey method of delivery, and the study uncovered the choice of contracts and bidding processes to have a large influence over project development. The impact of said aspects on the implementation of model maturity would in other words be interesting areas for future work.

Chosen contracts and bidding processes were also found to have close interaction with project development during the ”concept-phase”, which was found to be underdeveloped in terms of managerial structure. Standardization efforts of work conducted during this phase is an interesting field for future research, particularly the integration of decision-making processes such as CBA into the MMI framework.

Additionally, the findings from the study highlight two areas of improvement in the current implementations of MMI in large design build contractors. The most obvious area of interest were the specifications of maturity levels. Although the study concludes with clear recommendations regarding the approach to this aspect, there is still a lot of work to be done in clarifying these levels. Such a study would be fairly in-depth and would require an extensive documentation of dependencies between disciplines in different projects. As a result, one might make the argument that this task should be left to management on a per-project basis rather than suggesting it for academic analysis.

The last area of improvement uncovered in the study was that of the possibilities of automation in the BIM, by example in relation to automated verification of the maturity of deliveries or by the management of maturity as properties for individual objects in the BIM, automatically displaying current model state at any time. The automation of BIM in design should be a topic of high interest for companies operating in the AEC-industry, and present huge opportunities for the future of the platform.

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Part 2: Scientific Article

The following is the scientific article written as a part of the study, which was published in the proceedings of the 26th annual conference for the International Group for Lean Construction (IGLC) during the summer of 2018.

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ENABLING LEAN DESIGN WITH MANAGEMENT OF MODEL MATURITY

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ABSTRACT

Traditional construction management has struggled with an ad hoc approach to design, increasing the number of negative iterations and sacrificing potential value. Building Information Modelling (BIM) has been driving information management in design, but its use has yet to be described in a way which makes it compatible with planning tools such as Last Planner™. Level of Development (LOD) could allow for this by attributing maturity to the BIM-model, yet previous studies of LOD implementation have shown potential for improvement. This paper researches current approaches, experiences and requirements for using maturity-based management in design.

A study of two large projects with maturity-based management using interviews and an analysis of measurements was conducted in addition to a literature scoping study.

The paper formulates five aspects of BIM-based workflows which needs to be addressed in order to manage their development. In addition, the study reveals how use of maturity-based management can provide a foundation for managing BIM-based workflows according to lean principles.

Finally, the paper concludes with practical recommendations for enabling lean design with management of model maturity, such as how to specify maturity levels or how to disaggregate the model into disciplinary sections.

KEYWORDS

Lean design, BIM, LOD, Set-Based Design (SBD), Last Planner

INTRODUCTION

Whereas production has a clear set of sequentially dependant, pre-defined tasks, design is better described as a set of interdependent, reciprocal iterations (Knotten et al. 2014). Because of this, the design workflow is much harder to manage, often resulting in an ad hoc approach (Carlos T. Formoso and Liedtke 1998; Knotten et al. 2017).

With the evolution of information technologies over the last decades, several new tools have become available to designers, most notably Building Information Modelling (BIM). Although they have provided an effective way for integrating product information into the

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design process, especially when used together with Integrated Concurrent Engineering (ICE), these new tools are still being managed with a traditional mindset (Leite et al. 2011).

By planning and executing work according to lean principles, the Last Planner™ system has yielded significant returns when applied in the production phase of AEC-projects. As such, similar improvements in the design phase could be attained by applying Last Planner™ to BIM-based workflows. However, BIM-based development lacks an orderly process, effectively making it incompatible with such planning tools.

The concept of Level of Development (LOD) was introduced as a means to formalize the development of a BIM-model (BIMForum 2017), and could be used as a way of attributing a work process to the BIM, making it compatible with Last Planner™. LOD has been approached in several ways (Abou-Ibrahim and Hamzeh 2016; Leite et al. 2011; McPhee 2013), yet lack of consistent understanding and utilization of LOD are common in projects (Hooper 2015), and no documentation regarding LOD as an enabler for Last Planner™ in BIM-based workflows could be found by the authors during the process of writing this paper. The research questions for the study were as follows:

1) What are current approaches to maturity-based management?
2) What are the experiences from maturity-based management?
3) What are the requirements for successful maturity-based management?

Five key aspects of BIM-based workflows were formulated from lean theory. These aspects were later examined in two large pilot projects using maturity-based management in order to present practical requirements for implementation and use.

METHOD

A literature scoping study was conducted to map existing literature on the topic. More than 130 of the most relevant scientific works were assessed from sources such as IGLC, Scopus and Compendex. In addition, general interviews were conducted with four professionals proficient in BIM and LOD in order to achieve a greater understanding of the field.

Two pilot projects using maturity-based management conducted by two of the largest Norwegian design build contractors (Skanska Norway and Veidekke Entreprenør AS) were studied using interviews with case practitioners ranging from managers to designers, in addition to a document study. All interviewees had prior experiences using Last Planner™ and ICE. All interviews were recorded and transcribed. Said transcripts were later verified by interview participants as representative of their views. Cases include Tiedemannsbyen, an apartment complex of five, six-storey buildings (Skanska, approx. $54M, ~14 designers), and E6: Arnkvern-Moelv, a 24km long Class A road project, part of the international E-road network (Veidekke, approx. $260M, 30+ designers).

BACKGROUND

LEAN IMPLEMENTATION OF TOOLS

Lean systems utilize standardization and continuous improvement in order to improve their practices (Moore 2007). By doing so, systems are enabled to dynamically adjust towards their lowest point of entropy, avoiding needless creation of waste in implementation efforts.

LAST PLANNER™ AND BIM IN DESIGN

There exist several definitions of BIM, depending on whether one is addressing it as a model, a tool or a platform (Fosse et al. 2017). For the purposes of this paper, BIM is best described as a computerized foundation for an integrated collaborative design process (Jacob and Varghese 2012). This computer model consists of a sum of geometrical objects, each associated with certain disciplines. Development of the model is expressed through a series of iterations of said objects and their relationship relative to each other (Knotten et al. 2014), which eventually results in a digital representation of the final building.

The Last Planner™ system enables lean management by applying pull-based planning of tasks, thus reducing waste (Ballard 2000a). Some studies have proven the potential for applying Last Planner™ in building design (Fosse and Ballard 2016; Hamzeh et al. 2009), although only in limited applications. The challenge in doing so has been attributed to the differences in workflow between design and production (Grytting et al. 2017). To implement Last Planner™, one must thus be able to describe the iterative nature of design, assign responsibilities and relate these processes to a clear project development structure.

One of the primary differentiators of design and production is the fact that iterations in design can be both positive and negative (Ballard 2000b). As such, managing building design according to lean principles becomes a matter of reducing negative iterations while keeping the positive ones. The Toyota design approach (Set-Based Design) starts with mapping available design space and functional requirements for an object, then using input from different disciplines to narrow down the number of available concepts, converging towards a final design (Sobek et al. 1999). By determining the boundaries within which work will be conducted, workflow iterations are more likely to be positive, and thus value-creating for the project. Another benefit of this approach is the ability to systematically share incomplete information, a feature vital to the design process (Busby 2001).

LOD

Level of Development (LOD) is a measure of the reliability of the information associated with a specific object within the BIM, expressed as a series of levels (BIMForum 2017).

The application of LOD in construction design becomes apparent when viewing it in relation to Set-Based Design. The different levels of LOD expresses the gradual development of the BIM, specifiyng points of interest related to the increasing reliability of designs. This effectively describes the development of the model as a set of milestones relating to its attributes, which is a neccesity for using Last Planner™, seeing as the progressively developing work packages in design are hard to associate to its binary attitude towards task completion. In doing so, planners are enabled to pull certain generations of designs only when needed, thus reducing the risk of rework.

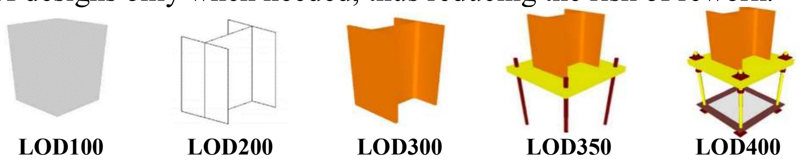

Figure 1: Visual illustration of LOD-levels for a column (BIMForum 2017)

Table 1: Example of generic LOD-levels (BIMForum 2017)

Levels	Description
LOD100	Graphical representation in the model as a symbol or a generic object.
LOD200	Graphical representation in the model as a generic object with approximate quantities, size, shape, location and orientation.
LOD300	Graphical representation in the model as a specific object with quantities, size, shape, location and orientation.
LOD350	Graphical representation in the model as a specific object with quantities, size, shape, location, orientation and interfaces with other building systems.
LOD400	Graphical representation in the model as a specific object with quantities, size, shape, location and orientation with detailing, fabrication, assembly, and installation information.
LOD500	A field verified representation in regards to information and geometry.

Although possible to do on a per-object-level, it is often more practical to manage LOD-levels on a section basis when dealing with larger projects, combining multiple objects within the same room, floor, or similar to define larger sections of the BIM. The relative size of these sections ultimately determines the degree of specificity LOD will be managed in the project. In keeping with theory, the specificity should be managed in a way such that designers and other stakeholders are enabled to understand design development as two distinct processes. Firstly, the process of developing a specific section from idea towards production ready design, and secondly, the process of interactions and inter-dependencies between sections as they develop, influencing the design space and functional requirements of each other as they do so. In addition, effective concurrent communication can only be established once the model state is accurately communicated to designers. Surmising these aspects, theory dictates maturity-based design-approaches as presented in Table 2.

Table 2: Theoretical approaches to aspects of BIM-based workflows

Aspect	Approaches from theory
Specification of maturity levels	Requirements for an object achieving a certain maturity should be related to make-ready of future tasks. Being unrelated to the volume of detail, levels should specify the necessary information for model progression towards value creation.
Degree of model disaggregation	The disaggregation of the BIM into sections should be done in such a way that the amount of information within one section remains comprehensible for all designers, and so that all project participants are enabled to understand the overall development of sections.
Communication of model maturity	The method of communicating the maturity levels of the different parts of the model should enable designers to know the fitness of the information they are working with, without being needlessly complicated to manage.
Planning and control of workflow	Planning tools for visualizing and optimizing flow of work during design, such as Last Planner, should be used. LOD deliveries should be incorporated into plans.
Responsibility for assigning maturity	In keeping with principles from Last Planner, having the designers declare the maturity of their own work increases their ownership to tasks and responsibilities.

CURRENT APPROACHES

TIEDEMANNSBYEN

Implementation of model maturity was done according to Skanska Norway's guidelines for using MMI (Model Maturity Index, which in practice uses the same maturity levels as LOD with simplified descriptions and the inclusion of a "MMI250"-level"). The model was separated into ten sections, one for every basement and building in the complex (Figure 2). Maturity was assigned to all geometry managed by each discipline within each section. The design team was coordinated in ICE-sessions utilizing Last Planner™ for planning and control. Milestones for different sections achieving MMI was represented by post-it notes

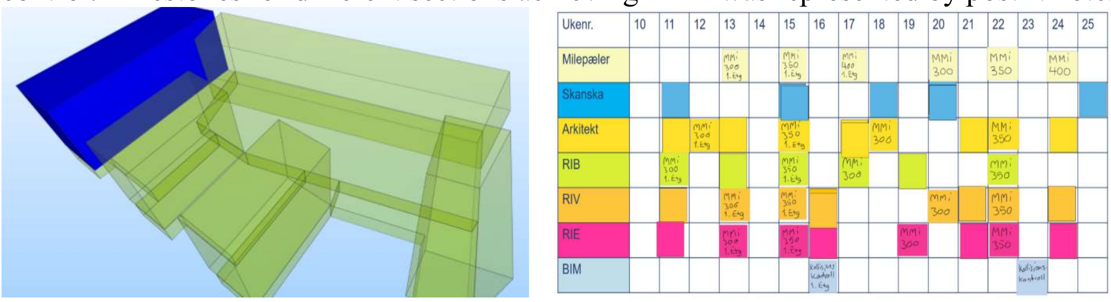

Figure 2: Model sections (left) and MMI-milestones in Last Planner (right)

in Last Planner (Figure 2). Management opted not to develop a specific tool for communicating the development of model maturity, relying on designers being up to date regarding model maturity from the weekly ICE-sessions. Maturity deliveries for the 300-, and 350-level were controlled by BIM-coordinators. Maturity levels were tied to specific tasks that designers were required to accomplish. In addition, weekly charting of the number of collisions detected in the model was used as an indicator of progress, both externally and for the design team.

E6: ARNKVERN-MOELV

Arnkvern-Moelv was conducted with a similar approach to Tiedemannsbyen, using similar maturity levels for large sections (Figure 3) in addition to ICE-meetings and Last Planner™. Differences include use of a 3D-chart for visualizing development of model maturity (Figure 3) and the absence of collision-control metrics to indicate progress. The exclusion of these metrics was not made because it was impossible to do, but rather the fact that it would not benefit the design process. This is a result of the project being a road, which

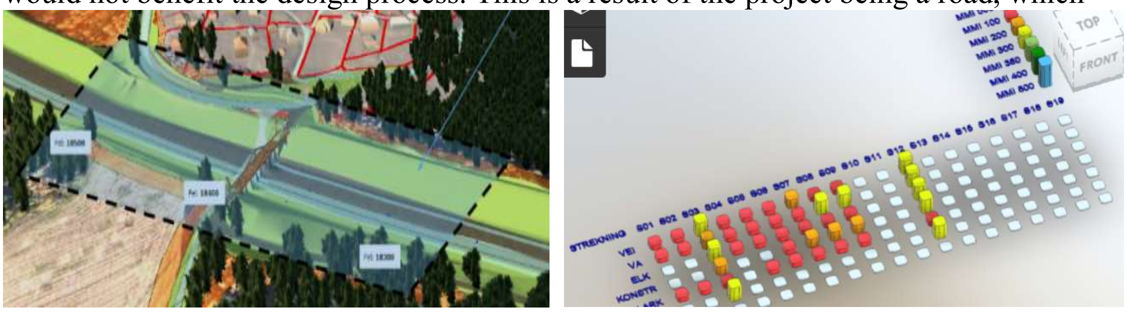

Figure 3: Example of section (left) and Visualization of MMI-levels, sections on x-axis, disciplines on y-axis (right)

generally is less constricted by small geometrical tolerances and intersections than building projects. MMI-levels were based on functional requirements for design deliveries, and often tied to specific tasks. Level requirements were adjusted per discipline in order to more accurately reflect individual functional requirements of different deliveries.

EXPERIENCES FROM CURRENT APPROACHES

RESULTS COMPARED TO TRADITIONAL APPROACHES

Practitioners from both cases cited the following differences in design work compared to traditional practice:

- **Increased understanding of the current state of the BIM model:** Designers reported having an easier time understanding the extent to which they could rely on the information they were working with.
- **Increased understanding of needs and responsibilities:** Designers reported having a better understanding of what they were supposed to deliver, as well as providing clear guidance to other designers regarding what information they needed.
- **Increased sharing of incomplete information:** As opposed to traditional means of withholding incomplete designs from other disciplines, designers were now enabled to systematically share qualified incomplete information.
- **Increased ability for project participants to express project development:** In contrast to traditional practice (having designers make subjective approximations of design development to external stakeholders), project progress was now quantifiable and easily understood by everyone.

The tracking of the number of model clashes for Tiedemannsbyen illustrates cultural inertia in adoption of new technologies. Performance was initially sub-par, the team missing all relevant deadlines for the first of the five buildings (Figure 4).

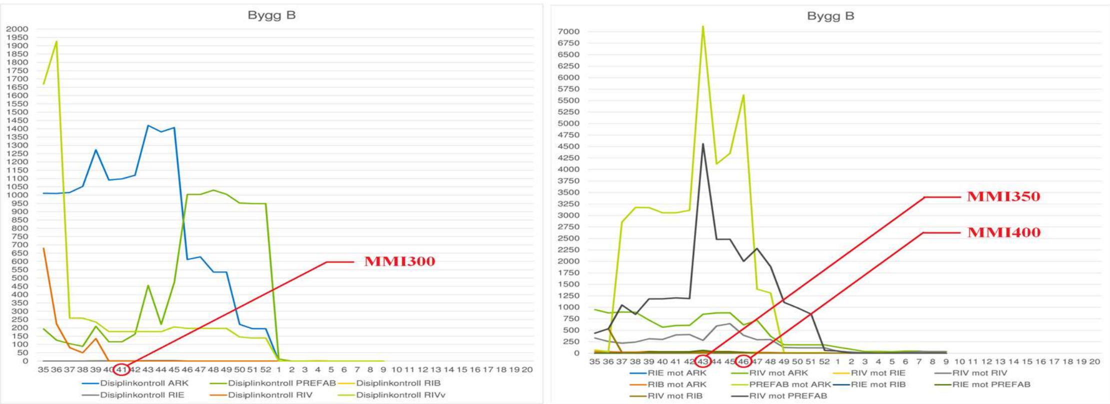

Figure 4: Weekly charting of the number of clashes within "Building B", disciplinary (left) and interdisciplinary (right), Tiedemannsbyen.

Although the team was unable to meet its deadlines for the first section, efficiency and reliability in meeting deadlines grew as the designers were increasingly exposed to the framework. Four months later, during the design of the third building, the model matured sufficiently to enable the same team to meet their deadlines (Figure 5).

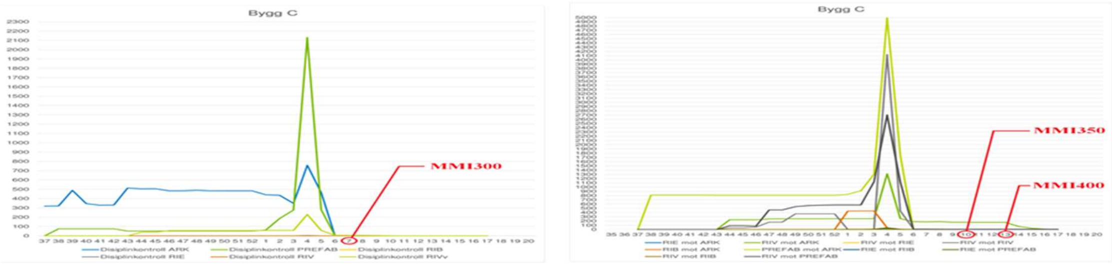

Figure 5: Weekly charting of the number of clashes within “Building C”, disciplinary (left) and interdisciplinary (right), Tiedemannsbyen.

Although in some cases showing a slight tendency to inversely correlate to the number of tasks, Percent Plan Complete (PPC) remained around 80% for the entire project, while the number of tasks completed per week increased by 69% from the average number of tasks completed in weeks 36-1 to the averages recorded in weeks 2-10 (Figure 6).

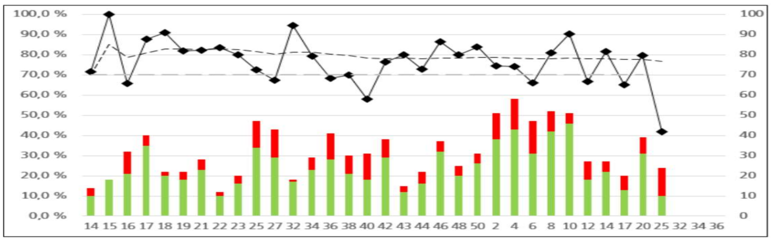
Figure 6: Tracking of PPC (linegraph) and number of tasks (bars), Tiedemannsbyen

It should be noted that Figures 4 and 5 reflect the total number of clashes in the BIM, including several cases of objects clashing with no relevance to constructability. However, this automated weekly chart generation requires little effort and is used to track trends rather than absolute number of clashes. More thorough clash reviews were performed specifically at MMI300 and 350 both by each discipline and by the project’s design manager. Although some improvements are to be expected by designers throughout a design project, the trends in the graphs reveal a significant shift in practice, especially when considered relative to the increase in the total number of tasks completed per week.

REFLECTION ON IMPLEMENTATION APPROACHES

The following positive observations regarding implementation were made:

- **Voluntary adoption by designers:** As a sign of successful implementation, designers resolved to use the system rather than reverting to traditional practices.
- **Management of maturity for large sections rather than individual objects was regarded as a factor for success:** While remaining small enough for designers to comprehend the amount of information within each section, the larger sections made it easier for all project participants to understand the overarching flow of the project. Management of maturity on a per-object level would render this unfeasible.
- **Simple visual aids greatly benefited designers:** Graphing collisions per week as in Tiedemannsbyen or charting maturity in 3D as in E6: Arnkvern-Moelv exemplified relatively minor undertakings which greatly improved communication of model state, increasing the transparency of project flow for all participants.

- **Case-specific adjustments were regarded as a factor for success:** While keeping a certain level of standardization of the system, flexibility in including or excluding functionality based on unique project circumstances made implementation easier.

On the other hand, the following areas of improvement were discovered:

- **Lack of clarity in MMI-level specifications:** Designers cited somewhat ambiguous specifications for MMI-levels, which at times required subjective interpretations from the designers as to what they were supposed to deliver.
- **Lack of software guidelines:** Several minor issues hindering communication due to lack of clear guidelines for software use were reported. Designers were in some cases working with different datums and units, in addition to being unable to load different files due to server-side errors or faults related to naming conventions.
- **Third party evaluation of model maturity required:** Designer did on some occasions deliver models which was not mature enough to warrant a new MMI-level. The inclusion of a BIM-coordinator evaluating deliveries proved necessary.
- **Cultural inertia:** As with any efforts to implement new methods, one of the greatest obstacles to success was the inability or reluctance of some designers to change their existing practices.

REQUIREMENTS FOR SUCCESSFUL MANAGEMENT

Positive results in implementation in both cases can largely be attributed to an approach of establishing a simple foundation for standardization and continuous improvement. The solutions to the first three aspects in each case illustrates this, where efforts have been made only to implement what is necessary for adjusting designers to a new way of working. After all, the tasks designers were responsible for carrying out were the same as before, the only difference being the process-related context now associated to the tasks. The importance of this approach is made further evident in the observation that cultural inertia was deemed to be one of the biggest obstacles for successful implementation. The results also highlight the fact that the software is in no way finalized or fool-proof, requiring management to pre-emptively address common pitfalls. This observation may serve as a reminder that design management is still an exercise in managing people, despite technological innovations.

The maturity-level specifications were discovered to have the most potential for improvement, being relatively simple in its current state. Although room for improvement was discovered, theory cannot go further than to suggest that these levels should reflect the functional requirements necessary for pull actuation of future tasks, recognizing that more detailed specifications of levels would differ with discipline and type of project.

The management approach of separating models into larger sections and managing these sections by discipline, rather than trying to manage individual objects, was determined to be a factor underpinning success in both cases, serving as a better way of explaining the overall model development from concept to final design.

Although both projects illustrated a necessity for standardization of practice, having some flexibility in management approaches was also deemed necessary. The solution to this issue given in the cases was to standardize functionality, yet provide the ability for management to choose which functionality to implement on a case by case basis.

CONCLUSION

Findings illustrate that there is a theoretical case to be made for maturity-based management as an enabler for using Last Planner™ in BIM workflows, and that experiences from case studies seem to support this notion. In practical terms, projects utilizing maturity-based management indicates a greater ability to communicate model state and progress as well as designer needs and responsibilities, resulting in the design process being more transparent and manageable. Successes in adoption can be attributed to a practice of utilizing standardization and continuous improvement while still allowing for a certain degree of flexibility in project implementations.

Based on theory and experiences from case studies, recommendations for using maturity-based management of BIM workflows are as listed in Table 3.

Table 3: Management recommendations based on theory and case experiences

Aspect	Recommendations
Specification of maturity levels	Maturity-levels are based on the future functional needs, formulated as specific tasks. Tasks are specified for each level, per respective discipline.
Degree of model disaggregation	Segregation of model into sections as large as possible without making the amount of information for each discipline within each section incomprehensible for designers (Examples: Figures 2&3).
Communication of model maturity	Visualization of maturity per discipline, per section in a chart, possibly excel (Examples: Figure 3).
Planning and control of workflow	Last Planner™ and ICE. Milestones for maturity-levels are attributed to post-it notes used as deliveries in collaborative planning.
Responsibility for assigning maturity	Designers should feel ownership to the maturity of their tasks, although an independent evaluation of maturity may prove necessary until level-requirements has been sufficiently standardized to avoid misunderstandings.

It should be noted that a vital point of success for implementation in both cases has been the simplicity in their approach, as well as successful, project-specific choices made by management. Having historically been approached as an object-level attribute, one could make the case that failed LOD implementations in the past have been a result of pushing needless functionality instead of pulling technologies from project needs. After all, the positive yields documented in this study does not come from a radical change in practice, but rather a simple approach of associating existing work and tools to project development.

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Part 3: Appendix

The following appendix is comprised of 11 attachments:

- Attachment 1: 1st Literature Search - Compendex/IGLC
- Attachment 2: Narrowing 1st Literature Pool
- Attachment 3: 1st Pool Charted
- Attachment 4: 1st Finished Pool
- Attachment 5: 2nd Literature Search - Compendex/IGLC
- Attachment 6: Acquired Relevant Literature
- Attachment 7: Citation-Chaining Data
- Attachment 8: Snowballing Data
- Attachment 9: All Sources Acquired During Rework
- Attachment 10: 2nd Pool Charted
- Attachment 11: 2nd Final Pool
- Attachment 12: Evaluation of Sources according to TONE-criteria
- Attachment 13: Interview guide

Attachment 1: 1st literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
Compendex		"construction management"	English, Journal article, Book chapter, Book,	386	-	Relevance					Large amount of hits, reducing size
Compendex		"construction management phases"	English, Journal article, Book chapter, Book,	0	0	Relevance					No hits
Compendex		"construction management" AND phases	English, Journal article, Book chapter, Book,	2	0	Relevance					Two identical hits
Compendex		"construction management" AND phases	English, Journal article, Book chapter, Book, Remove duplicates	1	0	Relevance					Removing identical matches in Compendex are quite bothersome to do for every entry, for later searches, the number of total hits should to considered to smaller than presented seeing as some of these hits could be duplicates.
Compendex	"construction management" AND phases		English, Journal article, Book chapter, Book,	202	-	Relevance					Large amount of hits, reducing size
Compendex	"construction management phases"		English, Journal article, Book chapter, Book,	1	1	Relevance	New relevant literature:				
							Umut Gökçe, K. ; Scherer, Raimar J. ; Attila Dikbas, H.	Integrated construction project management system based on IFC and IS09001: 2000	2007	Springer New York LLC	Relevant for further study
Compendex	"construction design management"		English, Journal article, Book chapter, Book,	8	4	Relevance	New relevant literature:				
							Hyun Woo Lee ; Tommelein, I.D. ; Ballard, G.	Design of an Infrastructure Project Using a Point-Based Methodology	2012	American Society of Civil Engineers, USA	Relevant for further study
							Senthilkumar, V. ; Varghese, K.	Structured methodology to formulate drawing dependency structure matrix for construction design	2009	Earthscan, UK	Relevant for further study
							Yi, S.L. ; Zhang, X. ; Calvo, M.H.	Construction safety management of building project based on BIM	2015	Bangladesh University of Engineering and Technology	Relevant for further study
							Mills, F.T. ; Glass, J.	The Construction Design Manager's Role in Delivering Sustainable Buildings	2009	Earthscan, UK	Relevant for further study
Compendex		"construction design" AND "management"	English, Journal article, Book chapter, Book,	8	0	Relevance					No hits relevant for further study
Compendex		"construction design phases"	English, Journal article, Book chapter, Book,	0	0	Relevance					No hits
Compendex		"construction design" AND "phases"	English, Journal article, Book chapter, Book,	1	0	Relevance					No hits relevant for further study
Compendex	"construction design" AND "phases"		English, Journal article, Book chapter, Book,	24	3	Relevance	New relevant literature:				
							Brandon, Peter; Betts, Martin; Wamelink, Hans	Information technology support to construction design and production	1998	Elsevier Sci B. V.	Relevant for further study
							Harig, R.F; McDermott, D.J.	Structural and foundation computer-based design	1971		Relevant for further study
							Arayici, Y.; Aouad, G.; Ahmed, V.	Requirements engineering for innovative integrated ICT systems for the construction industry	2005	Arnold, Hodder, Headline Group, UK	Relevant for further study
Compendex		"lean construction"	English, Journal article, Book chapter, Book,	77	-	Relevance					Small enough pool for inspection, removing duplicates

Attachment 1: 1st literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
Compendex		"lean construction"	English, Journal article, Book chapter, Book, Remove duplicates	63	14	Relevance	New relevant literature:				
							Erol, H.; Dikmen, I.; Birgonul, M. T.	Measuring the impact of lean construction practices on project duration and variability: A simulation-based study on residential buildings	2017	Taylor & Francis, UK	Relevant for further study
							Bajjou. Mohameed Saad; Chafi, Anas; En-Nadi, Abdelali	A comparative study between lean construction and the traditional production system	2017	Trans Tech Publications Ltd	Relevant for further study
							Zhang, Lianying; Chen, Xi; Sou, Yongqing;	Interrelationships among critical factors of work flow reliability in lean construction	2017	Taylor & Francis, Ltd.	Relevant for further study
							Sertyesilisik, B.	Embeding sustainability dynamics in the lean construction supply chain management	2016	De Gruyter Open, Hungary	Relevant for further study
							Tauriainen, M.; Marttinen, P.; Dave, B.; Koskela, L.	The effects of BIM and Lean Construction on Design Management Practices	2016	Elsevier B.V., Netherlands	Relevant for further study
							Nguyen Thanh Binh	Applying Lean Construction to Construction Project	2014	Trans Tech Publications Ltd, Switzerland	Relevant for further study
							Ogunbiyi, O.; Oladapo, A.; Goulding, J.	An empirical study of the impact of lean construction techniques on sustainable construction in the UK	2014	Emerald, UK	Relevant for further study
							Gao, Shang; Low, Sui Pheng	Lean construction management: The Toyota way	2014	Springer Singapore	Relevant for further study
							Zhenyu Zhong; Yonggao Chen	Principles of Sustainable Construction Project Management Based on Lean Construction	2011	Trans Tech Publications Ltd, Switzerland	Relevant for further study
							Wang Guangbin; He Guiyou; Bian Li	Sustainable construction project under lean construction theory	2011	Trans Tech Publications Ltd, Switzerland	Relevant for further study
							Thomas, H. Randolph; Horman, Michael J.; De Souza, Ubiraci Espinelli Lennes; Zavr'ski, Ivica	Reduicing variability to improve performance as a lean construction principle	2002	American Society of Civil Engineers	Relevant for further study
							Breit, Manfred; Vogel, Manfred; Haubi, Fritz; Marki, Fabian; Raps, Michael	4D Design and Simulation Technologies and Process Design Patterns to Support Lean Construction Methods	2008	Tsinghua University Press	Relevant for further study
							Salem, O.; Solomon, J.; Genaidy, A.; Minkarah, I.	Lean construction: From Theory to implemenation	2006	American Society of Civil Engineers	Relevant for further study
							Sacks, R.; Treckmann, M.; Rozenfield, O.	Visualization of work flow to support lean construction	2009	American Society of Civil Engineers	Relevant for further study
Compendex	"lean construction" AND "design" AND "planning"		English, Journal article, Book chapter, Book,	32	-	Relevance					Small enough pool for inspection, removing duplicates

Attachment 1: 1st literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
Compendex	"lean construction" AND "design" AND "planning"		English, Journal article, Book chapter, Book, Remove duplicates	26	7	Relevance	New relevant literature:				
							Zimina, Daria; Ballard, Glenn; Pasquire, Christine	Target Value Design: Using collaboration and lean approach to reduce construction cost	2012	Routledge	Relevant for further study
							Sacks, Rafael; Radosavljevic, Milan; Barak, Ronen	Requirements for building information modeling based lean production management systems for construction	2010	Elsevier	Relevant for further study
							Nesteby, A. I.; Aarrestad, M.E.; Lohne, J.; Bohne, R. A.	Integration of BREEAM-NOR in Construction Projects: Utilizing the Last Planner System	2016	Elsevier B.V., Netherlands	Relevant for further study
							Sacks, Rafael; Koskela, Lauri; Dave, Bhargav, A.; Owen, Robert	Interaction of lean and building information modeling in construction	2010	American Society of Civil Engineers	Relevant for further study
							Alsehaimi, Abdullah O.; Fazenda, Patricia Tzortzopoulus; Koskela, Lauri	Improving construction management practice with the Last Planner System: A case study	2014	Emerald Group Publishing Ltd.	Relevant for further study
							Al-Aomar, R.	A lean construction framework with Six Sigma rating	2012	Emerald , UK	Relevant for further study
							Bjornfot, A.; Jongeling, R.	Application of line-balance and 4D CAD for lean planning	2007	Emerald , UK	Relevant for further study
Compendex	"lean construction" AND "design management"		English, Journal article, Book chapter, Book,	4	0	Relevance					Only previously acquired relevant hits
Compendex	"lean construction" AND "phases"		English, Journal article, Book chapter, Book,	6	1	Relevance	New relevant literature:				
							Ballard, Glenn; Howell, Gregory, A.	Lean project management	2003	Routledge	Relevant for further study
Compendex	"lean construction" AND "decision"		English, Journal article, Book chapter, Book,	19	0	Relevance					Only previously acquired relevant hits
Compendex	"construction design" AND "decision"		English, Journal article, Book chapter, Book,	49	-	Relevance					Small enough pool for inspection, removing duplicates
Compendex	"construction design" AND "decision"		English, Journal article, Book chapter, Book, Remove duplicates	39	4	Relevance	New relevant literature:				
							Thomson, D. S.; Austin, S. A.; Root, D. S.; Thorpe, A.; Hammond, J. W.	A problem- solving approach to value-adding decision making in construction design	2006	Emerald Group Publishing Ltd.	Relevant for further study
							Suryawanshi, C.S.	Management of design - Concept to execution	1988	Government of Maharashtra	Relevant for further study
							Torrance, Victor	Building process summary	1997	Elsevier Sci B. V.	Relevant for further study
							McKinney, Kathleen; Kim, Jennifer; Fischer, Martin; Howard, Craig	Interactive 4D-CAD	1996	Stanford Uni, Stanford, United States	Relevant for further study
Compendex	"building information modeling" OR bim		English, Journal article, Book chapter, Book,	3590	-	Relevance					Large amount of hits, reducing size

Attachment 1: 1st literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
Compendex		"building information modeling" OR bim	English, Journal article, Book chapter, Book,	1589	-	Relevance					Large amount of hits, reducing size
Compendex		("building information modeling" OR bim) AND design	English, Journal article, Book chapter, Book,	209	-	Relevance					Small enough pool for inspection, removing duplicates
Compendex		("building information modeling" OR bim) AND design	English, Journal article, Book chapter, Book, Remove duplicates	165	10	Relevance	New relevant literature:				
							Zanni, Maria Angeliki; Soetanto, Robby; Ruikar, Kirti	Towards a BIM-enabled sustainable building design process: roles, responsibilities and requirements	2017	Taylor & Francis, Ltd.	Relevant for further study
							Liu, Yan; van Nederveen, Sander; Hertogh, Marcel	Understanding effects of BIM on collaborative design and construction, an empirical study in China	2017	Elsevier Ltd	Relevant for further study
							Oduyemi, O. Okoroh, M.I.; Fajana, O.S.	The application and barriers of BIM in sustainable building design	2017	Emerald, UK	Relevant for further study
							Wang, Li; Leite, Fernanda	Process Knowledge Capture in BIM-based Mechanical, Electrical, and plumbing Design Coordination Meetings	2016	American Society of Civil Engineers	Relevant for further study
							Cennamo, G.M.; Savoia, S.	The approach to BIM - Building Information Modeling as excellent instrument for the definition of design strategies and for knowledge, simulation and management of the buildings and architectural heritage	2014	NAUN - North Atlantic University Union, USA	Relevant for further study
							Oh, Minho; Lee, Jaewook; Hong, Seung Wan; Jeong, Yongwook	Integrated system for BIM-based collaborative design	2015	Elsevier	Relevant for further study
							Trani, M.L.; Cassano, M.; Todaro, D.; Bossi, B.	BIM Level of Detail for Construction Site Design	2015	Elsevier B.V., Netherlands	Relevant for further study
							Minagawa, M.; Kusayanagi, S.	Study on BIM utilization for design improvement of infrastructure project	2015	Elsevier B.V., Netherlands	Relevant for further study
							Mengjiao Zhou	Research on the Design of the Project Management Processes and Organization Based on BIM	2014	Trans Tech Publications Ltd, Switzerland	Relevant for further study
							Ilhan, Bahriye; Yaman, Hakan;	Green building assessment tool (GBAT) for integrated BIM-based design decisions	2016	Elsevier	Relevant for further study
Compendex		("building information modeling" OR bim) AND management	English, Journal article, Book chapter, Book,	173	-	Relevance					Small enough pool for inspection, removing duplicates
Compendex		("building information modeling" OR bim) AND management	English, Journal article, Book chapter, Book, Remove duplicates	131	0	Relevance					Only previously acquired relevant hits
Compendex		("building information modeling" OR bim) AND process	English, Journal article, Book chapter, Book,	62	-	Relevance					Small enough pool for inspection, removing duplicates

Attachment 1: 1st literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
Compendex		("building information modeling" OR bim) AND process	English, Journal article, Book chapter, Book, Remove duplicates	44	1	Relevance	New relevant literature:				
							Sigalov, Kateryna; Konig, Markus	Recognition of process patterns for BIM-based construction schedules	2017	Elsevier Ltd	Relevant for further study
Compendex	"model maturity index" OR mmi		English, Journal article, Book chapter, Book,	2753	-	Relevance					Large amount of hits, reducing size
Compendex		"model maturity index" OR mmi	English, Journal article, Book chapter, Book,	435	-	Relevance					Large amount of hits, reducing size
Compendex		("model maturity index" OR mmi) AND "construction design"	English, Journal article, Book chapter, Book,	0	0	Relevance					No hits
Compendex	("model maturity index" OR mmi) AND "construction design"		English, Journal article, Book chapter, Book,	0	0	Relevance					No hits
Compendex	("model maturity index" OR mmi) AND "construction"		English, Journal article, Book chapter, Book,	68	-	Relevance					Small enough pool for inspection, removing duplicates
Compendex	("model maturity index" OR mmi) AND "construction"		English, Journal article, Book chapter, Book,	44	0	Relevance					No relevant hits
Compendex	("level of detail" OR "level of development" OR lod) AND "construction design"		English, Journal article, Book chapter, Book,	0	0	Relevance					No hits
Compendex	("level of detail" OR "level of development" OR lod) AND "construction"		English, Journal article, Book chapter, Book,	505	-	Relevance					Large amount of hits, reducing size
Compendex	("level of detail" OR "level of development" OR lod) AND ("building information modeling" OR bim)		English, Journal article, Book chapter, Book,	56	0	Relevance					Small enough pool for inspection, removing duplicates
Compendex	("level of detail" OR "level of development" OR lod) AND ("building information modeling" OR bim)		English, Journal article, Book chapter, Book, Remove duplicates	41	5	Relevance	New relevant literature:				
							Latiffi, A.A.; Brahim, J.; Mohd, S.; Fathi, M.S.	Building information modeling (BIM): Exploring level of development (LOD) in construction projects	2015	Trans Tech Publications Ltd, Switzerland	Relevant for further study
							Tae-Song Shin	Building information modeling (BIM) collaboration from the structural engineering perspective	2017	Springer, Germany	Relevant for further study
							Boton, C.; Kubicki, S.; Halin, G.	The Challenge of Level of Development in 4D/BIM Simulation Across AEC Project Lifecycle. A Case Study	2015	Elsevier B.V., Netherlands	Relevant for further study
							Hooper, M.	Automated model progression scheduling using level of development	2015	Emerald, UK	Relevant for further study
							Leite, Fernanda; Akcamete, Asli; Akinci, Burcu; Atasoy, Guzide; Kiziltas, Semiha	Analysis of modeling effort and impact of different levels of detail in building information models	2011	Elsevier	Relevant for further study

Attachment 1: 1st literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
Compendex	("level of detail" OR "level of development" OR lod) AND "construction" AND "design"		English, Journal article, Book chapter, Book,	170	-	Relevance					Small enough pool for inspection, removing duplicates
Compendex	("level of detail" OR "level of development" OR lod) AND "construction" AND "design"		English, Journal article, Book chapter, Book, Remove duplicates	164	4	Relevance	New relevant literature:				
							Liu, Yan; Li, Shirong	Research on virtual construction in the construction phase and it's 4D LOD analysis	2013	American Society of Civil Engineers	Relevant for further study
							Calleja-Rodriguez, Gloria; Guruz, Romy; Geibler, Marie-Christine; Steinmann, R; Linhard, K. Dangl. G.	Collaboration requirements and interoperability fundementals in BIM based multi-disciplinary building design processes	2016	CRC Press/Balkema	Relevant for further study
							Treldal, N.; Vestergaard, F.; Karlshøj, J.	Pragmatic use of lod - a modular approach	2016	CRC Press/Balkema	Relevant for further study
							Uusitalo, Petteri; Olivieri, Hylton; Seppanen, Olli; Pikas, Ergo; Peltokorpi, Antti	Review of Lean Design Management: Processes, methods and technologies	2017	The International Group for Lean Construction	Relevant for further study
IGLC Database of conferance papers	level of detail	N/A	N/A	6	0	N/A					No additional relevant hits
IGLC Database of conferance papers	level of development	N/A	N/A	2	2	N/A	New relevant literature:				
							Hisham Abou-Ibrahim & Farook Hamzeh	BIM: A TFV Perspective to Manage Design Using the LOD Concept	2016	The International Group for Lean Construction	Relevant for further study
							Hisham Abou-Ibrahim & Farook Hamzeh	Design Management: Metrics and Visual Tools	2017	The International Group for Lean Construction	Relevant for further study
IGLC Database of conferance papers	lod	N/A	N/A	2	0	N/A					No additional relevant hits
IGLC Database of conferance papers	design phases	N/A	N/A	7	2	N/A	New relevant literature:				
							Senthilkumar Venkatachalam, Koshy Varghese & C.Y. Shivaji	Achieving Lean Design Using Design Interface Management Tool	2009	The International Group for Lean Construction	Relevant for further study
							Pablo Orihuela, Jorge Oriheula & Karem Ulloa	Tools for Design Management in Building Projects	2011	The International Group for Lean Construction	Relevant for further study
IGLC Database of conferance papers	design management	N/A	N/A	7	4	N/A	New relevant literature:				
							Lauri Koskela, Glenn Ballard & Veli-Pekka Tanhuanpää	Towards Lean Design Management	1997	The International Group for Lean Construction	Relevant for further study
							Patricia Tzortzopoulos & Carlos Torres Formoso	Considerations on Application of Lean Construction Principles to Design Management	1999	The International Group for Lean Construction	Relevant for further study
							Javier Freire & Luis F. Alarcon	Achieving a Lean Design Process	2000	The International Group for Lean Construction	Relevant for further study
							Malak Al Hattab & Farook Hamzeh	Modeling Design Workflow: Integrating Process and Organization	2016	The International Group for Lean Construction	Relevant for further study

Attachment 1: 1st literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
IGLC Database of conferance papers	design management	N/A	N/A	101	3	N/A	New relevant literature:				
							L. Rischmoller1 & L.F. Alarcón2	Using Lean Principles as a Framework to Study Information Technology in Construction	2005	The International Group for Lean Construction	Relevant for further study
							Josana G. B. Wesz1, Carlos T. Formoso2 & Patrícia Tzotzopoulos3	Design process planning and control last planner system adaptation	2013	The International Group for Lean Construction	Relevant for further study
							Stephen Emmitt1, Dag Sander2 & Anders Kirk Christoffersen3	Implementing Value Through Lean Design Management	2004	The International Group for Lean Construction	Relevant for further study

Attachment 2: Narrowing 1st literature pool

Acquired with	Author(s)	Title	Year	Publisher	Inclusion/exclusion based on Title/Abstract/Summary
Compendex	Umut Gökçe, K. ; Scherer, Raimar J. ; Attila Dikbas, H.	Integrated construction project management system based on IFC and IS09001:2000	2007	Springer New York LLC	
Compendex	Hyun Woo Lee ; Tommelein, I.D. ; Ballard, G.	Design of an Infrastructure Project Using a Point-Based Methodology	2012	American Society of Civil Engineers, USA	
Compendex	Senthilkumar, V. ; Varghese, K.	Structured methodology to formulate drawing dependency structure matrix for construction design	2009	Earthscan, UK	
Compendex	Yi, S.L. ; Zhang, X. ; Calvo, M.H.	Construction safety management of building project based on BIM	2015	Bangladesh University of Engineering and Technology	Safety not relevant
Compendex	Mills, F.T. ; Glass, J.	The Construction Design Manager's Role in Delivering Sustainable Buildings	2009	Earthscan, UK	Sustainability not relevant
Compendex	Brandon, Peter; Betts, Martin; Wamelink, Hans	Information technology support to construction design and production	1998	Elsevier Sci B.V.	Too specific to IT
Compendex	Harig, R.F; McDermott, D.J.	Structural and foundation computer-based design	1971		Specific to foundation design
Compendex	Arayici, Y.; Aouad, G.; Ahmed, V.	Requirements engineering for innovative integrated ICT systems for the construction industry	2005	Arnold, Hodder, Headline Group, UK	Bit too specific to IT
Compendex	Erol, H.; Dikmen, I.; Birgonul, M.T.	Measuring the impact of lean construction practices on project duration and variability: A simulation-based study on residential buildings	2017	Taylor & Francis, UK	More focused on lifecycle analysis
Compendex	Bajjou. Mohameed Saad; Chafi, Anas; En-Nadi, Abdelali	A comparative study between lean construction and the traditional production system	2017	Trans Tech Publications Ltd	Comparative study between traditional and lean construction not necessary with the abundance of other LC-literature in this pool
Compendex	Zhang, Lianying; Chen, Xi; Sou, Yongqing;	Interrelationships among critical factors of work flow reliability in lean construction	2017	Taylor & Francis, Ltd.	Focused on construction phase
Compendex	Sertyesilisik, B.	Embeding sustainability dynamics in the lean construction supply chain management	2016	De Gruyter Open, Hungary	Sustainability not relevant
Compendex	Tauriainen, M.; Marttinen, P.; Dave, B.; Koskela, L.	The effects of BIM and Lean Construction on Design Management Practices	2016	Elsevier B.V., Netherlands	Impact assessments not relevant
Compendex	Nguyen Thanh Binh	Applying Lean Construction to Construction Project	2014	Trans Tech Publications Ltd, Switzerland	
Compendex	Ogunbiyi, O.; Oladapo, A.; Goulding, J.	An empirical study of the impact of lean construction techniques on sustainable construction in the UK	2014	Emerald, UK	Impact on industry not relevant
Compendex	Gao, Shang; Low, Sui Pheng	Lean construction management: The Toyota way	2014	Springer Singapore	Could be an interesting read, but unrelated to research topics
Compendex	Zhenyu Zhong; Yonggao Chen	Principles of Sustainable Construction Project Management Based on Lean Construction	2011	Trans Tech Publications Ltd, Switzerland	Sustainability not relevant
Compendex	Wang Guangbin; He Guiyou; Bian Li	Sustainable construction project under lean construction theory	2011	Trans Tech Publications Ltd, Switzerland	Sustainability not relevant
Compendex	Thomas, H. Randolph; Horman, Michael J.; De Souza, Ubiraci Espinelli Lennes; Zavr'ski, Ivica	Reducing variability to improve performance as a lean construction principle	2002	American Society of Civil Engineers	Focused on construction phase
Compendex	Breit, Manfred; Vogel, Manfred; Haubi, Fritz; Marki, Fabian; Raps, Michael	4D Design and Simulation Technologies and Process Design Patterns to Support Lean Construction Methods	2008	Tsinghua University Press	
Compendex	Salem, O.; Solomon, J.; Genaidy, A.; Minkarah, I.	Lean construction: From Theory to implemenation	2006	American Society of Civil Engineers	
Compendex	Sacks, R.; Treckmann, M.; Rozenfield, O.	Visualization of work flow to support lean construction	2009	American Society of Civil Engineers	
Compendex	Zimina, Daria; Ballard, Glenn; Pasquire, Christine	Target Value Design: Using collaboration and lean approach to reduce construction cost	2012	Routledge	Focused on construction phase
Compendex	Sacks, Rafael; Radosavljevic, Milan; Barak, Ronen	Requirements for building information modeling based lean production management systems for construction	2010	Elsevier	Focused on construction phase
Compendex	Nesteby, A.I.; Aarrestad, M.E.; Lohne, J.; Bohne, R. A.	Integration of BREEAM-NOR in Construction Projects: Utilizing the Last Planner System	2016	Elsevier B.V., Netherlands	Focused environment and sustainability
Compendex	Sacks, Rafael; Koskela, Lauri; Dave, Bhargav, A.; Owen, Robert	Interaction of lean and building information modeling in construction	2010	American Society of Civil Engineers	

Compendex	Alsehaimi, Abdullah O.; Fazenda, Patricia Tzortzopoulus; Koskela, Lauri	Improving construction management practice with the Last Planner System: A case study	2014	Emerald Group Publishing Ltd.	Case study not as relevant for research topics as theory
Compendex	Al-Aomar, R.	A lean construction framework with Six Sigma rating	2012	Emerald , UK	Not particularrily relevant for research topics
Compendex	Bjornfot, A.; Jongeling, R.	Application of line-balance and 4D CAD for lean planning	2007	Emerald , UK	Focus on Line-of-Balance implementation
Compendex	Ballard, Glenn; Howell, Gregory, A.	Lean project management	2003	Routledge	
Compendex	Thomson, D.S.; Austin, S.A.; Root, D.S.; Thorpe, A.; Hammond, J. W.	A problem- solving approach to value-adding decision making in construction design	2006	Emerald Group Publishing Ltd.	Focus on Value adding Toolbox implementation
Compendex	Suryawanshi, C.S.	Management of design - Concept to execution	1988	Government of Maharashtra	
Compendex	Torrance, Victor	Building process summary	1997	Elsevier Sci B.V.	Broad scope
Compendex	McKinney, Kathleen; Kim, Jennifer; Fischer, Martin; Howard, Craig	Interactive 4D-CAD	1996	Stanford Uni, Stanford, United States	Specific and practical focus on CAD
Compendex	Zanni, Maria Angeliki; Soetanto, Robby; Ruikar, Kirti	Towards a BIM-enabled sustainable building design process: roles, responsibilities and requirements	2017	Taylor & Francis, Ltd.	Sustainability not relevant
Compendex	Liu, Yan; van Nederveen, Sander; Hertogh, Marcel	Understanding effects of BIM on collaborative design and construction, an empirical study in China	2017	Elsevier Ltd	Empirical study / Case studies not as desired as theory
Compendex	Oduyemi, O. Okoroh, M.I.; Fajana, O.S.	The application and barriers of BIM in sustainable building design	2017	Emerald, UK	Sustainability not relevant
Compendex	Wang, Li; Leite, Fernanda	Process Knowledge Capture in BIM-based Mechanical, Electrical, and plumbing Design Coordination Meetings	2016	American Society of Civil Engineers	
Compendex	Cennamo, G.M.; Savoia, S.	The approach to BIM - Building Information Modeling as excellent instrument for the definition of design strategies and for knowledge, simulation and management of the buildings and architectural heritage	2014	NAUN - North Atlantic University Union, USA	Focus on architecture and historical conservation of old buildings
Compendex	Oh, Minho; Lee, Jaewook; Hong, Seung Wan; Jeong, Yongwook	Integrated system for BIM-based collaborative design	2015	Elsevier	
Compendex	Trani, M.L.; Cassano, M.; Todaro, D.; Bossi, B.	BIM Level of Detail for Construction Site Design	2015	Elsevier B.V., Netherlands	Focused on construction phase
Compendex	Minagawa, M.; Kusayanagi, S.	Study on BIM utilization for design improvement of infrastructure project	2015	Elsevier B.V., Netherlands	Infrastructure focus
Compendex	Mengjiao Zhou	Research on the Design of the Project Management Processes and Organization Based on BIM	2014	Trans Tech Publications Ltd, Switzerland	
Compendex	Ilhan, Bahriye; Yaman, Hakan;	Green building assassment tool (GBAT) for integrated BIM-based design decisions	2016	Elsevier	Environmental focus
Compendex	Sigalov, Kateryna; Konig, Markus	Recognition of process patterns for BIM-based construction schedules	2017	Elsevier Ltd	
Compendex	Latiffi, A.A.; Brahim, J.; Mohd, S.; Fathi, M.S.	Building information modeling (BIM): Exploring level of development (LOD) in construction projects	2015	Trans Tech Publications Ltd, Switzerland	
Compendex	Tae-Song Shin	Building information modeling (BIM) collaboration from the structural engineering perspective	2017	Springer, Germany	
Compendex	Boton, C.; Kubicki, S.; Halin, G.	The Challenge of Level of Development in 4D/BIM Simulation Across AEC Project Lifecycle. A Case Study	2015	Elsevier B.V., Netherlands	
Compendex	Hooper, M.	Automated model progression scheduling using level of development	2015	Emerald, UK	
Compendex	Leite, Fernanda; Akcamete, Asli; Akinci, Burcu; Atasoy, Guzide; Kiziltas, Semiha	Analysis of modeling effort and impact of different levels of detail in building information models	2011	Elsevier	
Compendex	Liu, Yan; Li, Shirong	Research on virtual construction in the construction phase and it's 4D LOD analysis	2013	American Society of Civil Engineers	
Compendex	Calleja-Rodriguez, Gloria; Guruz, Romy; Geibler, Marie-Christine; Steinmann, R; Linhard, K. Dangl. G.	Collaboration requirements and interoperability fundementals in BIM based multi-disciplinary building design processes	2016	CRC Press/Balkema	
Compendex	Treldal, N.; Vestergaard, F.; Karlshøj, J.	Pragmatic use of lod - a modular approach	2016	CRC Press/Balkema	

Compendex	Uusitalo, Petteri; Olivieri, Hylton; Seppanen, Olli; Pikas, Ergo; Peltokorpi, Antti	Review of Lean Design Management: Processes, methods and technologies	2017	The International Group for Lean Construction	
Guidance councilor	Abou-Ibrahim, Hisham, and Farook Hamzeh	Enabling Lean Design Management: An LOD Based Framework.	2016	Lean construction Journal	
Guidance councilor	Adler, Patrica A., and Peter Adler	Handbook of qualitative research	2013	American Insituite of Architects	Not relevant to research topic
Guidance councilor	Aslesen, Sigmund, and Sven Bertelsen	Last Planner in a Social Perspective A Shipbuilding Case.	2008	16th Annual Conference of the International Group for Lean Construction, Manchester, UK, 2008/07/16.	Not relevant to research topic
Guidance councilor	Alan Bryman	Social Research methods	2015	Oxford University Press	
Guidance councilor	Bell, Bradford S., and Steve W. J. Kozlowski	A Typology of Virtual Teams: Implications for Effective Leadership."	2002	Group Et Organization Management 27	Not relevant to research topic
Guidance councilor	Borrmann, Andre, Matthias Flurl, Javier Ramos Jubierre, Ralf-Peter Mundani, and Ernst Rank	Synchronous collaborative tunnel design based on consistency-preserving multi-scale models.	2014	Advanced Engineering Informatics	Not relevant to research topic
Guidance councilor	Brinkmann, Svend, and Steinar Kvale	InterViews - Learning the Craft of Qualitative Research Interviewing	2015	SAGE Publications Inc.	
Guidance councilor	Project management Institute	Project Management Body of Knowledge (PMBOK Guide) Fifth edition	2013	Project management Institute	
Guidance councilor	Browning, T. R.	Applying the design structure matrix to system decomposition and integration problems: a review and new directions.	2001	IEEE Transactions on Engineering Management 48	Not relevant to research topic
Guidance councilor	Bolviken, Trond.	Collaborative design management	2010		
Guidance councilor	Emmitt, S., and K. Ruikar.	Collaborative Design Management.	2013	London: Routledge	
Guidance councilor	Forbes, Lincoln H., and Syed M. Ahmed.	Modern construction: lean project delivery and integrated practices	2011	Boca Raton, Fla.: CRC Press.	Not relevant to research topic
Guidance councilor	Fundli, Ingvild S., and Frode Drevland.	Collaborative Design Management - A Case Study.	2014	22nd Annual Conference of the International Group for Lean Construction, Oslo, Norway, 2014/06/25.	Case studies not relevant to research topic
Guidance councilor	Kalsaas, Bo Terje, and Rafael Sacks.	Conceptualization of Interdependency and Coordination Between Construction Tasks.	2011	19th anual conference of the International Group of Lean Construction. .	
Guidance councilor	Kerosuo, Hannele.	BIM-based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking	2015	Procedia Economics and Finance	
Guidance councilor	Knotten, Vegard, and Fredrik Svalestuen.	Veidekke: collaborative planning in design.	2016	Design Management, edited by Stephen Emmitt, 133-147. Taylor Et Francis.	
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lwdre, and Geir K. Hansen.	Organizational Power in Building Design Management	2015	23rd Annual Conference of the International Group for Lean Construction, 2015.	Not relevant to research topic
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lwdre, and Geir Karsten Hansen.	Learning Across Disciplines - Use of the Constant Comparative Method.	2017	Proceedings of the 9th Nordic Conference on Construction Economics and Organization, 273-284. Polyteknisk Forlag.	
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lwdre, Jardar Lohne, and Geir K Hansen.	Design Management- Learning across trades.	2016	Creating built environments of new opportunities	
Guidance councilor	Kunz, John, and Martin Fischer.	Virtual design and construction: themes, case studies and implementation suggestions.	2009	Center for Integrated Facility Engineering (CIFE), Stanford University.	
Guidance councilor	Rosas, Eduardo.	Integrating the Design Structure Matrix and the Last Planner System into Building Design.	2013	21th Annual Conference of the International Group for Lean Construction, Fortaleza, Brazil.	Not relevant to research topic
Guidance councilor	Ballard, Glenn, and Lauri Koskela.	On the Agenda of Design Management Research	1998	6th Annual Conference of the International Group for Lean Construction, 1998.	Not relevant to research topic
Guidance councilor	Boyle, Griff.	Design project management.	2003	Aldershot: Ashgate.	
Guidance councilor	BrAthen, Ketil.	Collaboration with BIM - Learning from the Front Runners in the Norwegian Industry.	2015	Procedia Economics and Finance	
Guidance councilor	Chachere, John, John Kunz, and Raymond Levitt.	Observation, Theory, and Simulation of Integrated Concurrent Engineering: Grounded Theoretical Factors that Enable Radical Project Acceleration.	2004		

Guidance councilor	El. Reifi, M. H., and S. Emmitt.	Perceptions of lean design management.	2013	Architectural Engineering and Design Management 9	Not relevant to research topic
Guidance councilor	Mejlwnder-Larsen, Oystein.	Generalising via the Case Studies and Adapting the Oil and Gas Industry's Project Execution Concepts to the Construction Industry.	2015	Procedia Economics and Finance	
IGLC	Hisham Abou-Ibrahim & Farook Hamzeh	BIM: A TFV Perspective to Manage Design Using the LOD Concept	2016	The International Group for Lean Construction	
IGLC	Hisham Abou-Ibrahim & Farook Hamzeh	Design Management: Metrics and Visual Tools	2017	The International Group for Lean Construction	Not relevant to research topic
IGLC	Senthilkumar Venkatachalam, Koshy Varghese & C.Y. Shivaji	Achieving Lean Design Using Design Interface Management Tool	2009	The International Group for Lean Construction	Not relevant to research topic
IGLC	Pablo Orihuela, Jorge Oriheula & Karem Ulloa	Tools for Design Management in Building Projects	2011	The International Group for Lean Construction	Not relevant to research topic
IGLC	Lauri Koskela, Glenn Ballard & Veli-Pekka Tanhuanpää	Towards Lean Design Management	1997	The International Group for Lean Construction	
IGLC	Patricia Tzortzopoulos & Carlos Torres Formoso	Considerations on Application of Lean Construction Principles to Design Management	1999	The International Group for Lean Construction	Not relevant to research topic
IGLC	Javier Freire & Luis F. Alarcon	Achieving a Lean Design Process	2000	The International Group for Lean Construction	
IGLC	Malak Al Hattab & Farook Hamzeh	Modeling Design Workflow: Integrating Process and Organization	2016	The International Group for Lean Construction	
IGLC	L. Rischmoller1 & L. F. Alarcón2	Using Lean Principles as a Framework to Study Information Technology in Construction	2005	The International Group for Lean Construction	Not relevant to research topic
IGLC	Josana G. B. Wesz1, Carlos T. Formoso2 & Patrícia Tzotzopoulos3	Design process planning and control last planner system adaptation	2013	The International Group for Lean Construction	Not relevant to research topic
IGLC	Stephen Emmitt1, Dag Sander2 & Anders Kirk Christoffersen3	Implementing Value Through Lean Design Management	2004	The International Group for Lean Construction	Not relevant to research topic
Master thesis, Iver Grytting	(UiO), U. M.	Kvalitativ og kvantitativ analyse.	2015	snl.no.	
Master thesis, Iver Grytting	Ballard, G.	Positive vs negative iteration in design.	2000	Proceedings Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK. 17-19 s	Not relevant to research topic
Master thesis, Iver Grytting	Ballard, G., Hammond, J. & Nickerson, R.	Production planning control principles	2009	The International Group for Lean Construction	
Master thesis, Iver Grytting	Sigve Pettersen.	LoD i norsk byggebransje og europeisk standardiseringsarbeid	2017	BuildingSmartNorge	
Master thesis, Iver Grytting	Busch, T.	Akademisk skriving for bachelor og masterstudenter	2014		
Master thesis, Iver Grytting	Drevland, F. (2016)	Historien bak Lean Construction	2016	frodedrevland.no	Not relevant to research topic
Master thesis, Iver Grytting	Eastman, C., Teicholz, P., Sacks, R. & Liston, K.	BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.	2011	Hoboken: Wiley	
Master thesis, Iver Grytting	Eikeland, P.	Teoretisk analyse av byggeprosjekter. Samspillet i Byggeprosessen.	2016		Not relevant to research topic
Master thesis, Iver Grytting	Haanws, S., Nolte, E. & Larsen, S. V.	Beslutningsunderlag og beslutninger i store statlige investeringsprosjekt	2010	Concept- programmet.	Not relevant to research topic
Master thesis, Iver Grytting	Howell, I.	The value information has on decision-making.	2016	New Hampshire Business Review, 38	
Master thesis, Iver Grytting	Kim, J. I., Kim, J., Fischer, M. & Orr, R.	BIM-based decision-support method for master planning of sustainable large-scale developments.	2015	Automation in Construction, 58	Not relevant to research topic
Master thesis, Iver Grytting	Knotten, V.	Involverende Planlegging i Prosjektering - Lean i prosjektering.	2015		Not relevant to research topic
Master thesis, Iver Grytting	Knutsen, E., Drevland, F. 0. & Barreth, M.	BIM-Koordinering.	2014	Institutt for bygg, anlegg og transport.	
Master thesis, Iver Grytting	Nowak, P., Ksiqiek, M., Draps, M. & Zawistowski, J.	Decision Making with Use of Building Information Modeling.	2016	Procedia Engineering, 153	

Attachment 3: 1st pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Guidance councilor	Brinkmann, Svend, and Steinar Kvale	InterViews - Learning the Craft of Qualitative Research Interviewing	2015	Book	SAGE Publications Inc.	Interviews, qualitative focus	Providing structure and tips for concucting interviews	Aid for project report / master thesis writing	
Master thesis, Iver Grytting	(UiO), U. M.	Kvalitativ og kvantitativ analyse	2015	Scientific Paper	snl.no	Qualitative/quantitative analysis	Qualitative/quantitative analysis	Aid for project report / master thesis writing	
Master thesis, Iver Grytting	Busch, T.	Akademisk skriving for bachelor og masterstudenter	2014	Book	Fagbokforlaget	Academic writing, master thesis, phd	Providing structure and tips for writing academic articles	Aid for project report / master thesis writing	
Guidance councilor	Alan Bryman	Social Research methods	2015	Book	Oxford University Press	Interviews, qualitative/quantitative, social scientific research	Guide for conducting scientific research on people	Aid for project report / master thesis writing	
Compendex	Sacks, Rafael; Koskela, Lauri; Dave, Bhargav, A.; Owen, Robert	Interaction of lean and building information modeling in construction	2010	Scientific Paper	American Society of Civil Engineers	Lean construction, BIM	Comparing lean construction principles with BIM	BIM	
Compendex	Oh, Minho; Lee, Jaewook; Hong, Seung Wan; Jeong, Yongwook	Integrated system for BIM-based collaborative design	2015	Scientific Paper	Elsevier	BIM integration, Collaborative design	Providing a framework for implemention BIM	BIM	
Compendex	Tae-Song Shin	Building information modeling (BIM) collaboration from the structural engineering perspective	2017	Scientific Paper	Springer, Germany	interoperability, open standard BIM, structure model, asrchitecture model, construction model, work-process simulation	Study on interoperability between design actors in BIM	BIM	
Compendex	Calleja-Rodriguez, Gloria; Guruz, Romy; Geibler, Marie-Christine; Steinmann, R; Linhard, K. Dangl. G.	Collaboration requirements and interoperability fundementals in BIM based multi-disciplinary building design processes	2016	Scientific Paper	CRC Press/Balkema	buildingSMART, LoD, BIM	Describes the ways to make specifications of data exchange scenarios between different software systems possible and introduces the concepts and technologies behind them	BIM	
Guidance councilor	Bråthen, Ketil.	Collaboration with BIM - Learning from the Front Runners in the Norwegian Industry.	2015	Scientific Paper	Procedia Economics and Finance	BIM, collaboration, interoperability	Making an analytical generalisation of findings from case studies in Norway	BIM	
Master thesis, Iver Grytting	Eastman, C., Teicholz, P., Sacks, R. & Liston, K.	BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.	2011	Book	Hoboken: Wiley	BIM, collaboration, interoperability, implementation, practical advice	A general guide for users of BIM	BIM	
Master thesis, Iver Grytting	Knutsen, E., Drevland, F. 0. & Barreth, M.	BIM-Koordinering.	2014	Scientific Paper	Institutt for bygg, anlegg og transport.	BIM, collaboration, interoperability	Coordination between design actors in BIM	BIM	
Compendex	Umut Gökçe, K. ; Scherer, Raimar J. ; Attila Dikbas, H.	Integrated construction project management system based on IFC and IS09001:2000	2007	Book	Springer New York LLC	BIM, project management, Construction Management Phases	Establish a conceptual framework for managing of BIM processes.	Construction project management	
Compendex	Suryawanshi, C.S.	Management of design - Concept to execution	1988	Scientific Paper	Government of Maharashtra	Design management	General guide to construction management	Construction project management	
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lædre, Jardar Lohne, and Geir K Hansen.	Design Management-Learning across trades	2016	Scientific Paper	Creating built environments of new opportunities	Design management, planning, coordination	Study on differences between AEC and offshore industries	Construction project management	

Attachment 3: 1st pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Guidance councilor	Boyle, Griff.	Design project management	2003	Book	Aldershot: Ashgate.	Management, contracting	Guide to contracting and working with designers, and managing projects proactively through to successfull completion	Construction project management	
Master thesis, Iver Grytting	Ballard, G., Hammond, J. & Nickerson, R.	Production planning control principles	2009	Scientific Paper	The International Group for Lean Construction	Last planner, production control	Design for production and last planner	Construction project management	
Guidance councilor	Project management Institute	Project Management Body of Knowledge (PMBOK Guide) Fifth edition	2013	Book	Project management Institute	Project management	Establishing a common body of knowledge regarding project management	Construction project management	
Compendex	Nguyen Thanh Binh	Applying Lean Construction to Construction Project	2014	Scientific Paper	Trans Tech Publications Ltd, Switzerland	Lean construction	Discussing phases of lean construction and waste during construction	Lean construction	
Compendex	Salem, O.; Solomon, J.; Genaidy, A.; Minkarah, I.	Lean construction: From Theory to implemenation	2006	Scientific Paper	American Society of Civil Engineers	Lean construction, construction management	Lean construction principles in building construction	Lean construction	
Compendex	Ballard, Glenn; Howell, Gregory, A.	Lean project management	2003	Scientific Paper	Routledge	Construction management, LPDS, project management	Contrasting lean and traditional project management principles	Lean construction	
Guidance councilor	Uusitalo, Petteri; Olivieri, Hylton; Seppanen, Olli; Pikas, Ergo; Peltokorpi, Antti	Review of Lean Design Management: Processes, methods and technologies	2017	Scientific Paper	The International Group for Lean Construction	Lean design management, lean construction, Virtual design and construction, collaboration	Analysing design management attributes from Norway, Finland and the US	Lean construction	
IGLC	Chachere, John, John Kunz, and Raymond Levitt.	Observation, Theory, and Simulation of Integrated Concurrent Engineering: Grounded Theoretical Factors that Enable Radical Project Acceleration	2004	Scientific Paper	CIFE - Center for Integrated Facility Engineering	Business processes, collaborative engineering, concurrent design, process models	A study on ICE - Integrated Concurrent Engineering in construction projects	Lean construction	
IGLC	Lauri Koskela, Glenn Ballard & Veli-Pekka Tanhuanpää	Towards Lean Design Management	1997	Scientific Paper	The International Group for Lean Construction	Design management, concurrent engineering, value management	A review of current thinking regarding conversion, flow and value in the AEC-industry	Lean construction	
Compendex	Javier Freire & Luis F. Alarcon	Achieving a Lean Design Process	2000	Scientific Paper	The International Group for Lean Construction	Construction management	Proposing an improvement methodology is proposed for the design process in construction projects.	Lean construction	
Compendex	Latiffi, A.A:; Brahim, J.; Mohd, S.; Fathi, M.S.	Building information modeling (BIM): Exploring level of development (LOD) in construction projects	2015	Chapter from book	Trans Tech Publications Ltd, Switzerland	BIM, LoD, Malaysian construction industry	Explore implementation of lod in projects using BIM	LoD	
Compendex	Boton, C.; Kubicki, S.; Halin, G.	The Challenge of Level of Development in 4D/BIM Simulation Across AEC Project Lifecycle. A Case Study	2015	Scientific Paper	Elsevier B.V., Netherlands	4D simulation, construction scheduling, BIM, LoD	Case study of two cases of implementation of 4D and LoD	LoD	
Compendex	Hooper, M.	Automated model progression scheduling using level of development	2015	Scientific Paper	Emerald, UK	LoD, BIM, Model progression	Describing use of LoD as a measure of progression in a design model	LoD	

Attachment 3: 1st pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Compendex	Leite, Fernanda; Akcamete, Asli; Akinci, Burcu; Atasoy, Guzide; Kiziltas, Semiha	Analysis of modeling effort and impact of different levels of detail in building information models	2011	Scientific Paper	Elsevier	BIM, LoD	Evaluating impact of using LoD in different disciplines, and the modeling effort using LoD in AEC-projects	LoD	
Compendex	Liu, Yan; Li, Shirong	Research on virtual construction in the construction phase and it's 4D LOD analysis	2013	Scientific Paper	American Society of Civil Engineers	BIM, construction phase	Analysis of BIM and LoD in the construction phase	LoD	
Guidance councilor	Treldal, N.; Vestergaard, F.; Karlshøj, J.	Pragmatic use of lod - a modular approach	2016	Scientific Paper	CRC Press/Balkema	BIM, LoD, different LoD concepts	Analysis of LoD and different LoD-concepts in AEC-projects	LoD	
IGLC	Abou-Ibrahim, Hisham, and Farook Hamzeh	Enabling Lean Design Management: An LOD Based Framework.	2016	Article	Lean construction Journal	TFV, BIM, LoD	Relating LoD to TFV	LoD	
Master thesis, Iver Grytting	Hisham Abou-Ibrahim & Farook Hamzeh	BIM: A TFV Perspective to Manage Design Using the LOD Concept	2016	Scientific Paper	The International Group for Lean Construction	TFV, BIM, LoD	Relating LoD to TFV	LoD	
Guidance councilor	Sigve Pettersen.	LoD i norsk byggebransje og europeisk standardisering sarbeid	2017	N/A	BuildingSmartNorge	N/A	Unable to acquire	LoD	
Compendex	Mejlwnder-Larsen, Oystein.	Generalising via the Case Studies and Adapting the Oil and Gas Industry's Project Execution Concepts to the Construction Industry.	2015	Scientific Paper	Procedia Economics and Finance	BIM, Case Study, Project execution model	To explore whether it is possible to generalise findings on project execution in the oil and gas industry related to the use of project execution models and a 3D design environment	Oil/gas - AEC	
Compendex	Senthilkumar, V. ; Varghese, K.	Structured methodology to formulate drawing dependency structure matrix for construction design	2009	Article, Architectural Engineering and Design Management	Earthscan, UK	Construction design management, dependency structure matrix, interface managementq	Exploring the dependency structure matrix as a tool for construction design management	Process, flow and disciplines	
Compendex	Breit, Manfred; Vogel, Manfred; Haubi, Fritz; Marki, Fabian; Raps, Michael	4D Design and Simulation Technologies and Process Design Patterns to Support Lean Construction Methods	2008	Scientific Paper	Tsinghua University Press	4D, process and organization, process patterns, lean cosntruction	Determining how 3D/4D, BIM, POP can support lean construction	Process, flow and disciplines	
Compendex	Sacks, R.; Treckmann, M.; Rozenfield, O.	Visualization of work flow to support lean construction	2009	Scientific Paper	American Society of Civil Engineers	CAD, construction management, interfaces, lean construction	Implementing of two concrete interfaces for BIM	Process, flow and disciplines	
Compendex	Wang, Li; Leite, Fernanda	Process Knowledge Capture in BIM-based Mechanical, Electrical, and plumbing Design Coordination Meetings	2016	Scientific Paper	American Society of Civil Engineers	BIM, Model-based design review	Uncover knowledge about the process of interactions between Mechanical, Electrical and Plumbing disciplines in AEC-projects	Process, flow and disciplines	
Compendex	Mengjiao Zhou	Research on the Design of the Project Management Processes and Organization Based on BIM	2014	Scientific Paper	Trans Tech Publications Ltd, Switzerland	BIM, CAD, process design	Exploring which traditional industry problems BIM can solve	Process, flow and disciplines	
Guidance councilor	Sigalov, Kateryna; Konig, Markus	Recognition of process patterns for BIM-based construction schedules	2017	Scientific Paper	Elsevier Ltd	Pattern recognition, process patterns, BIM	Pattern recognition in BIM-based project in the AEC-industry	Process, flow and disciplines	

Attachment 3: 1st pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Guidance councilor	Bølviken, Trond.	Collaborative design management	2010	Scientific Paper	IGLC	Construction design management, decision making	Examining the decision-making in parallel design and construction	Process, flow and disciplines	
Guidance councilor	Emmitt, S., and K. Ruikar.	Collaborative Design Management.	2013	Book	London: Routledge	collaborative design, project management	Establishing a foundation for design project management based on a number of case studies	Process, flow and disciplines	
Guidance councilor	Kalsaas, Bo Terje, and Rafael Sacks.	Conceptualization of Interdependency and Coordination Between Construction Tasks.	2011	Scientific Paper	19th anual conference of the International Group of Lean Construction. .	Coordination theory, interdependance, production planning, LPS		Process, flow and disciplines	
Guidance councilor	Kerosuo, Hannele.	BIM-based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking	2015	Scientific Paper	Procedia Economics and Finance	Active theory, BIM, disciplinary boundries, knotworking	Examine how the fragmentation of design and construction work could be reduced through knotworking in building projects.	Process, flow and disciplines	
Guidance councilor	Knotten, Vegard, and Fredrik Svalestuen.	Veidekke: collaborative planning in design.	2016	N/A	Design Management, edited by Stephen Emmitt, 133-147. Taylor Et Francis.	N/A	Unable to acquire details	Process, flow and disciplines	
IGLC	Knotten, Vegard, Fredrik Svalestuen, Ola Lwdre, and Geir Karsten Hansen.	Learning Across Disciplines - Use of the Constant Comparative Method.	2017	Scientific Paper	Proceedings of the 9th Nordic Conference on Construction Economics and Organization, 273-284. Polyteknisk Forlag.	Building design management, constant comparative method, qualitative analysis	Examining methods used for learning in the AEC industry	Process, flow and disciplines	
Master thesis, Iver Grytting	Malak Al Hattab & Farook Hamzeh	Modeling Design Workflow: Integrating Process and Organization	2016	Scientific Paper	The International Group for Lean Construction	Work flow, lean design managment, BIM	Integrate process, flow and social network in AEC-projects	Process, flow and disciplines	
Master thesis, Iver Grytting	Howell, I.	The value information has on decision-making.	2016	Article	New Hampshire Business Review, 38	Information, decision making		Process, flow and disciplines	
Master thesis, Iver Grytting	Nowak, P., Ksiqiek, M., Draps, M. & Zawistowski, J.	Decision Making with Use of Building Information Modeling.	2016	Scientific Paper	Procedia Engineering, 153	BIM, decision making	Presents possibilities of BIM techniques and relevant software for decision making optimization in construction	Process, flow and disciplines	

Attachment 4: 1st finished pool

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Master thesis, Iver Grytting	Busch, T.	Akademisk skriving for bachelor og masterstudenter	2014	Book	Fagbokforlaget	Academic writing, master thesis, phd	Providing structure and tips for writing academic articles	Aid for project report / master thesis writing
Guidance councilor	Alan Bryman	Social Research methods	2015	Book	Oxford University Press	Interviews, qualitative/quantitative, social scientific research	Guide for conducting scientific research on people	Aid for project report / master thesis writing
Compendex	Sacks, Rafael; Koskela, Lauri; Dave, Bhargav, A.; Owen, Robert	Interaction of lean and building information modeling in construction	2010	Scientific Paper	American Society of Civil Engineers	Lean construction, BIM	Comparing lean construction principles with BIM	BIM
Compendex	Oh, Minho; Lee, Jaewook; Hong, Seung Wan; Jeong, Yongwook	Integrated system for BIM-based collaborative design	2015	Scientific Paper	Elsevier	BIM integration, Collaborative design	Providing a framework for implemention BIM	BIM
Compendex	Tae-Song Shin	Building information modeling (BIM) collaboration from the structural engineering perspective	2017	Scientific Paper	Springer, Germany	interoperability, open standard BIM, structure model, asrchitecture model, construction model, work-process simulation	Study on interoperability between design actors in BIM	BIM
Master thesis, Iver Grytting	Eastman, C., Teicholz, P., Sacks, R. & Liston, K.	BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.	2011	Book	Hoboken: Wiley	BIM, collaboration, interoperability, implementation, practical advice	A general guide for users of BIM	BIM
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lædre, Jardar Lohne, and Geir K Hansen.	Design Management- Learning across trades	2016	Scientific Paper	Creating built environments of new opportunities	Design management, planning, coordination	Study on differences between AEC and offshore industries	Construction project management
Guidance councilor	Boyle, Griff.	Design project management	2003	Book	Aldershot: Ashgate.	Management, contracting	Guide to contracting and working with designers, and managing projects proactively through to successfull completion	Construction project management
Guidance councilor	Project management Institute	Project Management Body of Knowledge (PMBOK Guide) Fifth edition	2013	Book	Project management Institute	Project management	Establishing a common body of knowledge regarding project management	Construction project management
Guidance councilor	Uusitalo, Petteri; Olivieri, Hylton; Seppanen, Olli; Pikas, Ergo; Peltokorpi, Antti	Review of Lean Design Management: Processes, methods and technologies	2017	Scientific Paper	The International Group for Lean Construction	Lean design management, lean construction, Virtual design and construction, collaboration	Analysing design management attributes from Norway, Finland and the US	Lean construction
IGLC	Chachere, John, John Kunz, and Raymond Levitt.	Observation, Theory, and Simulation of Integrated Concurrent Engineering: Grounded Theoretical Factors that Enable Radical Project Acceleration	2004	Scientific Paper	CIFE - Center for Integrated Facility Engineering	Business processes, collaborative engineering, concurrent design, process models	A study on ICE - Integrated Concurrent Engineering in construction projects	Lean construction

Attachment 4: 1st finished pool

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
IGLC	Lauri Koskela, Glenn Ballard & Veli-Pekka Tanhuanpää	Towards Lean Design Management	1997	Scientific Paper	The International Group for Lean Construction	Design management, concurrent engineering, value management	A review of current thinking regarding conversion, flow and value in the AEC-industry	Lean construction
Compendex	Javier Freire & Luis F. Alarcon	Achieving a Lean Design Process	2000	Scientific Paper	The International Group for Lean Construction	Construction management	Proposing an improvement methodology for the design process in construction projects.	Lean construction
Compendex	Hooper, M.	Automated model progression scheduling using level of development	2015	Scientific Paper	Emerald, UK	LoD, BIM, Model progression	Describing use of LoD as a measure of progression in a design model	LoD
Compendex	Leite, Fernanda; Akcamete, Asli; Akinci, Burcu; Atasoy, Guzide; Kiziltas, Semiha	Analysis of modeling effort and impact of different levels of detail in building information models	2011	Scientific Paper	Elsevier	BIM, LoD	Evaluating impact of using LoD in different disciplines, and the modeling effort using LoD in AEC-projects	LoD
Guidance councilor	Treldal, N.; Vestergaard, F.; Karlshøj, J.	Pragmatic use of lod - a modular approach	2016	Scientific Paper	CRC Press/Balkema	BIM, LoD, different LoD concepts	Analysis of LoD and different LoD-concepts in AEC-projects	LoD
IGLC	Abou-Ibrahim, Hisham, and Farook Hamzeh	Enabling Lean Design Management: An LOD Based Framework.	2016	Article	Lean construction Journal	TFV, BIM, LoD	Relating LoD to TFV	LoD
Master thesis, Iver Grytting	Hisham Abou-Ibrahim & Farook Hamzeh	BIM: A TFV Perspective to Manage Design Using the LOD Concept	2016	Scientific Paper	The International Group for Lean Construction	TFV, BIM, LoD	Relating LoD to TFV	LoD
Compendex	Mejlwnder-Larsen, Oystein.	Generalising via the Case Studies and Adapting the Oil and Gas Industry's Project Execution Concepts to the Construction Industry.	2015	Scientific Paper	Procedia Economics and Finance	BIM, Case Study, Project execution model	To explore whether it is possible to generalise findings on project execution in the oil and gas industry related to the use of project execution models and a 3D design environment	Oil/gas - AEC
Compendex	Senthilkumar, V. ; Varghese, K.	Structured methodology to formulate drawing dependency structure matrix for construction design	2009	Article, Architectural Engineering and Design Management	Earthscan, UK	Construction design management, dependency structure matrix, interface managementq	Exploring the dependency structure matrix as a tool for construction design management	Process, flow and disciplines
Compendex	Wang, Li; Leite, Fernanda	Process Knowledge Capture in BIM-based Mechanical, Electrical, and plumbing Design Coordination Meetings	2016	Scientific Paper	American Society of Civil Engineers	BIM, Model-based design review	Uncover knowledge about the process of interactions between Mechanical, Electrical and Plumbing disciplines in AEC-projects	Process, flow and disciplines
Guidance councilor	Sigalov, Kateryna; Konig, Markus	Recognition of process patterns for BIM-based construction schedules	2017	Scientific Paper	Elsevier Ltd	Pattern recognition, process patterns, BIM	Pattern recognition in BIM-based project in the AEC-industry	Process, flow and disciplines

Attachment 4: 1st finished pool

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Guidance councilor	Kerosuo, Hannele.	BIM-based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking	2015	Scientific Paper	Procedia Economics and Finance	Active theory, BIM, disciplinary boundries, knotworking	Examine how the fragmentation of design and construction work could be reduced through knotworking in building projects.	Process, flow and disciplines
Master thesis, Iver Grytting	Malak Al Hattab & Farook Hamzeh	Modeling Design Workflow: Integrating Process and Organization	2016	Scientific Paper	The International Group for Lean Construction	Work flow, lean design managment, BIM	Integrate process, flow and social network in AEC-projects	Process, flow and disciplines
Master thesis, Iver Grytting	Nowak, P., Ksiqiek, M., Draps, M. & Zawistowski, J.	Decision Making with Use of Building Information Modeling.	2016	Scientific Paper	Procedia Engineering, 153	BIM, decision making	Presents possibilities of BIM techniques and relevant software for decision making optimization in construction	Process, flow and disciplines

Attachment 5: 2nd literature search - Compendex/IGLC

Search engine/ source	Search term(s) (Anywhere in article)	Search term(s) (Title)	Filters	# total hits	# relevant hits	Sorted by	Author(s)	Title	Year	Puplisher	Conclusions
Compendex	(transformation AND flow AND value) OR tfv		English, Journal article, Book chapter, Book,	11565	-	Relevance					Large amount of hits, reducing size
Compendex		(transformation AND flow AND value) OR tfv	English, Journal article, Book chapter, Book,	4	0	Relevance					No relevant hits
Compendex	((transformation AND flow AND value) OR tfv) AND koskela		English, Journal article, Book chapter, Book,	3	1	Relevance	New relevant literature:				
							Koskela, Lauri	An exploration towards a production theory and its application to construction	2000	Technical research center of Finland	Relevant for further study
Compendex		"construction management" AND "interdisciplinary"	English, Journal article, Book chapter, Book,	0	0	Relevance					Large amount of hits, reducing size
Compendex	"construction management" AND "interdisciplinary"		English, Journal article, Book chapter, Book,	34	-	Relevance					Small enough pool for inspection, removing duplicates
Compendex	"construction management" AND "interdisciplinary"		English, Journal article, Book chapter, Book,	30	1	Relevance	New relevant literature:				
							Zerjav, Vedran; Hartmann, Timo; Achammer, Christoph	Managing the process of interdisciplinary design: Identifying, enforcing, and anticipating decision-making frames	2013	Taylor and Francis Ltd.	Relevant for further study
Compendex	"construction design" AND "interdisciplinary"		English, Journal article, Book chapter, Book,	8	1	Relevance	New relevant literature:				
							C idik, M.S.; Boyd, D.; Thurairajah, N.	Innovative capability of Building Information Modeling in Construction Design	2017	American Society of Civil Engineers, USA	Relevant for further study
Compendex	"construction design" AND "interdisciplinary"		English, Journal article, Book chapter, Book,	2	0	Relevance					No relevant hits
Compendex	"construction design" AND "interdisciplinary"		English, Journal article, Book chapter, Book,	29	-	Relevance					Small enough pool for inspection, removing duplicates
Compendex	"construction design" AND "interdisciplinary"		English, Journal article, Book chapter, Book,	25	0	Relevance					Small enough pool for inspection, removing duplicates
Compendex	"construction management AND "collaborative engineering"		English, Journal article, Book chapter, Book,	2	1	Relevance	New relevant literature:				
							Stumpf, Annette, L.; Ganeshan, Rajam; Chin, Sangyoon; Liu, Liang, Y.	Object-oriented model for integrating construction product and process information	1996	American Society of Civil Engineers, USA	Relevant for further study
Compendex	"construction design AND "collaborative engineering"		English, Journal article, Book chapter, Book,	-	-	Relevance					No hits
Compendex	"construction design" AND discipline		English, Journal article, Book chapter, Book,	1	1	Relevance	New relevant literature:				
							Tiwari, S.; Gupta, A.	Constraint managment on distributed design configurations	1995	Department of Civil engineering, Stanford Uni, Stanford CA, USA	Relevant for further study
Compendex	"construction design" AND workflow		English, Journal article, Book chapter, Book,	4	1	Relevance	New relevant literature:				
							Li, Baizhan; Yang, Mingyu; Liu, Xiaodong, Liu Ling; Li, Dan	A workflow management system based-on construction project designing	2005	Faculty of Urban Construction and Environmental Engineering, Chonqing Uni, Chonqing, China	Relevant for further study
							Oloufa, Amr A.; Hosni, Yasser, A.; Fayez, Mohamed; Axelsson, Par	Using DSM for modeling information flow in construction design projects	2004	Department of Civil Engineering, Central Florida Uni, USA	Relevant for further study

Compendex	"construction design" AND (dependency structure matrix" OR dsm)		English, Journal article, Book chapter, Book,	5	0	Relevance					No relevant hits
Compendex	"construction design" AND (lod AND (maturity OR progression))		English, Journal article, Book chapter, Book,	8	0	Relevance					No relevant hits
Compendex	"construction design" AND (bim AND "model progression")		English, Journal article, Book chapter, Book,	1	0	Relevance					No relevant hits

Attachment 6: Acquired relevant literature

Acquired with	Author(s)	Title	Year	Publisher	Inclusion/exclusion based on Title/Abstract/Summary
Compendex, 2nd search	Koskela, Lauri	An exploration towards a production theory and its application to construction	2000	Technical research center of Finland	Construction-focus
Compendex, 2nd search	Zerjav, Vedran; Hartmann, Timo; Achammer, Christoph	Managing the process of interdisciplinary design: Identifying, enforcing, and anticipating decision-making frames	2013	Taylor and Francis Ltd.	
Compendex, 2nd search	C idik, M.S.; Boyd, D.; Thurairajah, N.	Innovative capability of Building Information Modeling in Construction Design	2017	American Society of Civil Engineers, USA	"innovative capability of the industry" not relevant
Compendex, 2nd search	Stumpf, Annette, L.; Ganeshan, Rajam; Chin, Sangyoon; Liu, Liang, Y.	Object-oriented model for integrating construction product and process information	1996	American Society of Civil Engineers, USA	Construction-focus
Compendex, 2nd search	Tiwari, S.; Gupta, A.	Constraint managment on distributed design configurations	1995	Department of Civil engineering, Stanford Uni, Stanford CA, USA	BIM-specified on areas outside of LoD
Compendex, 2nd search	Li, Baizhan; Yang, Mingyu; Liu, Xiaodong, Liu Ling; Li, Dan	A workflow management system based-on construction project designing	2005	Faculty of Urban Construction and Environmental Engineering, Chonqing Uni, Chonqing, China	
Compendex, 2nd search	Oloufa, Amr A.; Hosni, Yasser, A.; Fayez, Mohamed; Axelsson, Par	Using DSM for modeling information flow in construction design projects	2004	Department of Civil Engineering, Central Florida Uni, USA	

Attachment 7: Citation-chaining										
Acquired with/by	**Author(s)**	**Title**	**Year**	**Type of work**	**Puplisher**	**Keywords**	**Goals/ scope**	**Relevant field**	**# number of citations**	**Inclusion/ exclusion**
Decision Making with Use of Building Information Modeling	N/A	Current Economic Aspects of Geoinformation Modeling in Underground Development	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	0	(Deemed non-relevant)
Decision Making with Use of Building Information Modeling	N/A	Implementation of BIM-technologies in Russian construction industry according to the international experience	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	0	(Deemed non-relevant, lifecycle analysis)
Recognition of process patterns for BIM-based construction schedules	N/A	2015 edition of the Workshop of European Group for Intelligent Computing in Engineering (EG-ICE)	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	0	(Deemed non-relevant)
Structured methodology to formulate drawing dependency structure matrix for construction design	N/A	A web-based system for design interface management of construction projects	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	27	(Deemed non-relevant)
Structured methodology to formulate drawing dependency structure matrix for construction design	N/A	Use of design drivers, process mapping, & dsm to improve integration within an introductory BIM course	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	11	(Deemed non-relevant)
Structured methodology to formulate drawing dependency structure matrix for construction design	N/A	A Case Study based Testing of Design Interface Management System (diMs)	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	0	(Deemed non-relevant)
Structured methodology to formulate drawing dependency structure matrix for construction design	N/A	A Case Study based Testing of Design Interface Management System (diMs)	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	0	(Deemed non-relevant)
Structured methodology to formulate drawing dependency structure matrix for construction design	N/A	Formulating the application functional requirements of a BIM-based collaboration platform to support IPD projects	N/A	N/A	N/A	N/A	N/A	Process, flow and disciplines	1	(Deemed non-relevant)
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Tyson Browning	Design Structure Matrix Extensions and Innovations: A Survey and New Opportunities	2015	Article	Neeley School of Business, Texas Christian University, Fort Worth, United States	DSM, organization architecture, multidomain matrix	Surveys the DSM literature, primarily from archival journals, and organizes the developments pertaining to building, displaying, analyzing, and applying product, process, and organization DSMs.	Process, flow and disciplines	10	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Jeevan, Jacob; Koshy, Varghese	A Model for Product-Process Integration in the Building Industry Using Industry Foundation Classes and Design Structure Matrix	2012	Conferance Paper	Construction Research Congress 2012	Product-Process, DMS, product model	Emphasises need for DSM in AEC projects	Process, flow and disciplines	2	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Srour, Issam; Abdul-Malak, Mohamed-Asem U.; Yassine, Ali A.; Ramadan, Maysaa	A methodology for scheduling overlapped design activities based on dependency information	2013	Article		DSM, design activities	Presents a four-step process for scheduling the design phase of fast-tracked construction projects	Process, flow and disciplines	23	23 cited articles, following up, but will not document every citation in this sheet

Attachment 7: Citation-chaining

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	# number of citations	Inclusion/ exclusion
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Tyson Browning	Systems Architecting and Program Management with the Design Structure Matrix (DSM)	2013	Article	Neeley School of Business, Texas Christian University, Fort Worth, United States	DSM, BIM		Process, flow and disciplines	0	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Zhiliang Ma; Jiankun Ma	Formulating the application functional requirements of a BIM-based collaboration platform to support IPD projects	2017	Article	Tsinghua University, Department of Civil Engineering	DSM, BIM. IPD		Process, flow and disciplines	1	
Citation-chaining, from A methodology for scheduling overlapped design activities based on dependency information	Ballesteros-Pérez, P.	Modelling the boundaries of project fast-tracking	2017	Article	Automation in Construction, School of the Built Environment, University of Reading Whiteknights, Reading, United Kingdom	Fast-tracking, dependencies		Process, flow and disciplines	0	
Citation-chaining, from A methodology for scheduling overlapped design activities based on dependency information	Gálvez, E.D.; Ordieres, J.B.; Capuz-Rizo, S. F.	A method for identification of critical scheduling decisions	2017	Article	Journal of Modern Project Management	DSM, Monte Carlo simulation, Monte Carlo filtering	Presents a method for determining and controlling variables which are critical to the desired duration of a project.	Process, flow and disciplines	1	
Citation-chaining, from Automated model progression scheduling using level of development	Gigante-Barrera; Ruikar, D.; Crunden, M.; Ruikar, K.	Lod object content specification for manufacturers within the UK using the idm standard	2017	Article	Department of Civil Engineering, University of Birmingham, United Kingdom	Model View definition, BIM, LoD, Product data templates, IDM	Propose a generic industry approach to create and maintain model element product data at different LODs using the Information Delivery Manual (IDM)	LoD	0	
Citation-chaining, from Automated model progression scheduling using level of development	Abou-Ibrahim, Hisham, and Farook Hamzeh	Enabling Lean Design Management: An LOD Based Framework.	2016	Article	Lean construction Journal	TFV, BIM, LoD	Relating LoD to TFV	LoD	0	(Already in pool)
Citation-chaining, from Automated model progression scheduling using level of development	Hisham Abou-Ibrahim & Farook Hamzeh	BIM: A TFV Perspective to Manage Design Using the LOD Concept	2016	Scientific Paper	The International Group for Lean Construction	TFV, BIM, LoD	Relating LoD to TFV	LoD	0	(Already in pool)
Citation-chaining, from Enabling Lean Design Management: An LOD Based Framework.	Hisham Abou-Ibrahim & Farook Hamzeh	Design Management: Metrics and Visual Tools	2017	N/A	The International Group for Lean Construction	N/A	N/A	LoD	0	(Already deemed non-relevant and filtered out of previous pool)
Citation-chaining, from Interaction of lean and building information modeling in construction	María G Mandujano R; Claudio Mourgues; Luis F Alarcon; John Kunz	Modeling Virtual Design and Construction Implementation Strategies Considering Lean Management Impacts	2017	Article	Pontifical Catholic University of Chile	VDC, BIM, implementation	Presents a performance modeling methodology that allows companies to assess VDC implementation strategies	BIM	0	
Citation-chaining, from Interaction of lean and building information modeling in construction	Tauriainen, Matti; Marttinen, Pasi; Dave, Bhargav; Koskela, Lauri J.	The Effects of BIM and Lean Construction on Design Management Practices	N/A	N/A	N/A	N/A	N/A	BIM	0	(Already deemed non-relevant and filtered out of previous pool)
Citation-chaining, from Towards Lean Design Management	N/A	Enabling Lean Design Management: an LOD Based Framework	N/A	N/A	N/A	N/A	N/A	Lean construction	0	(Already in pool)
Citation-chaining, from Towards Lean Design Management	N/A	BIM: A TFV Perspective to Manage Design Using the LOD Concept	N/A	N/A	N/A	N/A	N/A	Lean construction	0	(Already in pool)

Attachment 7: Citation-chaining

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	# number of citations	Inclusion/ exclusion
Citation-chaining, from Towards Lean Design Management	Jonathan Lee, Wan-Yo Deng; Wen-Tin Lee; Shang-Pin Ma	Integrating Process and Work Breakdown Structure with Design Structure Matrix	2010	Article		Process, WBS, DSM	Proposing a systematic approach that supports bi-directional transformation between processes and the Work Breakdown Structure (WBS), the paper proposes Process2WBS and WBS2Process to assist project managers in project planning with an organization's set of standard processes	Process, flow and disciplines	0	
Citation-chaining, from Towards Lean Design Management	Paul Tilley	Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	2005	Article		Lean construction, design management, quality improvement	Investigates whether the way in which the design process is managed, may provide more immediate and easily measurable results for improving quality. Reviews the LDM approach to determine how new it really is and whether its implementation has the potential to achieve the design and documentation quality improvements required	Lean construction	0	
Citation-chaining, from Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	Effi Tribelsky; Rafael Sacks	An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures	2011	Article		Flow, multidisciplinary, construction design	Examining correlation between the degree of success achieved, in terms of design document effectiveness, meeting budget and schedule targets, and participant satisfaction, on the one hand, and the occurrence of information flow problems, on the other	Process, flow and disciplines	13	
Citation-chaining, from Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	Effi Tribelsky; Rafael Sacks	The relationship between information flow and project success in multi-disciplinary civil engineering design	2010	Article		Flow, multidisciplinary, construction design	Study on the presence or absence of bottlenecks, rework, large batches and long cycle times in design in AEC-projects	Process, flow and disciplines	4	
Citation-chaining, from An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures	Malak Al Hattab; Farook Hamzeh	A Process-Social Perspective for Understanding Design Information Flow	2017	Article		Process, flow, interaction between design teams	to present a formerly unexplored perspective that integrates both the process, i. e., flow of design information, and the social network, i.e., interactions among design teams.	Process, flow and disciplines	0	
Citation-chaining, from An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures	Malak Al Hattab; Farook Hamzeh	Modeling Design Workflow: Integrating Process and Organization	2016	Conferance Paper				Lean construction	0	(Already in pool)

Attachment 8: Snowballing data

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	# number of references	Inclusion/ exclusion
From reference list of Design Management-Learning across trades	Md. Aslam Hossain; D. K. H. Chua	Simulation-Based Model for Handling Iteration and Feedback Loop in Design	2009	Scientific paper	IGLC	Iteration, rework, simulation model		Process, flow and disciplines	11	
From reference list of Design Management-Learning across trades	Jerrard, B., & Hands, D	Design management: exploring fieldwork and applications	2008	Book	London: Routledge	Design management, organistion, case study	Description of how design management theory and it's practice can contribute to organisational success	Construction project management	-	
From reference list of Design Management-Learning across trades	Kalsaas, B. T., Finsådal, S., & Hasle, K.	To Achieve Predictability in Engineering	2014	Scientific paper	IGLC	Engineering control, predictability	How to achieve increased predictability in engineering. The research approach is constructive research. It is drawn on theoretical principles and ideas from Last Planner System	Construction project management	22	
From reference list of Design Management-Learning across trades	Knotten, V., Svalestuen, F., Aslesen, S., & Dammerud, H.	Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	2014	Scientific paper	IGLC	Design management, design process, reflective logic, complex process.	Evaluates the design process as a two dimensional logic, which to some degree happens at the same time - in different phases of the process. Sequential and reflective logic	Process, flow and disciplines	34	
From reference list of Simulation-Based Model for Handling Iteration and Feedback Loop in Design	Smith, R. P., and Eppinger, S. D.	A Predictive Model of Sequential Iteration in Engineering Design.	1997	Scientific paper	Management Science, 43	Product development, Engineering Design, Design iteration	Presents a model describing sequential iteration, one of the fundemental solution processes experienced in complex engineering design projects	Process, flow and disciplines	32	
From reference list of To Achieve Predictability in Engineering	Ballard, G.	Positive vs negative iteration in design	2000	Article	Proceedings for the Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK	Iteration, lean design, set-based design, value, value generation, value loss, waste	Contributes to the development of lean design by examining how waste can be reduced through elimination of negative iteration	Process, flow and disciplines	18	(previously considered not relevant, now included based on improved understanding of topic)
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Kunz, J., & Fischer, M.	Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions.	2009	Paper	CIFE	3-D, 4-D, Construction, Design, Organization Models, Process Models, Product Models, VDC, Virtual Design and Construction	Case study regarding effectiveness and implementation of BIM	BIM	38	(previously considered not relevant, now included based on improved understanding of topic)
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Moe, K., Westgaard, H., & Arge, K.	Prosjekteringsplanlegging og prosjekteringsledelse	2010		Rapport til byggekostnads programmet		An analysis of construction project design management in the Norwegian AEC-industry and the function of the design manager in said projects	Construction project management	-	
From reference list of A Predictive Model of Sequential Iteration in Engineering Design.	Gebala, David, A.; Eppinger, Steven D.	Methods for Analyzing Desing Procedures	1991	Article	ASME Design Theory and Methodology Conference, Miami, FL		Surveys several common models which can be used to represent and study design procedures	Construction project management	20	

Attachment 8: Snowballing data

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	# number of references	Inclusion/ exclusion
From reference list of Positive vs negative iteration in design	Ballard, Glenn	Improving Work Flow Reliability	1999	Article	Proceedings of the 7th Annual Conference of the International Group for Lean Construction, University of California, Berkeley, CA.	Capacity, decomposition, design process, explosion, flow, last planner, lean construction, load, productivity, project planning and control, reliability, throughput, variability.	A proposal is made for experiments to increase PPC	Process, flow and disciplines	8	
From reference list of Positive vs negative iteration in design	Ballard, Glenn	Can Pull Techniques Be Used In Design?	1999	Article	Proceedings of the Conference on Concurrent Engineering in Construction, Espoo, Finland, August 1999	Design, production control, pull, work flow	Can pull techniques be used in the management of design as well? Pull techniques are explained and obstacles to their application in design are reviewed. Benefits and preconditions of pulling are also presented. Concepts and techniques are proposed to overcome obstacles and satisfy preconditions for pulling. Future research is suggested in the application and testing of these concepts and techniques	Process, flow and disciplines	21	
-	-	Review of Lean Design Management: Processes, methods and technologies	-	-	-	-	-	-	24	
From reference list of Interaction of Lean and Building Information Modeling in Construction	Dave, B., Koskela, L., Kagioglou, M., and Bertelsen, S.	A critical look at integrating people, process and information technology within the construction industry.	2008	Conferance Paper	Proc., 16th Annual Conf. of the Int. Group for Lean Construction IGLC16	Construction process integration, ICT in construction, Construction efficiency		Process, flow and disciplines	41	
From reference list of Automated model progression scheduling using level of development	McPhee, A. , Lighthart, B. and Succar, B.	What is LOD, is it useful or just another pointless BIM deliverable?	2013	-	-	-	-	LoD	-	
From reference list of Automated model progression scheduling using level of development	Renehan, B.	Developing LOD (level of development)	2013	Blogpost	BIMFix Blog	LoD, Model progression, LoD specifications	Descriptions of different LoD models	LoD	-	
From reference list of Structured methodology to formulate drawing dependency structure matrix for construction design	Austin, S., Baldwin, A. and Newton, A.	A data flow model to plan and manage the building design process	1996	Article	Journal of Engineering Design, 7	Flow, construction design management	Describes a data flow model of the building design process that is subsequently analyzed in a design structure matrix	Process, flow and disciplines	28	
From reference list of Analysis of modeling effort and impact of different levels of detail in building information models	National Building Information Modeling Standard (NBIMS)	National Building Information Modeling Standard, Overview, Principles and Methodologies, Version 1.0 - Part 1	2007	Standard	National Building Information Modeling Standard (NBIMS)	BIM	An improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model	BIM	-	

Attachment 8: Snowballing data

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	# number of references	Inclusion/ exclusion
From reference list of Analysis of modeling effort and impact of different levels of detail in building information models	U.S. General Services Administration, Public Buildings Service, Office of the Chief Architect	Building Information Modeling Guide Series 1	2007	Standard	U.S. General Services Administration, Public Buildings Service, Office of the Chief Architect	BIM	-	BIM	-	

Attachment 9: All sources acquired during rework

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Compendex, 2nd search	Zerjav, Vedran; Hartmann, Timo; Achammer, Christoph	Managing the process of interdisciplinary design: Identifying, enforcing, and anticipating decision-making frames	2013	Scientific Paper	Taylor and Francis Ltd.	Interdisciplinary design, construction project management, decision-making	Exploration of managerial decision making in the interdisciplinary design process. To this end, the paper derives a theoretical framework, which posits that process-level design management is based on decision-making frames that set the context for design activity.	Process, flow and disciplines	
Compendex, 2nd search	Li, Baizhan; Yang, Mingyu; Liu, Xiaodong, Liu Ling; Li, Dan	A workflow management system based-on construction project designing	2005	Scientific Paper	Faculty of Urban Construction and Environmental Engineering, Chonqing Uni, Chonqing, China	DSM, coupled activity, information flow, CPM	DSM and CPM in AEC design management	Process, flow and disciplines	
Compendex, 2nd search	Oloufa, Amr A.; Hosni, Yasser, A.; Fayez, Mohamed; Axelsson, Par	Using DSM for modeling information flow in construction design projects	2004	Scientific Paper	Department of Civil Engineering, Central Florida Uni, USA	Workflow, BIM, monitoring	Establish a workflow management system for construction design project through the application of workflow technology	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Tyson Browning	Design Structure Matrix Extensions and Innovations: A Survey and New Opportunities	2015	Article	Neeley School of Business, Texas Christian University, Fort Worth, United States	DSM, organization architecture, multidomain matrix	Surveys the DSM literature, primarily from archival journals, and organizes the developments pertaining to building, displaying, analyzing, and applying product, process, and organization DSMs.	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Jeevan, Jacob; Koshy, Varghese	A Model for Product-Process Integration in the Building Industry Using Industry Foundation Classes and Design Structure Matrix	2012	Conferance Paper	Construction Research Congress 2012	Product-Process, DMS, product model	Emphasises need for DSM in AEC projects	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Srour, Issam; Abdul-Malak, Mohamed-Asem U.; Yassine, Ali A.; Ramadan, Maysaa	A methodology for scheduling overlapped design activities based on dependency information	2013	Article		DSM, design activities	Presents a four-step process for scheduling the design phase of fast-tracked construction projects	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Tyson Browning	Systems Architecting and Program Management with the Design Structure Matrix (DSM)	2013	Article	Neeley School of Business, Texas Christian University, Fort Worth, United States	DSM, BIM		Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Zhiliang Ma; Jiankun Ma	Formulating the application functional requirements of a BIM-based collaboration platform to support IPD projects	2017	Article	Tsinghua University, Department of Civil Engineering	DSM, BIM. IPD		Process, flow and disciplines	

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Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Citation-chaining, from A methodology for scheduling overlapped design activities based on dependency information	Ballesteros-Pérez, P.	Modelling the boundaries of project fast-tracking	2017	Article	Automation in Construction, School of the Built Environment, University of Reading Whiteknights, Reading, United Kingdom	Fast-tracking, dependencies		Process, flow and disciplines	
Citation-chaining, from A methodology for scheduling overlapped design activities based on dependency information	Gálvez, E.D.; Ordieres, J.B.; Capuz-Rizo, S. F.	A method for identification of critical scheduling decisions	2017	Article	Journal of Modern Project Management	DSM, Monte Carlo simulation, Monte Carlo filtering	Presents a method for determining and controlling variables which are critical to the desired duration of a project.	Process, flow and disciplines	
Citation-chaining, from Automated model progression scheduling using level of development	Gigante-Barrera; Ruikar, D.; Crunden, M.; Ruikar, K.	Lod object content specification for manufacturers within the UK using the idm standard	2017	Article	Department of Civil Engineering, University of Birmingham, United Kingdom	Model View definition, BIM, LoD, Product data templates, IDM	Propose a generic industry approach to create and maintain model element product data at different LODs using the Information Delivery Manual (IDM)	LoD	
Citation-chaining, from Interaction of lean and building information modeling in construction	María G Mandujano R; Claudio Mourgues; Luis F Alarcon; John Kunz	Modeling Virtual Design and Construction Implementation Strategies Considering Lean Management Impacts	2017	Article	Pontifical Catholic University of Chile	VDC, BIM, implementation	Presents a performance modeling methodology that allows companies to assess VDC implementation strategies	BIM	
Citation-chaining, from Towards Lean Design Management	Jonathan Lee, Wan-Yo Deng; Wen-Tin Lee; Shang-Pin Ma	Integrating Process and Work Breakdown Structure with Design Structure Matrix.	2010	Article		Process, WBS, DSM	Proposing a systematic approach that supports bi-directional transformation between processes and the Work Breakdown Structure (WBS), the paper proposes Process2WBS and WBS2Process to assist project managers in project planning with an organization's set of standard processes	Process, flow and disciplines	
Citation-chaining, from Towards Lean Design Management	Paul Tilley	Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	2005	Article		Lean construction, design management, quality improvement	Investigates whether the way in which the design process is managed, may provide more immediate and easily measurable results for improving quality. Reviews the LDM approach to determine how new it really is and whether its implementation has the potential to achieve the design and documentation quality improvements required	Lean construction	

Attachment 9: All sources acquired during rework

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Citation-chaining, from Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	Effi Tribelsky; Rafael Sacks	An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures	2011	Article		Flow, multidisciplinary, construction design	Examining correlation between the degree of success achieved, in terms of design document effectiveness, meeting budget and schedule targets, and participant satisfaction, on the one hand, and the occurrence of information flow problems, on the other	Process, flow and disciplines	
Citation-chaining, from Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	Effi Tribelsky; Rafael Sacks	The relationship between information flow and project success in multi-disciplinary civil engineering design	2010	Article		Flow, multidisciplinary, construction design	Study on the presence or absence of bottlenecks, rework, large batches and long cycle times in design in AEC-projects	Process, flow and disciplines	
Citation-chaining, from An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures	Malak Al Hattab; Farook Hamzeh	A Process-Social Perspective for Understanding Design Information Flow	2017	Article		Process, flow, interaction between design teams	to present a formerly unexplored perspective that integrates both the process, i. e., flow of design information, and the social network, i.e., interactions among design teams.	Process, flow and disciplines	
From reference list of Design Management-Learning across trades	Md. Aslam Hossain; D. K. H. Chua	Simulation-Based Model for Handling Iteration and Feedback Loop in Design	2009	Scientific paper	IGLC	Iteration, rework, simulation model		Process, flow and disciplines	
From reference list of Design Management-Learning across trades	Jerrard, B., & Hands, D	Design management: exploring fieldwork and applications	2008	Book	London: Routledge	Design management, organistion, case study	Description of how design management theory and it's practice can contribute to organisational success	Construction project management	
From reference list of Design Management-Learning across trades	Knotten, V., Svalestuen, F., Aslesen, S., & Dammerud, H.	Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	2014	Scientific paper	IGLC	Design management, design process, reflective logic, complex process.	Evaluates the design process as a two dimensional logic, which to some degree happens at the same time - in different phases of the process. Sequential and reflective logic	Process, flow and disciplines	
From reference list of Simulation-Based Model for Handling Iteration and Feedback Loop in Design	Smith, R. P., and Eppinger, S. D.	A Predictive Model of Sequential Iteration in Engineering Design.	1997	Scientific paper	Management Science, 43	Product development, Engineering Design, Design iteration	Presents a model describing sequential iteration, one of the fundemental solution processes experienced in complex engineering design projects	Process, flow and disciplines	
From reference list of To Achieve Predictability in Engineering	Ballard, G.	Positive vs negative iteration in design	2000	Article	Proceedings for the Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK	Iteration, lean design, set-based design, value, value generation, value loss, waste	Contributes to the development of lean design by examining how waste can be reduced through elimination of negative iteration	Process, flow and disciplines	

Attachment 9: All sources acquired during rework

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Kunz, J., & Fischer, M.	Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions.	2009	Paper	CIFE	3-D, 4-D, Construction, Design, Organization Models, Process Models, Product Models, VDC, Virtual Design and Construction	Case study regarding effectiveness and implementation of BIM	BIM	
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Moe, K., Westgaard, H., & Arge, K.	Prosjekteringsplanlegging og prosjekteringsledelse	2010		Rapport til byggekostnadsprogrammet		An analysis of construction project design management in the Norwegian AEC-industry and the function of the design manager in said projects	Construction project management	
From reference list of A Predictive Model of Sequential Iteration in Engineering Design.	Gebala, David, A.; Eppinger, Steven D.	Methods for Analyzing Desing Procedures	1991	Article	ASME Design Theory and Methodology Conference, Miami, FL		Surveys several common models which can be used to represent and study design procedures	Construction project management	
From reference list of Positive vs negative iteration in design	Ballard, Glenn	Can Pull Techniques Be Used In Design?	1999	Article	Proceedings of the Conference on Concurrent Engineering in Construction, Espoo, Finland, August 1999	Design, production control, pull, work flow	Can pull techniques be used in the management of design as well? Pull techniques are explained and obstacles to their application in design are reviewed. Benefits and preconditions of pulling are also presented. Concepts and techniques are proposed to overcome obstacles and satisfy preconditions for pulling. Future research is suggested in the application and testing of these concepts and techniques	Process, flow and disciplines	
From reference list of Automated model progression scheduling using level of development	Renehan, B.	Developing LOD (level of development)	2013	Blogpost	BIMFix Blog	LoD, Model progression, LoD specifications	Descriptions of different LoD models	LoD	
From reference list of Structured methodology to formulate drawing dependency structure matrix for construction design	Austin, S., Baldwin, A. and Newton, A.	A data flow model to plan and manage the building design process	1996	Article	Journal of Engineering Design, 7	Flow, construction design management	Describes a data flow model of the building design process that is subsequently analyzed in a design structure matrix	Process, flow and disciplines	
From reference list of Analysis of modeling effort and impact of different levels of detail in building information models	National Building Information Modeling Standard (NBIMS)	National Building Information Modeling Standard, Overview, Principles and Methodologies, Version 1.0 - Part 1	2007	Standard	National Building Information Modeling Standard (NBIMS)	BIM	An improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model	BIM	

Attachment 9: All sources acquired during rework

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
From reference list of Analysis of modeling effort and impact of different levels of detail in building information models	U.S. General Services Administration, Public Buildings Service, Office of the Chief Architect	Building Information Modeling Guide Series 1	2007	Standard	U.S. General Services Administration, Public Buildings Service, Office of the Chief Architect	BIM	-	BIM	

Attachment 10: 2nd pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Master thesis, Iver Grytting	Busch, T.	Akademisk skriving for bachelor og masterstudenter	2014	Book	Fagbokforlaget	Academic writing, master thesis, phd	Providing structure and tips for writing academic articles	Aid for project report / master thesis writing	
Guidance councilor	Alan Bryman	Social Research methods	2015	Book	Oxford University Press	Interviews, qualitative/quantitative, social scientific research	Guide for conducting scientific research on people	Aid for project report / master thesis writing	
Compendex	Sacks, Rafael; Koskela, Lauri; Dave, Bhargav, A.; Owen, Robert	Interaction of lean and building information modeling in construction	2010	Scientific Paper	American Society of Civil Engineers	Lean construction, BIM	Comparing lean construction principles with BIM	BIM	
Compendex	Oh, Minho; Lee, Jaewook; Hong, Seung Wan; Jeong, Yongwook	Integrated system for BIM-based collaborative design	2015	Scientific Paper	Elsevier	BIM integration, Collaborative design	Providing a framework for implemention BIM	BIM	
Compendex	Tae-Song Shin	Building information modeling (BIM) collaboration from the structural engineering perspective	2017	Scientific Paper	Springer, Germany	interoperability, open standard BIM, structure model, asrchitecture model, construction model, work-process simulation	Study on interoperability between design actors in BIM	BIM	
Master thesis, Iver Grytting	Eastman, C., Teicholz, P., Sacks, R. & Liston, K.	BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.	2011	Book	Hoboken: Wiley	BIM, collaboration, interoperability, implementation, practical advice	A general guide for users of BIM	BIM	
Citation-chaining, from Interaction of lean and building information modeling in construction	María G Mandujano R; Claudio Mourgues; Luis F Alarcon; John Kunz	Modeling Virtual Design and Construction Implementation Strategies Considering Lean Management Impacts	2017	Article	Pontifical Catholic University of Chile	VDC, BIM, implementation	Presents a performance modeling methodology that allows companies to assess VDC implementation strategies	BIM	
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Kunz, J., & Fischer, M.	Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions.	2009	Paper	CIFE	3-D, 4-D, Construction, Design, Organization Models, Process Models, Product Models, VDC, Virtual Design and Construction	Case study regarding effectiveness and implementation of BIM	BIM	
From reference list of Analysis of modeling effort and impact of different levels of detail in building information models	National Building Information Modeling Standard (NBIMS)	National Building Information Modeling Standard, Overview, Principles and Methodologies, Version 1.0 - Part 1	2007	Standard	National Building Information Modeling Standard (NBIMS)	BIM	An improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model	BIM	
From reference list of Analysis of modeling effort and impact of different levels of detail in building information models	U.S. General Services Administration, Public Buildings Service, Office of the Chief Architect	Building Information Modeling Guide Series 1	2007	Standard	U.S. General Services Administration, Public Buildings Service, Office of the Chief Architect	BIM	-	BIM	
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lædre, Jardar Lohne, and Geir K Hansen.	Design Management-Learning across trades	2016	Scientific Paper	Creating built environments of new opportunities	Design management, planning, coordination	Study on differences between AEC and offshore industries	Construction project management	

Attachment 10: 2nd pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Guidance councilor	Boyle, Griff.	Design project management	2003	Book	Aldershot: Ashgate.	Management, contracting	Guide to contracting and working with designers, and managing projects proactively through to successfull completion	Construction project management	
Guidance councilor	Project management Institute	Project Management Body of Knowledge (PMBOK Guide) Fifth edition	2013	Book	Project management Institute	Project management	Establishing a common body of knowledge regarding project management	Construction project management	
From reference list of Design Management- Learning across trades	Jerrard, B., & Hands, D	Design management: exploring fieldwork and applications	2008	Book	London: Routledge	Design management, organistion, case study	Description of how design management theory and it's practice can contribute to organisational success	Construction project management	
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Moe, K., Westgaard, H., & Arge, K.	Prosjekteringsplanlegging og prosjekteringsledelse	2010		Rapport til byggekostnadsprogrammet		An analysis of construction project design management in the Norwegian AEC-industry and the function of the design manager in said projects	Construction project management	
From reference list of A Predictive Model of Sequential Iteration in Engineering Design.	Gebala, David, A.; Eppinger, Steven D.	Methods for Analyzing Desing Procedures	1991	Article	ASME Design Theory and Methodology Conference, Miami, FL		Surveys several common models which can be used to represent and study design procedures	Construction project management	
Guidance councilor	Uusitalo, Petteri; Olivieri, Hylton; Seppanen, Olli; Pikas, Ergo; Peltokorpi, Antti	Review of Lean Design Management: Processes, methods and technologies	2017	Scientific Paper	The International Group for Lean Construction	Lean design management, lean construction, Virtual design and construction, collaboration	Analysing design management attributes from Norway, Finland and the US	Lean construction	
IGLC	Chachere, John, John Kunz, and Raymond Levitt.	Observation, Theory, and Simulation of Integrated Concurrent Engineering: Grounded Theoretical Factors that Enable Radical Project Acceleration	2004	Scientific Paper	CIFE - Center for Integrated Facility Engineering	Business processes, collaborative engineering, concurrent design, process models	A study on ICE - Integrated Concurrent Engineering in construction projects	Lean construction	
IGLC	Lauri Koskela, Glenn Ballard & Veli-Pekka Tanhuanpää	Towards Lean Design Management	1997	Scientific Paper	The International Group for Lean Construction	Design management, concurrent engineering, value management	A review of current thinking regarding conversion, flow and value in the AEC-industry	Lean construction	
Compendex	Javier Freire & Luis F. Alarcon	Achieving a Lean Design Process	2000	Scientific Paper	The International Group for Lean Construction	Construction management	Proposing an improvement methodology for the design process in construction projects.	Lean construction	

Attachment 10: 2nd pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Citation-chaining, from Towards Lean Design Management	Paul Tilley	Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	2005	Article		Lean construction, design management, quality improvement	Investigates whether the way in which the design process is managed, may provide more immediate and easily measurable results for improving quality. Reviews the LDM approach to determine how new it really is and whether its implementation has the potential to achieve the design and documentation quality improvements required	Lean construction	
Compendex	Hooper, M.	Automated model progression scheduling using level of development	2015	Scientific Paper	Emerald, UK	LoD, BIM, Model progression	Describing use of LoD as a measure of progression in a design model	LoD	
Compendex	Leite, Fernanda; Akcamete, Asli; Akinci, Burcu; Atasoy, Guzide; Kiziltas, Semiha	Analysis of modeling effort and impact of different levels of detail in building information models	2011	Scientific Paper	Elsevier	BIM, LoD	Evaluating impact of using LoD in different disciplines, and the modeling effort using LoD in AEC-projects	LoD	
Guidance councilor	Treldal, N.; Vestergaard, F.; Karlshøj, J.	Pragmatic use of lod - a modular approach	2016	Scientific Paper	CRC Press/Balkema	BIM, LoD, different LoD concepts	Analysis of LoD and different LoD-concepts in AEC-projects	LoD	
IGLC	Abou-Ibrahim, Hisham, and Farook Hamzeh	Enabling Lean Design Management: An LOD Based Framework.	2016	Article	Lean construction Journal	TFV, BIM, LoD	Relating LoD to TFV	LoD	
Master thesis, Iver Grytting	Hisham Abou-Ibrahim & Farook Hamzeh	BIM: A TFV Perspective to Manage Design Using the LOD Concept	2016	Scientific Paper	The International Group for Lean Construction	TFV, BIM, LoD	Relating LoD to TFV	LoD	
Citation-chaining, from Automated model progression scheduling using level of development	Gigante-Barrera; Ruikar, D.; Crunden, M.; Ruikar, K.	Lod object content specification for manufacturers within the UK using the idm standard	2017	Article	Department of Civil Engineering, University of Birmingham, United Kingdom	Model View definition, BIM, LoD, Product data templates, IDM	Propose a generic industry approach to create and maintain model element product data at different LODs using the Information Delivery Manual (IDM)	LoD	
From reference list of Automated model progression scheduling using level of development	Renehan, B.	Developing LOD (level of development)	2013	Blogpost	BIMFix Blog	LoD, Model progression, LoD specifications	Descriptions of different LoD models	LoD	
Compendex	Mejlwnder-Larsen, Oystein.	Generalising via the Case Studies and Adapting the Oil and Gas Industry's Project Execution Concepts to the Construction Industry.	2015	Scientific Paper	Procedia Economics and Finance	BIM, Case Study, Project execution model	To explore whether it is possible to generalise findings on project execution in the oil and gas industry related to the use of project execution models and a 3D design environment	Oil/gas - AEC	

Attachment 10: 2nd pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Compendex	Wang, Li; Leite, Fernanda	Process Knowledge Capture in BIM-based Mechanical, Electrical, and plumbing Design Coordination Meetings	2016	Scientific Paper	American Society of Civil Engineers	BIM, Model-based design review	Uncover knowledge about the process of interactions between Mechanical, Electrical and Plumbing disciplines in AEC-projects	Process, flow and disciplines	
Guidance councilor	Sigalov, Kateryna; Konig, Markus	Recognition of process patterns for BIM-based construction schedules	2017	Scientific Paper	Elsevier Ltd	Pattern recognition, process patterns, BIM	Pattern recognition in BIM-based project in the AEC-industry	Process, flow and disciplines	
Guidance councilor	Kerosuo, Hannele.	BIM-based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking	2015	Scientific Paper	Procedia Economics and Finance	Active theory, BIM, disciplinary boundries, knotworking	Examine how the fragmentation of design and construction work could be reduced through knotworking in building projects.	Process, flow and disciplines	
Master thesis, Iver Grytting	Malak Al Hattab & Farook Hamzeh	Modeling Design Workflow: Integrating Process and Organization	2016	Scientific Paper	The International Group for Lean Construction	Work flow, lean design managment, BIM	Integrate process, flow and social network in AEC-projects	Process, flow and disciplines	
Compendex, 2nd search	Zerjav, Vedran; Hartmann, Timo; Achammer, Christoph	Managing the process of interdisciplinary design: Identifying, enforcing, and anticipating decision-making frames	2013	Scientific Paper	Taylor and Francis Ltd.	Interdisciplinary design, construction project management, decision-making	Exploration of managerial decision making in the interdisciplinary design process. To this end, the paper derives a theoretical framework, which posits that process-level design management is based on decision-making frames that set the context for design activity.	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Jeevan, Jacob; Koshy, Varghese	A Model for Product-Process Integration in the Building Industry Using Industry Foundation Classes and Design Structure Matrix	2012	Conferance Paper	Construction Research Congress 2012	Product-Process, DMS, product model	Emphasises need for DSM in AEC projects	Process, flow and disciplines	
Citation-chaining, from Towards Lean Design Management	Jonathan Lee, Wan-Yo Deng; Wen-Tin Lee; Shang-Pin Ma	Integrating Process and Work Breakdown Structure with Design Structure Matrix.	2010	Article		Process, WBS, DSM	Proposing a systematic approach that supports bi-directional transformation between processes and the Work Breakdown Structure (WBS), the paper proposes Process2WBS and WBS2Process to assist project managers in project planning with an organization's set of standard processes	Process, flow and disciplines	
Citation-chaining, from Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	Effi Tribelsky; Rafael Sacks	The relationship between information flow and project success in multi-disciplinary civil engineering design	2010	Article		Flow, multidisciplinary , construction design	Study on the presence or absence of bottlenecks, rework, large batches and long cycle times in design in AEC-projects	Process, flow and disciplines	

Attachment 10: 2nd pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Citation-chaining, from An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures	Malak Al Hattab; Farook Hamzeh	A Process-Social Perspective for Understanding Design Information Flow	2017	Article		Process, flow, interaction between design teams	to present a formerly unexplored perspective that integrates both the process, i. e., flow of design information, and the social network, i.e., interactions among design teams.	Process, flow and disciplines	
From reference list of Design Management-Learning across trades	Md. Aslam Hossain; D. K. H. Chua	Simulation-Based Model for Handling Iteration and Feedback Loop in Design	2009	Scientific paper	IGLC	Iteration, rework, simulation model		Process, flow and disciplines	
From reference list of Design Management-Learning across trades	Knotten, V., Svalestuen, F., Aslesen, S., & Dammerud, H.	Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	2014	Scientific paper	IGLC	Design management, design process, reflective logic, complex process.	Evaluates the design process as a two dimensional logic, which to some degree happens at the same time - in different phases of the process. Sequential and reflective logic	Process, flow and disciplines	
From reference list of To Achieve Predictability in Engineering	Ballard, G.	Positive vs negative iteration in design	2000	Article	Proceedings for the Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK	Iteration, lean design, set-based design, value, value generation, value loss, waste	Contributes to the development of lean design by examining how waste can be reduced through elimination of negative iteration	Process, flow and disciplines	
From reference list of Positive vs negative iteration in design	Ballard, Glenn	Can Pull Techniques Be Used In Design?	1999	Article	Proceedings of the Conference on Concurrent Engineering in Construction, Espoo, Finland, August 1999	Design, production control, pull, work flow	Can pull techniques be used in the management of design as well? Pull techniques are explained and obstacles to their application in design are reviewed. Benefits and preconditions of pulling are also presented. Concepts and techniques are proposed to overcome obstacles and satisfy preconditions for pulling. Future research is suggested in the application and testing of these concepts and techniques	Process, flow and disciplines	
From reference list of Structured methodology to formulate drawing dependency structure matrix for construction design	Austin, S., Baldwin, A. and Newton, A.	A data flow model to plan and manage the building design process	1996	Article	Journal of Engineering Design, 7	Flow, construction design management	Describes a data flow model of the building design process that is subsequently analyzed in a design structure matrix	Process, flow and disciplines	
Compendex	Senthilkumar, V. ; Varghese, K.	Structured methodology to formulate drawing dependency structure matrix for construction design	2009	Article, Architectural Engineering and Design Management	Earthscan, UK	Construction design management, dependency structure matrix, interface managementq	Exploring the dependency structure matrix as a tool for construction design management	Process, flow and disciplines	

Attachment 10: 2nd pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
From reference list of Simulation-Based Model for Handling Iteration and Feedback Loop in Design	Smith, R. P., and Eppinger, S. D.	A Predictive Model of Sequential Iteration in Engineering Design.	1997	Scientific paper	Management Science, 43	Product development, Engineering Design, Design iteration	Presents a model describing sequential iteration, one of the fundemental solution processes experienced in complex engineering design projects	Process, flow and disciplines	
Citation-chaining, from Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	Effi Tribelsky; Rafael Sacks	An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures	2011	Article		Flow, multidisciplinary, construction design	Examining correlation between the degree of success achieved, in terms of design document effectiveness, meeting budget and schedule targets, and participant satisfaction, on the one hand, and the occurrence of information flow problems, on the other	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Srour, Issam; Abdul-Malak, Mohamed-Asem U.; Yassine, Ali A.; Ramadan, Maysaa	A methodology for scheduling overlapped design activities based on dependency information	2013	Article		DSM, design activities	Presents a four-step process for scheduling the design phase of fast-tracked construction projects	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Tyson Browning	Systems Architecting and Program Management with the Design Structure Matrix (DSM)	2013	Article	Neeley School of Business, Texas Christian University, Fort Worth, United States	DSM, BIM		Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Zhiliang Ma; Jiankun Ma	Formulating the application functional requirements of a BIM-based collaboration platform to support IPD projects	2017	Article	Tsinghua University, Department of Civil Engineering	DSM, BIM. IPD		Process, flow and disciplines	
Citation-chaining, from A methodology for scheduling overlapped design activities based on dependency information	Ballesteros-Pérez, P.	Modelling the boundaries of project fast-tracking	2017	Article	Automation in Construction, School of the Built Environment, University of Reading Whiteknights, Reading, United Kingdom	Fast-tracking, dependencies		Process, flow and disciplines	
Citation-chaining, from A methodology for scheduling overlapped design activities based on dependency information	Gálvez, E.D.; Ordieres, J.B.; Capuz-Rizo, S. F.	A method for identification of critical scheduling decisions	2017	Article	Journal of Modern Project Management	DSM, Monte Carlo simulation, Monte Carlo filtering	Presents a method for determining and controlling variables which are critical to the desired duration of a project.	Process, flow and disciplines	
Compendex, 2nd search	Li, Baizhan; Yang, Mingyu; Liu, Xiaodong, Liu Ling; Li, Dan	A workflow management system based-on construction project designing	2005	Scientific Paper	Faculty of Urban Construction and Environmental Engineering, Chonqing Uni, Chonqing, China	DSM, coupled activity, information flow, CPM	DSM and CPM in AEC design management	Process, flow and disciplines	

Attachment 10: 2nd pool charted

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field	Inclusion/ exclusion
Compendex, 2nd search	Oloufa, Amr A.; Hosni, Yasser, A.; Fayez, Mohamed; Axelsson, Par	Using DSM for modeling information flow in construction design projects	2004	Scientific Paper	Department of Civil Engineering, Central Florida Uni, USA	Workflow, BIM, monitoring	Establish a workflow management system for construction design project through the application of workflow technology	Process, flow and disciplines	
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Tyson Browning	Design Structure Matrix Extensions and Innovations: A Survey and New Opportunities	2015	Article	Neeley School of Business, Texas Christian University, Fort Worth, United States	DSM, organization architecture, multidomain matrix	Surveys the DSM literature, primarily from archival journals, and organizes the developments pertaining to building, displaying, analyzing, and applying product, process, and organization DSMs.	Process, flow and disciplines	
Master thesis, Iver Grytting	Nowak, P., Ksiqiek, M., Draps, M. & Zawistowski, J.	Decision Making with Use of Building Information Modeling.	2016	Scientific Paper	Procedia Engineering, 153	BIM, decision making	Presents possibilities of BIM techniques and relevant software for decision making optimization in construction	Process, flow and disciplines	

Attachment 11: 2nd final pool

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Master thesis, Iver Grytting	Busch, T.	Akademisk skriving for bachelor og masterstudenter	2014	Book	Fagbokforlaget	Academic writing, master thesis, phd	Providing structure and tips for writing academic articles	Aid for project report / master thesis writing
Guidance councilor	Alan Bryman	Social Research methods	2015	Book	Oxford University Press	Interviews, qualitative/quantitative, social scientific research	Guide for conducting scientific research on people	Aid for project report / master thesis writing
Compendex	Sacks, Rafael; Koskela, Lauri; Dave, Bhargav, A.; Owen, Robert	Interaction of lean and building information modeling in construction	2010	Scientific Paper	American Society of Civil Engineers	Lean construction, BIM	Comparing lean construction principles with BIM	BIM
Compendex	Tae-Song Shin	Building information modeling (BIM) collaboration from the structural engineering perspective	2017	Scientific Paper	Springer, Germany	interoperability, open standard BIM, structure model, architecture model, construction model, work-process simulation	Study on interoperability between design actors in BIM	BIM
Master thesis, Iver Grytting	Eastman, C., Teicholz, P., Sacks, R. & Liston, K.	BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.	2011	Book	Hoboken: Wiley	BIM, collaboration, interoperability, implementation, practical advice	A general guide for users of BIM	BIM
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Kunz, J., & Fischer, M.	Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions.	2009	Paper	CIFE	3-D, 4-D, Construction, Design, Organization Models, Process Models, Product Models, VDC, Virtual Design and Construction	Case study regarding effectiveness and implementation of BIM	BIM
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lædre, Jardar Lohne, and Geir K Hansen.	Design Management- Learning across trades	2016	Scientific Paper	Creating built environments of new opportunities	Design management, planning, coordination	Study on differences between AEC and offshore industries	Construction project management
Guidance councilor	Project management Institute	Project Management Body of Knowledge (PMBOK Guide) Fifth edition	2013	Book	Project management Institute	Project management	Establishing a common body of knowledge regarding project management	Construction project management
From reference list of Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	Moe, K., Westgaard, H., & Arge, K.	Prosjekteringsplanlegging og prosjekteringsledelse	2010		Rapport til byggekostnads programmet		An analysis of construction project design management in the Norwegian AEC-industry and the function of the design manager in said projects	Construction project management
Guidance councilor	Uusitalo, Petteri; Olivieri, Hylton; Seppanen, Olli; Pikas, Ergo; Peltokorpi, Antti	Review of Lean Design Management: Processes, methods and technologies	2017	Scientific Paper	The International Group for Lean Construction	Lean design management, lean construction, Virtual design and construction, collaboration	Analysing design management attributes from Norway, Finland and the US	Lean construction

Attachment 11: 2nd final pool

Acquired with/by	Author(s)	Title	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
IGLC	Lauri Koskela, Glenn Ballard & Veli-Pekka Tanhuanpää	Towards Lean Design Management	1997	Scientific Paper	The International Group for Lean Construction	Design management, concurrent engineering, value management	A review of current thinking regarding conversion, flow and value in the AEC-industry	Lean construction
Compendex	Javier Freire & Luis F. Alarcon	Achieving a Lean Design Process	2000	Scientific Paper	The International Group for Lean Construction	Construction management	Proposing an improvement methodology for the design process in construction projects.	Lean construction
Compendex	Hooper, M.	Automated model progression scheduling using level of development	2015	Scientific Paper	Emerald, UK	LoD, BIM, Model progression	Describing use of LoD as a measure of progression in a design model	LoD
Compendex	Leite, Fernanda; Akcamete, Asli; Akinci, Burcu; Atasoy, Guzide; Kiziltas, Semiha	Analysis of modeling effort and impact of different levels of detail in building information models	2011	Scientific Paper	Elsevier	BIM, LoD	Evaluating impact of using LoD in different disciplines, and the modeling effort using LoD in AEC-projects	LoD
IGLC	Abou-Ibrahim, Hisham, and Farook Hamzeh	Enabling Lean Design Management: An LOD Based Framework.	2016	Article	Lean construction Journal	TFV, BIM, LoD	Relating LoD to TFV	LoD
Master thesis, Iver Grytting	Hisham Abou-Ibrahim & Farook Hamzeh	BIM: A TFV Perspective to Manage Design Using the LOD Concept	2016	Scientific Paper	The International Group for Lean Construction	TFV, BIM, LoD	Relating LoD to TFV	LoD
From reference list of Automated model progression scheduling using level of development	Renehan, B.	Developing LOD (level of development)	2013	Blogpost	BIMFix Blog	LoD, Model progression, LoD specifications	Descriptions of different LoD models	LoD
Compendex	Mejlwnder-Larsen, Oystein.	Generalising via the Case Studies and Adapting the Oil and Gas Industry's Project Execution Concepts to the Construction Industry.	2015	Scientific Paper	Procedia Economics and Finance	BIM, Case Study, Project execution model	To explore whether it is possible to generalise findings on project execution in the oil and gas industry related to the use of project execution models and a 3D design environment	Oil/gas - AEC
Compendex	Wang, Li; Leite, Fernanda	Process Knowledge Capture in BIM-based Mechanical, Electrical, and plumbing Design Coordination Meetings	2016	Scientific Paper	American Society of Civil Engineers	BIM, Model-based design review	Uncover knowledge about the process of interactions between Mechanical, Electrical and Plumbing disciplines in AEC-projects	Process, flow and disciplines
Guidance councilor	Sigalov, Kateryna; Konig, Markus	Recognition of process patterns for BIM-based construction schedules	2017	Scientific Paper	Elsevier Ltd	Pattern recognition, process patterns, BIM	Pattern recognition in BIM-based project in the AEC-industry	Process, flow and disciplines

Attachment 11: 2nd final pool								
Acquired with/by	**Author(s)**	**Title**	**Year**	**Type of work**	**Puplisher**	**Keywords**	**Goals/ scope**	**Relevant field**
Guidance councilor	Kerosuo, Hannele.	BIM-based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking	2015	Scientific Paper	Procedia Economics and Finance	Active theory, BIM, disciplinary boundries, knotworking	Examine how the fragmentation of design and construction work could be reduced through knotworking in building projects.	Process, flow and disciplines
Master thesis, Iver Grytting	Malak Al Hattab & Farook Hamzeh	Modeling Design Workflow: Integrating Process and Organization	2016	Scientific Paper	The International Group for Lean Construction	Work flow, lean design managment, BIM	Integrate process, flow and social network in AEC-projects	Process, flow and disciplines
Citation-chaining, from Structured methodology to formulate drawing dependency structure matrix for construction design	Jeevan, Jacob; Koshy, Varghese	A Model for Product-Process Integration in the Building Industry Using Industry Foundation Classes and Design Structure Matrix	2012	Conferance Paper	Construction Research Congress 2012	Product-Process, DMS, product model	Emphasises need for DSM in AEC projects	Process, flow and disciplines
Citation-chaining, from Lean Design Management–A New Paradigm for Managing the Design and Documentation Process to Improve Quality	Effi Tribelsky; Rafael Sacks	The relationship between information flow and project success in multi-disciplinary civil engineering design	2010	Article		Flow, multidisciplinary, construction design	Study on the presence or absence of bottlenecks, rework, large batches and long cycle times in design in AEC-projects	Process, flow and disciplines
From reference list of Design Management-Learning across trades	Knotten, V., Svalestuen, F., Aslesen, S., & Dammerud, H.	Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway	2014	Scientific paper	IGLC	Design management, design process, reflective logic, complex process.	Evaluates the design process as a two dimensional logic, which to some degree happens at the same time - in different phases of the process. Sequential and reflective logic	Process, flow and disciplines
From reference list of To Achieve Predictability in Engineering	Ballard, G.	Positive vs negative iteration in design	2000	Article	Proceedings for the Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK	Iteration, lean design, set-based design, value, value generation, value loss, waste	Contributes to the development of lean design by examining how waste can be reduced through elimination of negative iteration	Process, flow and disciplines

Attachment 11: 2nd final pool								
Acquired with/by	**Author(s)**	**Title**	**Year**	**Type of work**	**Puplisher**	**Keywords**	**Goals/ scope**	**Relevant field**
From reference list of Positive vs negative iteration in design	Ballard, Glenn	Can Pull Techniques Be Used In Design?	1999	Article	Proceedings of the Conference on Concurrent Engineering in Construction, Espoo, Finland, August 1999	Design, production control, pull, work flow	Can pull techniques be used in the management of design as well? Pull techniques are explained and obstacles to their application in design are reviewed. Benefits and preconditions of pulling are also presented. Concepts and techniques are proposed to overcome obstacles and satisfy preconditions for pulling. Future research is suggested in the application and testing of these concepts and techniques	Process, flow and disciplines

Attachment 12: Evaluation of sources

"Akademisk skriving for bachelor og masterstudenter"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Master thesis, Iver Grytting	Busch, T.	2014	Book	Fagbokforlaget	Academic writing, master thesis, phd	Providing structure and tips for writing academic articles	Aid for project report / master thesis writing

About source:	Written by dr.oeacon (doctor of economics) and lecturer at NTNU Business School Tor Busch, "Academic writing for bachelor- and master students", adresses several important aspects regarding writing academic works at a university level, such as formulating sentences correctly and having a precise, logical overall structure.		
Evaluation:	**Credibility:**	3	The writer has excellent credibility within this field.
	Objectivity:	3	Although the author is involved with the field, alterior motives can be discarded.
	Accuracy:	2	Presents one view-point.
	Relevance:	3	A close intitution to the one correcting my paper, made with master thesis' in mind.
Overall assessment:		3	Credible and highly relevant

"Social Research methods"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Guidance councilor	Alan Bryman	2015	Book	Oxford University Press	Interviews, qualitative/quantitative, social scientific research	Guide for conducting scientific research on people	Aid for project report / master thesis writing

About source:	Written for students conducting social studies, "Social Research Methods" gives advice on developing research methods and acquire results effectively and accurately. The book goes into detail on many of these topics, among other things how to correctly conduct interviews without arriving at wrongful conclusions.		
Evaluation:	**Credibility:**	3	Author acclaimed for several published works withing social science and research.
	Objectivity:	3	Alterior motives can be discarded.
	Accuracy:	3	Author acclaimed for several published works withing social science and research.
	Relevance:	3	Highly relevant for interviews later on.
Overall assessment:		3	Highly credible and relevant

"Interaction of lean and building information modeling in construction"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Compendex	Sacks, Rafael; Koskela, Lauri; Dave, Bhargav, A.; Owen, Robert	2010	Scientific Paper	American Society of Civil Engineers	Lean construction, BIM	Comparing lean construction principles with BIM	BIM

About source:	Scientific paper written by several distinguished authors within the field of AEC project management. "Interaction of lean and building information modeling in construction" takes aim at uncovering whether or not technologies such as BIM make construction projects act more or less according to lean construction principles.		
Evaluation:	**Credibility:**	3	Author acclaimed for several published works withing social science and research.
	Objectivity:	3	Author acclaimed for several published works withing social science and research.
	Accuracy:	3	Several different sources and views are considered.
	Relevance:	3	Relevant in regards to bridging other LC-theory and BIM-theory together
Overall assessment:		3	Highly credible and relevant

"Building information modeling (BIM) collaboration from the structural engineering perspective"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field

Compendex	Tae-Song Shin	2017	Scientific Paper	Springer, Germany	interoperability, open standard BIM, work-process simulation	Study on interoperability between design actors in BIM	BIM
About source:	A study on interoperability between structural engineers in projects using BIM, analyzing how structural design members work together in order to present guidlines for use of BIM in order to maximize collaboration and work efficiency.						
Evaluation:	**Credibility:**	3	Author professor at Tong Myong Uni, cited over 10,000 times on researchgate.				
	Objectivity:	3	Author highly distinguished, no alterior motives				
	Accuracy:	2	Quite specific in focus, alterior sources not prevalent				
	Relevance:	2	Specified on BIM-processess not neccesarrily directly related to research questions				
Overall assessment:		2	Credible and relevant				

"BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors"							
Acquired with/by	**Author(s)**	**Year**	**Type of work**	**Puplisher**	**Keywords**	**Goals/ scope**	**Relevant field**
Master thesis, Iver Grytting	Eastman, C., Teicholz, P., Sacks, R. & Liston, K.	2011	Book	Hoboken: Wiley	BIM, collaboration, interoperability, implementation, practical advice	A general guide for users of BIM	BIM
About source:	Often cited by scientific paper with a focus on BIM, the "BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors" provides an excellent basis for fundemental knowledge regarding BIM practices, fundtions and applications.						
Evaluation:	**Credibility:**	3	Distinguished authors with previous works in relevant field and almost 5000 citations.				
	Objectivity:	3	Authors highly distinguished, no alterior motives				
	Accuracy:	3	Great body of work made by several distinguished authors.				
	Relevance:	3	Highly relevant				
Overall assessment:		3	Highly credible and relevant				

"Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions"							
Acquired with/by	**Author(s)**	**Year**	**Type of work**	**Puplisher**	**Keywords**	**Goals/ scope**	**Relevant field**
From reference list of "Integrated methodology for design [...]"	Kunz, J., & Fischer, M.	2009	Paper	CIFE	Process Models, Product Models, VDC, Virtual Design and Construction	Case study regarding effectiveness and implementation of BIM	BIM
About source:	Commonly regarded as some of the key originators of the original Lean Construction principles, Martin Fischer, John Kunz and CIFE (Center for Integrated Facility Engineering) presents a great body of work regarding VDC. Much like the BIM handbook, this Paper presents a good foundation to VPC and it's principles.						
Evaluation:	**Credibility:**	3	Distinguished authors and asscociated faculty				
	Objectivity:	3	Authors highly distinguished, no alterior motives				
	Accuracy:	3	Great body of work based on several case studies				
	Relevance:	3	Highly relevant				
Overall assessment:		3	Highly credible and relevant				

"Design Management- Learning across trades"							
Acquired with/by	**Author(s)**	**Year**	**Type of work**	**Puplisher**	**Keywords**	**Goals/ scope**	**Relevant field**
Guidance councilor	Knotten, Vegard, Fredrik Svalestuen, Ola Lædre, Jardar Lohne, and Geir K Hansen.	2016	Scientific Paper	Creating built environments of new opportunities	Design management, planning, coordination	Study on differences between AEC and offshore industries	Construction project management

About source:	Analysis on the AEC industry compared to offshore and shipbuilding industries, which are all largely project-based. This comparison is made in order to learn and possibly increase efficiency in AEC design management.

Evaluation:	**Credibility:**	3	All authors are from the institute of which the relevant project report will be written
	Objectivity:	3	All authors phd candidates or scientist at NTNU
	Accuracy:	3	Based on several case studies, multiple authors
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"Project Management Body of Knowledge (PMBOK Guide) Fifth edition"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Guidance councilor	Project management Institute	2013	Book	Project management Institute	Project management	Establishing a common body of knowledge regarding prj. management	Construction project management

About source:	In many ways, the "Project Management Body of Knowledge" is to project management theory what "Virtual Design and Construction" (Kunz, Fischer) and the "BIM Handbook" (Eastman et al.) aree to their respective fields, a great body of work outlining fundementals and basics regarding good project management practices.

Evaluation:	**Credibility:**	3	Institute highly regarded
	Objectivity:	3	Institute highly regarded
	Accuracy:	3	Based on several case studies
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"Prosjekteringsplanlegging og prosjekteringsledelse"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
From reference list of "Integrated methodology for design management[...]	Moe, K., Westgaard, H., & Arge, K.	2010	Scientific report	Rapport til byggekostnads programmet	Norwegian AEC-industry, design management, design manager	Analysis of construction project design management in the Norwegian AEC-industry	Construction project management

About source:	An analysis of construction project design management in the Norwegian AEC-industry and the function of the design manager in said projects. "Prosjekteringsplanlegging og prosjekteringsledelse" is a collaborative effort between government agencies and several proffesional industry actors.

Evaluation:	**Credibility:**	3	Gov.ment and industry professionals
	Objectivity:	3	Made with a genuine effort to improve efficiency in the Norwegian AEC-industry
	Accuracy:	3	Based on several case studies and made by severl industry profefsionals
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"Review of Lean Design Management: Processes, methods and technologies"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Guidance councilor	Uusitalo, Petteri; Olivieri, Hylton; Seppanen, Olli; Pikas, Ergo; Peltokorpi, Antti	2017	Scientific Paper	The International Group for Lean Construction	Lean design management, Virtual design and construction, collaboration	Analysing design management attributes from Norway, Finland and the US	Lean construction

About source:	An analysis on whether or not lean design managment practices are being implemented in ways that complement each other, based on literature review and case studies from Finland, Norway and the US.

Evaluation:	**Credibility:**	3	All authors professors, phd candidates or greater in relevant field.
	Objectivity:	3	Authors presumed professionally inclined, no alterior motives
	Accuracy:	3	Based on several case studies, multiple authors
	Relevance:	2	Implementation not the focus of the project work, still relevant
Overall assessment:		3	Relevant and highly credible

"Towards Lean Design Management"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
IGLC	Lauri Koskela, Glenn Ballard & Veli-Pekka Tanhuanpää	1997	Scientific Paper	The International Group for Lean Construction	Design management, concurrent engineering, value management	A review of current thinking regarding conversion, flow and value in the AEC-industry	Lean construction

About source: "Towards Lean Design Management" studies the optimal sequence of task in design management, how to identify- and stay on it, in addition to whether or not the resources required to do so is woth the investment.

Evaluation:	**Credibility:**	3	Highly distinguished authors within relevant field
	Objectivity:	3	Highly distinguished authors within relevant field
	Accuracy:	3	Multiple distinguished authors
	Relevance:	3	Potentially highly relatable to LoD
Overall assessment:		3	Highly credible and relevant

"Achieving a Lean Design Process"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Compendex	Javier Freire & Luis F. Alarcon	2000	Scientific Paper	The International Group for Lean Construction	Construction management	Proposing an improvement methodology for design in AEC-projects.	Lean construction

About source: Proposing an improvement methodology for the design process in construction projects based on Lean Production principles as conversion, flow and value.

Evaluation:	**Credibility:**	3	Highly distinguished authors within relevant field
	Objectivity:	3	Highly distinguished authors within relevant field
	Accuracy:	3	Multiple distinguished authors
	Relevance:	2	Potentially relevant
Overall assessment:		3	Relevant and highly credible

"Automated model progression scheduling using level of development"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Compendex	Hooper, M.	2015	Scientific Paper	Emerald, UK	LoD, BIM, Model progression	Describing use of LoD as a measure of progression in a design model	LoD

About source: "Automated model progression scheduling using level of development" is a scientific paper based on the application and use of LoD in AEC design projects, specifying how scheduling the model development can be utilized to increase design effectiveness.

Evaluation:	**Credibility:**	3	Author doctorate in construction engineering, Lund University
	Objectivity:	3	Author doctorate in construction engineering, Lund University
	Accuracy:	2	Literature-review and two smaller case studies
	Relevance:	3	Highly relevant

Overall assessment:	3	Highly credible and relevant

"Analysis of modeling effort and impact of different levels of detail in building information models"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Compendex	Leite, Fernanda; Akcamete, Asli; Akinci, Burcu; Atasoy, Guzide; Kiziltas, Semiha	2011	Scientific Paper	Elsevier	BIM, LoD	Evaluating impact of using LoD in different disciplines, and the modeling effort using LoD in AEC-projects	LoD

About source:	Scientific paper analyzing industry efforts in utilizing LoD, and what impact different LoD are used.

Evaluation:			
	Credibility:	3	Highly cited authors, highly cited article
	Objectivity:	3	Highly cited authors, highly cited article
	Accuracy:	3	Multiple distinguished authors
	Relevance:	3	Highly relevant

Overall assessment:	3	Highly credible and relevant

"Enabling Lean Design Management: An LOD Based Framework"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
IGLC	Abou-Ibrahim, Hisham, and Farook Hamzeh	2016	Article	Lean construction Journal	TFV, BIM, LoD	Relating LoD to TFV	LoD

About source:	Analyzing the application of LoD based on the lean production principles of Transformation, Flow and Value

Evaluation:			
	Credibility:	3	Made by a phd-candidate and phd doctorate, published by IGLC
	Objectivity:	3	Made by a phd-candidate and phd doctorate, published by IGLC
	Accuracy:	2	Purely literature study
	Relevance:	3	Highly relevant

Overall assessment:	3	Highly credible and relevant

"BIM: A TFV Perspective to Manage Design Using the LOD Concept"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Master thesis, Iver Grytting	Hisham Abou-Ibrahim & Farook Hamzeh	2016	Scientific Paper	The International Group for Lean Construction	TFV, BIM, LoD	Relating LoD to TFV	LoD

About source:	An extension of the work presented in "Enabling Lean Design Management: An LOD Based Framework."

Evaluation:			
	Credibility:	3	Made by a phd-candidate and phd doctorate, published by IGLC
	Objectivity:	3	Made by a phd-candidate and phd doctorate, published by IGLC
	Accuracy:	2	Purely literature study
	Relevance:	3	Highly relevant

Overall assessment:	3	Highly credible and relevant

"Developing LOD (level of development)"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field

From reference list of Automated model progression scheduling using level of development	Renehan, B.	2013	Blogpost	BIMFix Blog	LoD, Model progression, LoD specifications	Descriptions of different LoD models	LoD
About source:	Blogpost witha complete walkthrough of different LoD definitions and models.						
Evaluation:	**Credibility:**	2	Blog made by BIM researcher				
	Objectivity:	2	Blog made by BIM researcher				
	Accuracy:	2	Blog made by BIM researcher				
	Relevance:	3	Highly relevant				
Overall assessment:		2	Credible and highly relevant				

"Generalising via the Case Studies and Adapting the Oil and Gas Industry's Project Execution Concepts to the Construction Industry."

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Compendex	Mejlænder-Larsen, Øystein	2015	Scientific Paper	Procedia Economics and Finance	BIM, Case Study, Project execution model	Comparison of 3D CAD in AEC and Oil projects	Oil/gas - AEC
About source:	An exploration on whether it is possible to generalise findings on project execution in the oil and gas industry related to the use of project execution models and a 3D design environment						
Evaluation:	**Credibility:**	3	Author research doctorate from NTNU				
	Objectivity:	2	One-man study in field the author has previous experience from working in				
	Accuracy:	2	One-man study in field the author has previous experience from working in				
	Relevance:	3	Highly relevant				
Overall assessment:		3	Credible and highly relevant				

"Process Knowledge Capture in BIM-based Mechanical, Electrical, and plumbing Design Coordination Meetings"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Compendex	Wang, Li; Leite, Fernanda	2016	Scientific Paper	American Society of Civil Engineers	BIM, Model-based design review	Examination of different design diciplines in AEC design projects	Process, flow and disciplines
About source:	Scientific paper with the intent of uncovering knowledge about the process of interactions between Mechanical, Electrical and Plumbing disciplines in AEC-projects						
Evaluation:	**Credibility:**	3	Made by two research doctorates in construction engineering				
	Objectivity:	3	Made by two research doctorates in construction engineering				
	Accuracy:	2	Literature review				
	Relevance:	3	Highly relevant				
Overall assessment:		3	Credible and highly relevant				

"Recognition of process patterns for BIM-based construction schedules"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Guidance councilor	Sigalov, Kateryna; Konig, Markus	2017	Scientific Paper	Elsevier Ltd	Pattern recognition, process patterns, BIM	Pattern recognition in BIM-based project in the AEC-industry	Process, flow and disciplines
About	"Recognition of process patterns for BIM-based construction schedules" presents an overall concept for porcess pattern						

About source:	"Recognition of process patterns for BIM-based construction schedules" presents an overall concept for porcess pattern recognitionin BIM-based construction by applying graph-based methods. Focuses on the estimation of similarity in construction schedules, describing feature-based methods and similarity measure definitions in detail.

Evaluation:	**Credibility:**	3	One author being a research doctorate and the other being a master of science
	Objectivity:	3	One author being a research doctorate and the other being a master of science
	Accuracy:	3	Great amount of data processed, objective methodology
	Relevance:	2	Relevant to research questions
Overall assessment:		3	Credible and relevant

"BIM-based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Guidance councilor	Kerosuo, Hannele.	2015	Scientific Paper	Procedia Economics and Finance	Active theory, BIM, disciplinary boundries, knotworking	Study on fragmentation of design groups in AEC-projects	Process, flow and disciplines

About source:	Scientific paper examining how the fragmentation of design and construction work could be reduced through knotworking in building projects.

Evaluation:	**Credibility:**	3	Author a doctorate of organizational psycology, cited over 700 times on researchgate
	Objectivity:	3	Author a doctorate of organizational psycology, objective methodology
	Accuracy:	2	One author, literature study
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"Modeling Design Workflow: Integrating Process and Organization"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Master thesis, Iver Grytting	Malak Al Hattab & Farook Hamzeh	2016	Scientific Paper	The International Group for Lean Construction	Work flow, lean design managment, BIM	Integrate process, flow and social network in AEC-projects	Process, flow and disciplines

About source:	Scientific paper approaching design workflow from a perspective of process, flow, human-interface and -networks.

Evaluation:	**Credibility:**	3	Made by two research doctorates in construction engineering
	Objectivity:	3	Made by two research doctorates in construction engineering
	Accuracy:	2	Literature study
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"A Model for Product-Process Integration in the Building Industry Using Industry Foundation Classes and Design Structure Matrix"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Citation-chaining, from Structured methodology[...]	Jeevan, Jacob; Koshy, Varghese	2012	Conferance Paper	Construction Research Congress 2012	Product-Process, DMS, product model	Emphasises need for DSM in AEC projects	Process, flow and disciplines

About source:	A study on integrating the design process in the product model during construction design. In practical terms, the paper presents a pilot study, where the integration of DSM (process) into BIM (product model) has been used.

Evaluation:	**Credibility:**	3	Made by two research doctorates in AEC, 670+ citations together
	Objectivity:	3	Distinguished authors, peer-reviewed
	Accuracy:	3	Distinguished authors, peer-reviewed

	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"The relationship between information flow and project success in multi-disciplinary civil engineering design"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
Citation-chaining, from Lean Design Management–A New [...]	Effi Tribelsky; Rafael Sacks	2010	Article		Flow, multidisciplinary, construction design	How does bottlenecks, rework etc. affect teamwork in AEC-projects	Process, flow and disciplines

About source:	Study on the presence or absence of bottlenecks, rework, large batches and long cycle times in design in AEC-projects.

Evaluation:	**Credibility:**	3	Highly distinguished authors (6800+ citations)
	Objectivity:	3	Distinguished authors, peer-reviewed
	Accuracy:	3	Distinguished authors, peer-reviewed
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"Integrated methodology for design management - a research project to improve design management for the AEC industry in Norway"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
From reference list of Design Management-Learning across trades	Knotten, V., Svalestuen, F., Aslesen, S., & Dammerud, H.	2014	Scientific paper	IGLC	Design management, design process, reflective logic, complex process.	Studying different types of interactions between designing actors in AEC-projects	Process, flow and disciplines

About source:	Evaluates the design process as a two dimensional logic, which to some degree happens at the same time in different phases of the process. The concepts of sequential and reflective logic are explored.

Evaluation:	**Credibility:**	3	All authors are from the institute of which the relevant project report will be written
	Objectivity:	3	All authors phd candidates or scientist at NTNU
	Accuracy:	3	Based on several case studies, multiple authors
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"Positive vs negative iteration in design"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
From reference list of To Achieve Predictability in Engineering	Ballard, G.	2000	Article	Proceedings for the Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK	Iteration, lean design, set-based design, value, value generation, value loss, waste	A study on iterations in design management and how they can be understood in order to reduce waste	Process, flow and disciplines

About source:	Contributes to the development of lean design by examining how waste can be reduced through elimination of negative iterations of tasks in AEC design projects.

Evaluation:	**Credibility:**	3	Highly distinguished author
	Objectivity:	3	Highly distinguished author
	Accuracy:	2	Literature study, one author

	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

"Can Pull Techniques Be Used In Design Management?"

Acquired with/by	Author(s)	Year	Type of work	Puplisher	Keywords	Goals/ scope	Relevant field
From reference list of Positive vs negative iteration in design	Ballard, Glenn	1999	Article	Proceedings of the Conference on Concurrent Engineering in Construction, Espoo, Finland, August 1999	Design, production control, pull, work flow	Can pull techniques be used in the management of design as well?	Process, flow and disciplines

About source:	Pull techniques are explained and obstacles to their application in design are reviewed. Benefits and preconditions of pulling are also presented. Concepts and techniques are proposed to overcome obstacles and satisfy preconditions for pulling. Future research is suggested in the application and testing of these concepts and techniques.

Evaluation:	**Credibility:**	3	Highly distinguished author
	Objectivity:	3	Highly distinguished author
	Accuracy:	2	Literature study, one author
	Relevance:	3	Highly relevant
Overall assessment:		3	Highly credible and relevant

Praktisk info

Introduksjon

Andreas Nøklebye, 23 år fra Oslo. Skriver prosjekt- og masteroppgave i Bygg og Anlegg på NTNU, fordypning prosjektledelse. Foreløpig tittel prosjektoppgave "Lean prosjektering gjennom modenhetsstyrt planlegging og kontroll". Oppgaven har som mål å resultere i en vitenskapelig artikkel skrevet sammen med Skanska Norge (Roar Fosse) og Veidekke Entreprenør (Fredrik Svalestuen). Har tidligere ett års erfaring som RIB i WSP Engineering (tidl. Høyer Finseth).

Bakgrunn for studiet

BIM blir i økende grad brukt i byggeindustrien, men tross fremgang er prosjektering preget av liten grad struktur og kontroll. Styring av modenhet er identifisert som en mulig løsning på å beskrive arbeid og leveranser i prosjektering, slik at prosjekteringsprosessen blir enklere å planlegge og kontrollere.

Forskningsspørsmål

1. Hva er nåværende tilnærminger til modenhets-styring av prosjektering?
2. Hvilke erfaringer har man fra modenhets-styring av prosjektering?
3. Hvordan bør prosjektering bli styrt i henhold til modenhet?

Praktisk info

For å sikre nøyaktighet og etterprøvbarhet vil intervju bli tatt opp og transkribert dersom dette er i orden for deltaker. Ferdig transkript vil bli sendt til deltaker for godkjennelse før publisering av resultatene.

Intervjuet er semistrukturert og vil kun benytte seg av malen som en rød tråd, det er ikke nødvendig å treffe alle spørsmål gitt her så lenge intervjuer føler at problemstilling er besvart.

LOD blir brukt her som modenhetsgrad til modell, på lik linje med MMI.

Deltakers bakgrunn

- Hvor mye erfaring har du med BIM?
- Hvilken rolle har du i hatt prosjektering?
- Hvilken rolle innehaver ditt selskap i byggeprosessen?
- Hvilke kontraktsstrategier har blitt brukt i prosjektene du har vært involvert i?

Spørsmålsrunde

Hva er nåværende tilnærminger til modenhets-styring av prosjektering?

- Hvordan blir prosjektering planlagt?
  1) *Hvilke generiske faser går prosjekteringen typisk gjennom?*
  2) *Hvem lager planene?*
  3) *Hvilke planleggingsverktøy brukes?*
  4) *Hvor mange milepæler inngår i en typisk prosjekteringsplan?*
  5) *Hvor mange leveranser brukes til å beskrive hendelsesforløpet i plan?*
  6) *Ligger fokus i planlegging på arbeid som skal utføres eller ressurser tilgjengelig?*

- Hvordan kontrolleres fremgang mot etablert plan?
  1) *Hvor ofte blir fremdrift kontrollert mot plan?*
  2) *Hvilke hjelpemidler/indikatorer brukes for å kontrollere fremgang?*
  3) *Hvilke tiltak er vanlige å utføre dersom et prosjekt faller bak plan?*

- Hvordan benyttes BIM i prosjektering?
  1) *Hvilke funksjoner ved BIM kan brukes til planlegging?*
  2) *Hvor stor andel av arbeidet under prosjekteringen gjøres gjennom BIM?*
  3) *Hvordan benyttes BIM til å kontrollere fremdrift?*
  4) *Brukes BIM som et sidestilt verktøy eller en sentral plattform under prosjektering?*

- Hvordan brukes modenhetsgrad av prosjektmodell i planlegging?
  1) *Hva er LOD? Hva var hensikten med å utvikle MMI-systemet?*
  2) *Hvilke krav settes til forskjellige LOD-nivåer (detaljgrad, mengde informasjon, gjøremål)?*
  3) *Indikerer LOD modenhet til individuelle objekter eller hele seksjoner av BIM-modellen?*
  4) *Hvordan blir ulike fag fulgt opp/organisert under prosjektering?*
  5) *Hvordan loggføres LOD?*
  6) *Hvem har ansvaret for å erklære deler av modellen for et LOD-nivå?*

Hvilke erfaringer har man fra modenhets-styring av prosjektering?

- Hvor godt blir prosjektering planlagt i dag?
    1) *Hvordan er erfaringene med bruk av generiske faser i prosjektering?*
    2) *Hvor stor vekt blir lagt på å tydelig kommunisere plan til prosjekterende aktører?*
    3) *Hva kan gjøre det vanskelig å planlegge prosjektering?*
    4) *Hvor ofte samsvarer planer med virkelig prosjektering?*
    5) *Hvor ofte blir milepæler overskredet?*
    6) *I hvilke stadier av prosjekteringen blir milepæler overskredet?*
    7) *Hvilke disipliner er typisk utsatt for overskridelse av milepæler?*

- Hvor godt blir fremgang kontrollert mot etablert plan?
    1) *I hvilken grad følger vanligvis prosjektering etablert plan?*
    2) *Hvilke tiltak iverksettes dersom progresjon ikke holdes?*
    3) *Hvor viktig er det for prosjektledelsen at prosjektering følger plan?*
    4) *Hvilke utfordringer finnes ved å måle fremgang mot etablert plan?*
    5) *Oppleves det ofte variasjon i tidsbruk på relativt like oppgaver mellom prosjekter?*
    6) *Hvor stor andel av produsert prosjekteringsarbeid må revideres?*

- Hvilke erfaringer har man fra bruk av BIM i prosjektering?
    1) *Er BIM og dets funksjoner fullstendig realisert/integrert i byggeprosjekter i dag?*
    2) *Hvilke egenskaper med BIM er ikke realisert i byggeprosjekter i dag?*
    3) *Hvilke utfordringer finnes ved implementering av BIM i dagens byggeprosjekter?*

- Hvilke erfaringer har man fra bruk av modenhet i BIM-modell?
    1) *Er kravene til hver LOD-leveranse tydelige for alle prosjekterende?*
    2) *Har prosjekterende ofte en god forståelse for hva de skal levere?*
    3) *Er hendelsesforløpet av LOD-leveranser tydelig for alle prosjekterende?*
    4) *Hvor suksessfull har tidligere forsøk på implementering av LOD vært?*
    5) *Oppleves loggføringen av LOD som unødvendig ressurskrevende?*
    6) *Har bruk av LOD ført til en opplevd forbedring i arbeidsflyt?*
    7) *Til hvilken grad blir LOD brukt som et kommunikasjonsverktøy?*

Hvordan bør prosjektering bli styrt i henhold til modenhet?

- Hvordan kan prosjektering planlegges bedre?
  1) *Bør planlegging skje med flere eller færre aktører?*
  2) *Er bruk av faser relevant i sammenheng med prosjektering?*
  3) *Hva er de vanligste grunnene til at prosjekter ikke følger plan?*
  4) *Hvorfor blir ikke prosjektering planlagt til en større grad enn den gjøres i dag?*
  5) *Hvorfor blir milepæler overskredet?*

- Hvordan kan framgang i prosjektering kontrolleres bedre?
  1) *Hvordan kan prosjekt-fremgang tydeliggjøres bedre for involverte aktører?*
  2) *Hva er vanlige årsaker til avvik fra plan?*
  3) *Hva er vanlige årsaker til at arbeid må revideres?*
  4) *Hvordan kan variasjon i varighet på leveranser reduseres?*

- Hvordan kan bruk av BIM forbedres?
  1) *Hva står ofte til hinder for utvidet bruk av BIM?*
  2) *Hvilken rolle burde BIM ha i et byggeprosjekt?*
  3) *Hvilket potensiale i BIM har man igjen å realisere?*

- Hvordan bør modenhet av modell brukes i prosjektering?
  1) *Hva bør inngå i krav til en LOD-leveranse?*
  2) *Hvordan kan bruk- og definisjoner av LOD tydeliggjøres for alle prosjekterende?*
  3) *Bør LOD føres per objekt eller seksjon av BIM-modellen?*
  4) *Hvordan bør fag bli fulgt opp og kontrollert?*
  5) *Hvordan bør LOD-nivå loggføres?*
  6) *Hvem bør stå ansvarlig for å erklære LOD-nivåer for ulike deler av modellen?*
  7) *Hvordan kan man oppnå en suksessfull implementering av LOD?*
  8) *Bør LOD bli betraktet som en status til BIM-modell eller et kommunikasjonsverktøy?*

Oppsummering

- (Oppsummering av tidligere svar) Har jeg/vi forstått deg riktig?
- Er det noe du føler er relevant som du vil legge til?
- Er det greit at jeg/vi tar kontakt igjen dersom vi skulle komme på noe mer?

Takk for at du kunne delta, et transkript vil bli sendt til deg for godkjenning så snart intervju er transkribert.