Haakon Skar

Industry 4.0: Potential Effects and Implementation

Master's thesis in Civil and Environmental Engineering
Supervisor: Ole Jonny Klakegg
May 2019

Master's thesis

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

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Kunnskap for en bedre verden

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Preface

This work was conducted in the spring of 2019 as a Master's Thesis at the Norwegian University of Science and Technology (NTNU). This project accounts for 30 credits as a part of the course TBA4910 - Project Management - Master's Thesis. The aim of the course is to develop abilities to conduct scientific research regarding a topic within the construction field, with an analytical methodical approach. The course is part of the Civil Engineering program at the Department of Civil and Environmental Engineering, NTNU.

Summary

Purpose - The industrialized construction industry is facing an ever evolving complexity and a growing customer demand. Innovative industries within the automotive and mechanical engineering sector have managed to integrate new technologies, whereas the industrialized construction industry to a lesser degree has succeeded with this. To enhance better performance for logistics in industrialized construction, a review of innovative technologies in the industry was conducted. A presentation of the potential benefits and how the innovative technologies are implemented could illustrate the plus side of implementation, and create a change of mindset in the conservative construction industry.

Methodology - The research is conducted with literature reviews of material related to existing solutions in industrialized construction logistics, the current "state of the art" and practice, combined with interviews with industry pioneers. Information gathered in the literature review was obtained through key word searches in acknowledged search engines and filtered by inclusion criteria. Interviews have been done semi structured mostly face to face, but also on phone.

Scope and Limitations - The focus in this thesis is on enhancement of logistics within the industrialized construction process. Industrialized construction is modern systemized methods of design, production, planning and control as well as mechanized and automated manufacturing, also known as Industry 4.0. Based on literature reviews, nine technologies with potential benefits for the logistic process in industrialized construction were selected. Potential of these nine innovative technologies and how to maintain the potential through an implementation processes is the basis for the research questions asked. Interviews have been conducted with representatives from a large Norwegian based construction firm, Veidekke. Experience and results are taken from recent projects with a special focus on innovation within Veidekke.

Results and Implications - Applications and benefits of central technologies already that have reached market maturity e.g. BIM, cloud computing and Big Data with as well as innovative technologies with low market maturity and huge potential like e.g. Additive Manufacturing, AR and IoT are presented. The technologies are found to be interlinked, and a coherent application of the different tools instrumental to optimize the illustrated benefits that innovation brings. Moreover, these technologies have different maturity levels, some are used daily, while others just influence the industry too some degree. The industrialized construction industry has not yet fully embraced all of these opportunities, and a change in mindset and investment strategies must take place to further enhance the development. However, the main dependencies related to training, competence, investments, coherence, collaboration and mindset prevail. The best way to implement innovative technologies seems to be by development of a long-term strategic plan for implementation including a thorough investigation of evaluation, preparation and commitment phases. More publications and future research specific data of improvement are referred as important factors to change of mindsets in the industry for a commitment to transformation.

Sammendrag

Hensikt - Industrialisert byggeindustri møter stadig mer komplekse og krevende krav fra kunder. Innovative industrier som bilindustrien og mekaniske prosessindustrier har klart å integrere nye teknologier, som den industrialiserte byggeindustrien ikke har. For å forbedre logistikk innen industrialisert byggeindustri er undersøkelser, presentasjon av potensielle fordeler ved innovative teknologier og hvordan disse blir implementert presentert. Dette kan illustrere viktigheten ved implementering av ny teknologi og skape en holdningsendring i en ellers konservativ byggenæring.

Metode - Arbeidet er utført gjennom litteratursøk av eksisterende løsninger i industrialisert bygningslogistikk, nåværende "state of the art" samt intervjuer med pionerer innen bransjen. Litteratursøket har blitt gjennomført via søk med nøkkelord i anerkjente søkemotorer, som igjen ble filtrert gjennom inkluderingskriteria. Intervjuer ble gjennomført semi-strukturert, ansikt til ansikt og via telefon.

Mål og begrensinger - Fokuset i rapporten er på logistikk i en industrialisert bygningsprosess. Industrialisert bygging skiller seg fra "vanlig" bygging, ved å ta i bruk moderne systematiserte metoder ved design, produksjon, planlegging og kontrollering. Dette er også kjent som "Industry 4.0". Ni teknologier med potensiale for forbedring av logistikkprosessene innen industrialisert bygging ble funnet gjennom litteratursøk. De potensielle effektene og hvordan bevare disse gjennom en implementeringsprosess er grunnlaget for forskningsspørsmålene. Intervjuer har blitt gjennomført med representanter fra et norsk entreprenørfirma, Veidekke. Erfaringer og resultater som er presentert er tatt fra nylige prosjekter i Veidekke med et spesielt fokus på innovasjon.

Resultater og implikasjoner - Bruk av og fordeler ved sentrale teknologier inkludert BIM, "Cloud Computing" og "Big Data" som allerede er etablert er presentert. "Additive Manufacturing", "Augmented Reality" og "Internet of Things" med liten grad av etablering, men stort potensiale er også blant annet inkludert. Teknologiene viser seg å være knyttet sammen, og samhandling mellom dem avgjørende for optimalisering av de illustrerte fordelene innovasjonene bringer. Nevnte teknologier har ulikt modningsnivå, noen er brukt daglig, andre påvirker bare bransjen. Industrialisert byggeindustri har ennå ikke omfavnet alle mulighetene og holdningsendringer sammen med investeringsstrategier må på plass for en videre utvikling. Uansett, er de største utfordringene knyttet til opplæring, kompetanse, samhandling, samarbeid og holdingsengringer. Den beste måten å implementer innovative teknologier virker å være utvikling av strategiske planer for implementering på lang sikt, inkludert nøye undersøkelser i evaluering-, forbredelse- og beslutningsfaser. Flere publikasjoner og forskning med reelle effekter er referert som viktige faktorer for å få til en holdningsendring og transformasjon i byggenæringen.

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Chapter 1

Introduction

1.1 Problem

The construction industry is complex and fragmented, consisting of a vast supply chain and various collaboration between contractors (Meld. St. 28, 2012). There are many influencing factors and interfaces mentioned by Moum et al. (2017) that complicates the construction process. An increasing globalized market facilitates an increasing complexity of the supply chain (Moum et al.). With an estimated 13% share of total Norwegian GDP (Meld. St. 28, 2012), the construction industry has major incentives to improve.

One of the potential opportunities is implementing industrialized construction principles. Industrialization concepts in construction mentioned by Gibb (1999) are Off-site Fabrication, Pre-assembly, Prefabrication and Modularization. Different strategies and platforms in industrialized construction include barriers as described by Gibb, 1999; Eriksson, 2010; Moum et al., 2017; Bonev, Wörösch & Hvam, 2015. Moum et al. argue thath the key to success for an industrialized construction process is a combination of efficient preliminary planning, that on-site logistics and delivery flow. Moreover, Schmenner (2015) implies supply chain management and continuous flows are main contributors to evolution in industrialization. Findings from literature about logistics in industrialized construction focus on logistic frameworks (Wegelius-Lehtonen, 2001; Bonev, Wörösch & Hvam, 2015) and tools (Sullivan, Barthorpe & Robbins, 2010; Erikshammer et al., 2013) to handle logistics. However, there are several identified problems with limitation created by transportation, lifting equipment, site dimensions and lack off on-site storage (Jaillon & Poon, 2009; Gan, Chang & Wen, 2018; Thuesen & Hvam, 2011; Bonev, Wörösch & Hvam, 2015).

Despite the huge potential of industrialized construction (Gibb, 2001), the construction industry still struggles to solve the interface between a production and construction processes. The logistics process and the definition of roles and responsibilities between contractor - subcontractor when utilizing industrialized construction modules, are examples of many barriers the industry face today. Countries, like Norway, with high-cost skilled labor have large incentives to solve these industrialized construction logistics problems by embracing innovative new technologies. A higher degree of automation is a way to capitalize on innovation and simultaneously enhance better logistics performance in the industrialized construction process.

In the search of innovative technologies to solve the current logistics challenges in industrialized construction industry, development of two main research questions with supplementary co-questions can be formulated:

Q1: Innovative Technology and Potential Effects

a) What kind of innovative technologies for handling of logistic challenges in industrialized construction exist?

b) How do innovative technologies and Industry 4.0 effect logistics in industrialized construction?

Q2: Implementation of Innovative Technologies

a) How are innovative technologies implemented?

b) What are the experiences with the implemented innovative technologies?

1.2 Order of Content

The research questions have been investigated throughout spring 2019. The research questions under Q1 and Q2 are in this paper arranged in different sections with constituent parts; Theory, Result, Discussion and Conclusion. This structure is chosen to get a more systematic paper were the questions are divided in two separate sections. When the research questions are separated, the findings related to each question is easier to grasp. The explanatory chapters are sorted under each chapter.

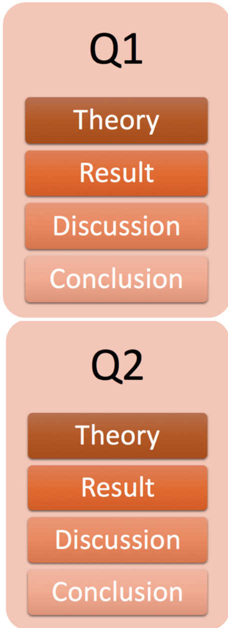

Figure 1.1: Order of content

1.3 Limitations

For Q1:

The research is limited to literature reviews of material related to existing challenges in industrialized construction logistics, the current "state of the art" and practice and interviews with representatives from Veidekke.

An analysis of best practice within industrialized construction logistics regarding innovation in technology and discussions creates an understanding of how these solutions could benefit the logistic process in industrialized construction industry.

The literature review investigates a broad spectre of academic journals and papers within the industrialized construction industry. The reason behind an evasive approach is to get an overview of construction logistics in order to find more specific problems to investigated in detail. The result was a literature review with a more general research of undefined larger topics. In spite of a few limitations, a wide search for information identified several different papers with unique areas of focus to illustrate the diversity of problems to solve with associated solutions. The review resulted in many interesting findings, and showcased future innovation in industrialized construction industry.

For Q2:

Q2 results are as with Q1 based on interviews and literature reviews. As mentioned, there are only few technologies implemented in the construction industry today and, as a consequence, limited real effect data exist. After conversations and interviews with the Norwegian construction firm Veidekke, two technologies were chosen for further investigation. These were IoT and AR. Veidekke has some experience regarding these innovative technologies, and a more detailed focus of implementation of these seemed reasonable. The BIM implementation is also considered together with other innovative technologies.

Chapter 2

Method

This section includes a description of the general methodology used for conducting the Master's Thesis, as well as how the literature review and article inclusion were conducted, interviews and how the interviews have been prepared. Finally the method is evaluated.

In this thesis, I set out to address innovative technologies an their potential effect and implementation of these in industrialized construction logistics. Conducting a systematic method of research enables an approach for answering the research questions asked for the thesis.

2.1 General Methodology

2.1.1 Inductive and Deductive Method

Logic reasoning is often divided in inductive and deductive method. Inductive method moves from specific facts within an area and creates larger principals and laws based on them. This method has the advantages that the laws then created are in line with reality and empiric findings, all though uncertain (Tranøy , 2019).

On the other hand deductive method is logic reasoning from common to less common facts. They are always true, but not as relevant for reality as the inductive method (Tranøy , 2019).

2.1.2 Qualitative and Quantitative Method

There are two types of general methods to gather information of a topic or process (Malt, 2015):

- Qualitative - Understanding attributes and characteristics of a subject or a phenomenon with analysis of coherence between different processes within the observed subject.

- Quantitative - Entails randomized clinical research to summarize result by measuring a quantum or number of occurrences in a process.

2.1.3 Reliability and Validity

Reliability refers to consistency of measures (Price, Jhangiani & Chiang , 2015). A research process with consequent findings is considered reliable. The validity is a measure whether the retrieved data target the research target (Price, Jhangiani & Chiang , 2015). Figure 2.1 illustrates data retrievals with combination of high and low validity and reliability. The right most target indicates a wanted result with both reliable and valid data.

Figure 2.1: Validity and reliability (Sander, 2014)

2.1.4 Triangulation

One common way to secure reliability and validity of data retrieval is triangulation. By triangulation more than one method are used to collect data on the same topic. The purpose is to capture different dimensions of the same phenomenon, and then get higher validity as a result (ResearchGate, 2013).

2.2 Selection of Method

To achieve the aim of finding appropriate sources, the method of search needs to be structured and targeted to substantiate an adequate foundation for the final thesis. Regardless of the selected method, whether it is qualitative or quantitative the first step of any research project is to review the field. Search investigations will reveal current knowledge gaps, and a "reinvention of the wheel" could be therefore avoided. A review also brings the benefit of relating own work to others in the field, retrieval of important works, set own work in perspective and get evidence to support own findings. A literature review was therefore chosen to be the first step of the research process.

After the literature review interviews based on findings in the literature review were conducted.

2.3 Literature Review

The main focus of the first search was the industrialized construction process. After a comprehensive search of the industrialized construction process, logistics seemed to be a key factor for industrialized construction to utilize it's promised potential. Logistics in industrialized construction was therefore investigated further with a new literature review. As a result of the findings regarding industrialized construction logistics, "state of the art" solutions to face the problems was innovative technology. A third literature review of "Future of construction" and "Industry 4.0" was then conducted.

2.3.1 Internet Search

For the literature review search engines like Google Scholar, Scopus and Oria were rapidly used. Searches in Google Scholar lead to other web databases for big journal publishers from all over the world. Examples of websites for two major publishers in the field are *sciencedirect.com* by Elsevier and *emeraldinsight.com* by Emerald Publishing Limited. Oria is a database for the NTNU university library and gives access to BIBSYS. Nevertheless, the database gives access to do searches in all of the library's collection of books, articles, journals, thesis and doctorates etc. (ORIA, 2018). Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings (Elsevier, 2018).

Keywords

For the internet search, key words which links reports, papers and articles towards the topics of the assessment were chosen. This strategy narrowed the search to a manageable amount of articles.

Searches with different keywords generated a vast diversity of articles and journals as shown in Table 2.1. A strategy for web search was then conducted. The first search started with the original keyword(s) to generate a literature overview. When the size of search results for journals, literature etc. was discovered, a process of filtering the search by adding more keywords and filters by recent publishing dates followed. The process narrowed the articles into a manageable amount of literature for further investigation.

Table 2.1: Search results

Key words	Oria	Google Scholar	Scopus
Industrialization of the construction process	4	1	7
On-site construction logistics	1202	58.300	121
Automated construction process	251.859	2.790.000	3436
Waste in construction logistics	34.435	168.000	249
Lean thinking on-site	105	28.700	9

After an adequate filtering through bibliometric searches in Google Scholar or other search engines, titles of different articles from the search were then read. The selection process continued with detailed reading of the relevant papers. By reading abstracts, introductions, conclusion and at last discussion parts of papers, the final findings were written down and the papers analyzed and reviewed.

Snowballing

Another method of finding sources for the literature review was snowballing. Snowballing is a process of generating new references from existing reliable papers on a relevant topic (Wohlin, 2014). There are two approaches to snowballing: Backward or forward. Whereas the backward focus on the references to the included article, a forward snowballing procedure identifies newer papers which have used the included paper as a reference (Wohlin, 2014).

2.4 Article Inclusion

To select the best information and knowledge related to the thesis, some inclusion criteria were developed: Is the article relevant to the topic? is it peer reviewed? what is the age of material? how are the studies conducted and where are the observations done?

These inclusion criteria were then used as a questionnaire for the article selection process. The relevance of each article selected was objectively discussed, hence the different inclusion criteria.

2.4.1 TONE Framework

The reliability of the references were screened by the "TONE-method". (TONE) is a framework for reviewing sources of information in a structured and objective manner (Lorange, 2018). Examples of how eight of the sources and articles used in this thesis were screened by the (TONE) framework are shown in the Appendix.

The TONE framework consists of four pillars of critical reference review (Lorange, 2018):

- Credibility - Who conducted the paper, is the author connected to a quality institution, is the publisher recognized, is there any contact information, how is the presentation of the work, could the findings in this report be linked to other scientific results.
- Objectivity - Is there any conflict of interest, is the paper dominated by a certain perspective, is the report written as interpretation, are all sides described, does the report try to convince the writer in a way.
- Accuracy - The level of detail in a paper is relative to the reader competence and expertise, when was the paper published or updated, is there documentation of facts or statements, is the information

provided detailed, precise, comprehensive, is the argumentation consistent and to the point, are references given, could you backtrack the references.

- Relevance - Is the information provided relevant for tour research, Which topic dose the literature cover, is this relevant, is this a publication for experts in the field or people with limited insight.

2.5 Interview

Interviews give an insight of the contractors perspective on today's on-site industrialized construction logistics, what challenges they face, how they handle these issues and development within the industry. The interviews conducted regarding the thesis were of a semi-structured manner based on previously made interview guides. One of the advantages with a semi-structured interview is the opportunity to follow up questions (Galetta, 2013).

2.5.1 Interview Guide

The interview guide is a foundation for the interview, with standard questions for a possible comparison of the participants' answers. A consistency in the question is vital for analyzing the answers on equal terms. The interview guide first presents the thesis and who is behind the research. Then the research question one and two with underlying questions were asked. The interview guide shown is in the Appendix.

2.5.2 Selection of Interviewees

There are many ways for selecting interviewees. Interviewing several different project managers in one specific construction company to analyze how different sites under the same logistics framework operate, is one. Another option is to find similar sized project, but within different companies. This approach will showcase diversity between different handling of on-site logistics. Moreover, the diversity of logistic practices could reveal a best practice to enhance improvement with smarter on-site logistics solutions. The chosen approach was to interview pioneers in innovation from one firm, Veidekke. Selecting innovative "champions" was the only way to retrieve true information regarding innovative technologies, hence they are the only ones who use the innovative technology frequently and commercial.

2.5.3 Conduction of Interviews

Conduction of interviews started with contacting potential candidates for interviews. By experience, the quickest way of contact is by phone, directly to the interview object. However, mail to HR departments to reach interviewees had the best outcome. An e-mail containing the interview guide and a date of interview was sent out. This was done to allow the interview object to prepare some of the answers.

The interviews were mostly conducted face to face in Veidekke's office at Skøyen, Norway. The participants are not named. To minimize errors, bias and other flaws, all interviews were recorded and notes were taken during the interviews.

2.6 Evaluation of Method

Selection of different methods of data retrieval for the Thesis is based on the previous description of approaches and the following evaluation of methods in this chapter. Yin (2003) addresses different forms of data retrieval in his book *Case study research: Design and Methods* (Table 2.2).

Table 2.2: Approaches of data retrieval based on Yin (2003)

Forms	Strengths	Weaknesses
Documentation	Stable- can be reviewed Exact - contains names, references Broad coverage - long span of time	Low retrievability Biased selectively Reporting bias - reflects bias of authors Blocked access
Archival records	Stable- can be reviewed Exact - contains names, references Broad coverage - long span of time Precise and quantitative	Low retrievability Biased selectively Reporting bias - reflects bias of authors Blocked access Accessibility due to privacy reasons
Interviews	Targeted - focused directly on the case of topic Insightful - provides perceived casual interferences	Bias due to poorly constructed questions Respons bias inaccuarcies due to poor recall Reflexivity - interviewee gives what interviewer wants to hear
Direct observations	Reality - covers information in the real time Contextual - covers context of the event	Time consuming Selectivity - unless broad coverage Reflexivity - event may proceed differently because its being observed Cost - hours needed by human observation
Participants observation	Reality - covers information in the real time Contextual - covers context of the event	Time consuming Selectivity - unless broad coverage Reflexivity - event may proceed differently because its being observed Cost - hours needed by human observation Bias due to investigators' manipulation of events
Physical artifacts	Insigthful into cultural features Insigthful into operations	Selectivity Availability

After a wide literature review of industrialized construction logistics and Industry 4.0, to get an overview of the "state of the art" and defining problems faced by the industry today, a greater knowledge of industrialized construction and logistics in general was obtained. The information gathered through the literature review was selected in a systematic manner by development of inclusion criteria. Moreover, the reliability of the references was screened by the "TONE-method", where each included reference was thoroughly read and described by its credibility, objectivity, accuracy and relevance. Through this process the included references were backtracked and proven to be adequate for abstracting information regarding the thesis. However, the literature review was only based on a set of key words, and therefore there are reasons to believe several relevant and good literature were neglected due to the use of few key words.

Reliability of results of the interview outcome were dependent on the answers given and the questions asked. If the questions were unclear, too wide, undefined or just wrong, they could impact the answers and give a not satisfactory outcome. The selection of interviewees could have resulted in wrong companies or people, or even an inadequate strategy for answering the research questions. Another possibility for non reliable results are false statements given by interviewees. In order to sustain objectivity when conducting interviews it is important not to ask rhetorical or leading questions to bias answers toward a wanted result. Limitation of participants interviewed will always be relative to the total available participants in a certain industry. Interviews were manly done with managers controlling, measuring or handling projects from a contractor's perspective. The research questions focus on challenges in industrialized construction on-site logistics and solutions for these issues today. Therefore, interviews with managers in the industry would most likely target many of the most important participants in the industry for answering the research questions.

Direct observations are minimized due to the weaknesses pointed out from Table 2.2. The results regarding observation of certain innovative technologies are gathered from observations from interviewees. These observations could however be biased selectively in the interest of the interviewee. The interviewees could have manipulated the results to present the innovative technologies utilized as better than they actually are. However, this is not likely when the implemented innovations are proven by numbers to generate high revenues and little motivation for twisting results.

A post evaluation of the method is done in the chapter *Post Evaluation of Method*.

Chapter 3

Q1 Theory: Potential Effects of Innovative Technologies

This section explains the different concepts looked into in this thesis. First, a historic time line is developed to get a perspective of the rapid development the world faces today. Then, definitions of the terms "logistics" and "industrialized construction" are explained and a merge of the two definitions to define logistics in industrialized construction is created. A general explanation of logistic concepts and the modern industrialized construction industry is then presented as a continuation of the definitions of the terms to get a better foundation for further investigations. Moreover, different innovative technologies' basic attributes are presented.

3.1 Historic Background

The industrial revolution in the 18th to 19th century was a period where rural societies in Europe and America became industrial and urban. Prior to the industrial revolution manufacturing was usually done within private homes with hand tools. After the first revolution industrialization gave machinery, factories and mass production. An example of an invention enhancing the industrial revolution is James Hargreaves' (1722-1778) Spinning Jenny. This was the start of mass production (History, 2009).

By the middle of the 19th century machine-assisted manufacturing and assembly of standardized parts were already established. In the late 19th century Frederick W. Taylor used quantitative approaches to organize production process by measurements of the time required to perform each step of the process. Henry Ford was on of the pioneers in creating modern integrated mass production with the assembly line (Tanenbaum & Holstein, 2016).

Through utilization of IT and electronic systems the automation process evolved even further. The first programmable logic controller (PLC) Modicon 084 (1969) was part of what some call the third industrial revolution (Ball, 2015).

As for logistics, an efficient flow of materials and information has always been a necessary principle to meet the requirements from customers, since the building of the pyramids. Wars give a historic look at the importance of logistics' strengths and capabilities - or the lack of them, to win (Christopher, 2016).

3.2 Definition

There are several definitions of industrialized construction and logistics. To find a suiting definition as a basis for conducting further research the term industrialized construction is first defined on its own. Sarja (1998) defines industrialized construction as:

"Industrialised building is the term given to building technology where modern systemised methods of design, production, planning and control as well as mechanised and automated manufacturing are applied."

This definition by Sarja was concluded by Moum et al. (2017) as the best definition of industrialized construction and what it entails, hence their own findings and definitions on industrialized construction processes. Other definitions from several other sources were analyzed but Sarja's was the best fit. As Moum et al. (2017) states "it seems easier to describe industrial construction process than defining it". There are also several different processes involved in industrialized construction. The third and fourth industrialized revolution have given a new shift for the term mass production to mass customization (Thuesen & Claeson-Jonsson, 2009). Sarja's definition still holds even after applying mass customization as production form within industrialized construction.

Also the term logistics has wide definitions. The process in industrialized construction is mentioned as one of the main contributors to the efficiency in industrialization and is influenced by factors as mentioned by Moum et al. (2017): globalization and urbanization, market and demand, technology, regulations and laws, standards, local relations, project management and organization. Moreover, factors to achieve success to logistics are identified as: Quantity, quality, time and location (Sullivan, Barthorpe & Robbins, 2010). All of these influencing factors complicate the definition of logistics. Christopher (2016) defines logistics as:

"Logistics is the process of strategically managing the procurement, movement and storage of materials, parts and finished inventory through the organization and its marketing channels in such a way that the current and future profitability are maximized through cost-effective fulfillment of orders."

To progress, a combination of definitions for industrialized construction and logistics must be developed. Logistics is as mentioned a major influencing factor in a construction project, and the meaning could vary substantially. The logistic aspect in construction specific terms involves strategic and cost-effective, storage handling, transportation and distribution of resources hence Sullivan, Barthorpe & Robbins (2010). Moreover, logistics are effected by geographical distances, processes, stakeholders, demand and supply. Supply Chain Management (SCM) (Vrijhoef & Koskela, 2000), Lean construction (Ballard, 2008) and Just-in-time principles (Gibb, 1999) are just three of many concepts within logistics.

By interpretation of Sarja's (1998) definition of industrialized construction and by combining definitions of construction logistic and logistics in general hence Christopher (2016), a definition of industrialized construction logistics was defined:

"Industrialized construction logistics is the process of managing the procurement, movement and storage of materials, parts and finished inventory through a construction process, where systematized methods of design, production, planning and control as well as mechanized and automated manufacturing are applied, in such a way that the current and future profitability is maximized through cost-effective fulfillment of orders."

3.3 Modern Industrialized Construction Process

Table 3.1: Summary of aspects in the industrialized construction industry based on Moum et al. (2017)

Pillars	**Objectives**	**Process**
Organization	Continue flow processes Sound logistics	Transportation and storage Order, responsibilities and management Transparency Interfaces Completness Quality and control
Variation	Standardisation Adaption and tailoring	Repetition Changability Quality checks Product standardisation Interface standardisation Recuierement standardisation Process standardisation Automated tailoring Engineer to Order (ETO)
Scale	Define product scale and production scale	Identification and differentiation of elements and components Evaluating economies of scale
Automatation	Speed up well performing processes	Repetition and similarity of processes on a detailed level
Technology	Utilize new technologies to enhance better performance	BIM Big data Automatisation and robots 3D printing/ additiv production

Moum et al. (2017) summarize the recent trends in the industrialized construction process. Moreover, they explain the concept, historic background and the implementation of industrialized processes in the construction industry. The paper gives an overview and discussion of topics like supply chain management, logistic and principles in a "state of the art" industrialized construction process. They conduct an analytical analysis and evaluation of the term industrialized construction through an elaboration of the main aspects of the process: Organization, scale, technology, automation and variation. Within these fields there are several influencing aspects on industrialized construction.

As Table 3.1 illustrates, new technology and utilization of these is one of the five main aspects to enhance better performance in a industrialized construction project. The elements of innovative technologies are further explained later in this chapter.

3.4 Construction Logistics

As mentioned before, by definition logistics is a process of managing the procurement, movement and storage of materials, parts and finished inventory through the organization in a sustainable and cost-effective manner. The process involves all life stages in the procurement of raw materials to waste utilization (Sobotka, Czarnigowska & Stefaniak, 2005). Figure 3.1 illustrates a possible simplified supply chain with flows of information, materials and money for a construction project.

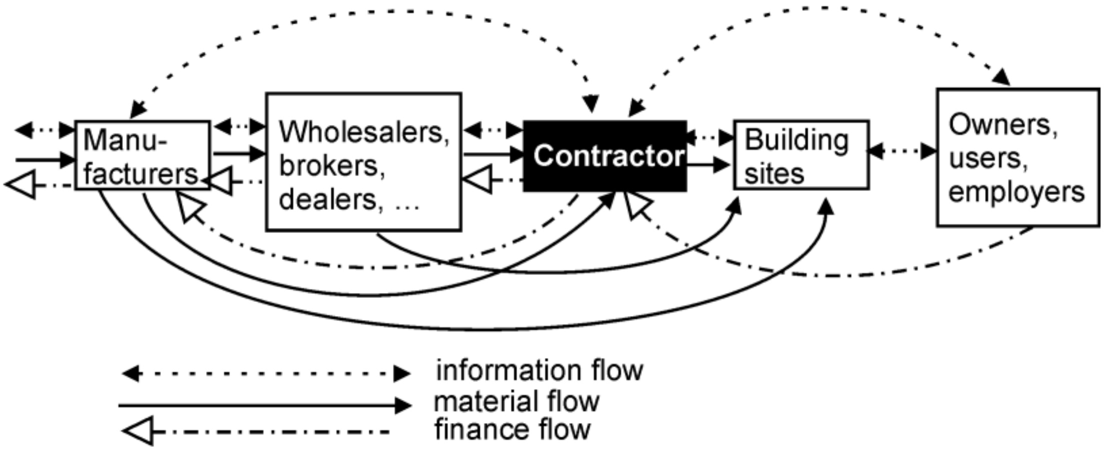

Figure 3.1: Basic construction logistics (Sobotka, Czarnigowska & Stefaniak, 2005)

Construction materials is just one example of logistic challenges that needs to be supplied and stored on construction sites (Said & El-Rayes, 2010). Moreover, schedules of activities with dependencies to timely plans, on-site space availability, and suppliers' constraints are issues when managing the logistics in construction. The complexity logistics bring to a project is the reason why logistics need effective management. The construction process is often divided in three stages: Preconstruction, construction and post construction. The logistics management in a construction project follows the same phases with different processes and tasks in each phase of the project. Figure 3.2 illustrates logistic processes by construction phase. This is the traditional way of handling logistics. to enhance the best performance, planning and scheduling different processes in the preconstruction phase to utilizing available tools are vital. During construction the planned processes are monitored to ensure the work is following schedule.

In Table 3.1 continuous flow processes and sound logistics are mentioned as one of the domains to secure a state of the art industrialized construction process.

In industrialized construction logistics there are different supply chain configurations to consider regarding material delivery (Oesterreich & Teuteberg, 2016). Make-to-Stock (MTS), Assemble-to-Order (ATO), Manufature-to order (MTO) and Engineer-to-Order (ETO) are all different manufacturing methods in the industrialized construction industry (Oesterreich & Teuteberg, 2016). Examples of the different supply chain configurations in industrialized construction logistics:

- MTS - Nails
- ATO - Doors
- MTO - Prefabricated elements
- ETO - Specialized facades

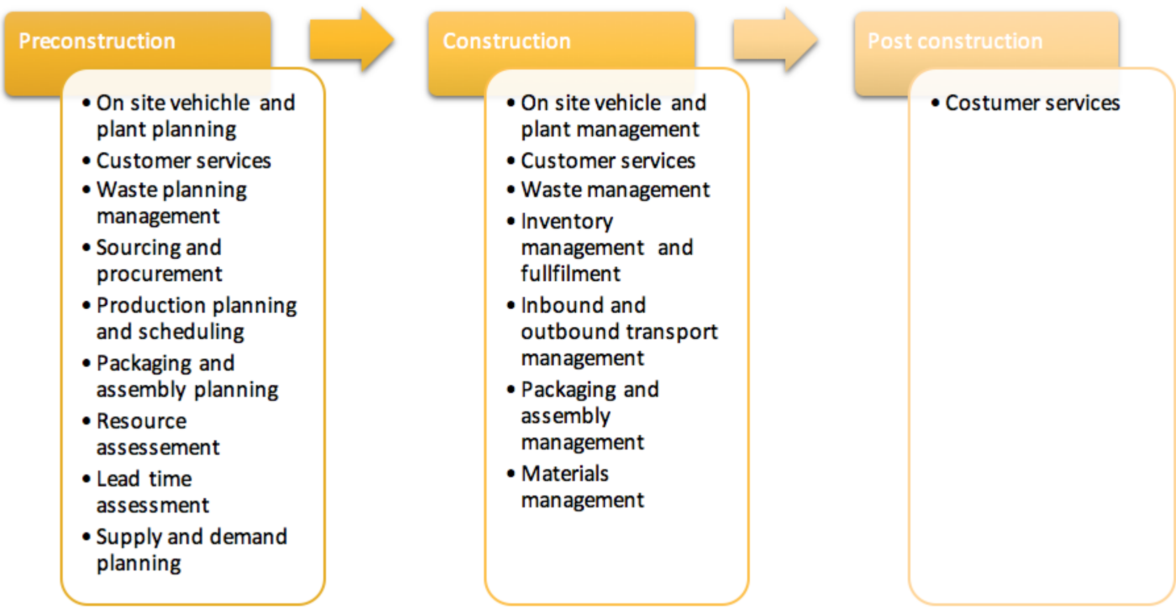

Figure 3.2: Construction logistics processes (DBW, 2018)

3.5 Innovative Technologies

New technology and the advancement of innovation and application of new opportunities are on the rise in the construction industry. As for industrialized industries like the car industry, logistic principles and advanced technology are collaborating (Boysen et al., 2015), while the construction industry has struggled to adapt to the new world of technological opportunities. Modern technologies in the construction industry mentioned by Future of Construction are: "Pre-fabrication and modular construction, advanced building materials, autonomous construction, augmented reality and viritualization, big data and predictive analysis, wireless monitoring and connected equipment, cloud and real time collaboration, 3D scanning and photogrammetry, and building information modeling." Any of these technological advancements could be utilized in an industrialized construction process to enhance better logistics. Innovative technologies in this paper are in other words non-trivial improvements in product, process or system that benefits the industry.

3.5.1 Pre-fabrication and Modular Construction

Pre-fabrication and modular construction have been parts of the industrialized construction process for a long time. There are several types of Pre-fabrication and modular construction, and different terms are used for various processes. The Construction Industry Institute (CII) differentiates the terms prefabrication, pre-assembly and off-site production. Pre-fabrication elements are produced in special facilities. The different components are brought together as components which on a later stage could become a final product. Pre-assembly is a process where different materials and pre-fabricated elements are compound ad units of a final system. Off-site production is a process involving production and compounding of elements on an off-site location. Moreover, Gibb (2001) differentiates the word pre-assembly:

- Non-volumetric pre-assembly – wall panels, structural sections and pipework assemblies
- Volumetric pre-assembly – toilet pods, plant room units, preassembled
- Modular building – Enclosing e.g. external clad

Another part of industrialized construction is the CC (Consolidation Center) concept of a temporary storage facility for a just-in-time delivery process (Sullivan, Barthorpe & Robbins, 2010). Sullivan, Barthorpe & Robbins (2010) divide consolidation centers in three different categories:

- Concealed consolidation center – Within the boundaries of the site' perimeter.
- Communal consolidation center – Purpose of serving numerous single-client or single contractor projects.
- Collaborative consolidation center – Shared use between different clients and contractors. The largest and most sophisticates type of CC.

3.5.2 Advanced Building Materials

Advanced building materials in the construction industry are evolving towards greener, more cost-effective, resources efficient and recyclable materials. These materials range from steel to plastic, and the intention of the different materials brought together creates improved artifacts. The various advanced building materials accomplish tasks very differently.

3.5.3 Autonomous Construction

Autonomous construction is a concept of an independent construction process, where certain machines are controlled by computers without a need for human control. Within this field Additive Manufacturing (AM), or 3D printing, is a prominent field. AM is a technology where structures are manufactured by layerwise applying of material based on a digital model (Camachoa et al., 2018). AM has the advantage of fabricating complex geometries on demand for the owner with huge potential benefits. There are several different methods and techniques of AM described by Camachoa et al. (2018):

- Vat Photopolymerization – A process of selectively curing a liquid light-activated polymer with a laser.
- Material Jetting – A process of selectively depositing drops of material in a layerwise fashion.
- Binder Jetting – A process of depositing a powdered material layer upon layer and selectively dropping a liquid binding agent onto each layer to bind the powders together.
- Powder Bed Fusion – A process of selectively fusing a powder bed using thermal energy, typically in the form of a laser or electron beam.
- Sheet Lamination – A process of successively shaping and bonding sheets of material to form an object.
- Direct Energy Deposition – A process of fusing materials with focused thermal energy that melts the material as it is being deposited.

3.5.4 Augmented Reality and Virtualization

Augmented reality gives an enhanced image or environment on a screen or a display with overlaying information on a real-world environment (SNL, 2018). Virtualization is a digital replication of something that represents itself and operates as it was the original.

3.5.5 Big Data and Predictive Analysis

Gartner's (2001) definition of Big data is: "Big data is data that contains greater variety arriving in increasing volumes and with ever-higher velocity. This is known as the three Vs." Big data is in other words large complex data sets, which are too voluminous for traditional data processing software (Oracle, 2018). This data used efficiently will gain a lot of information that will lead to improved solutions of e.g. current industrialized construction logistics. There are two domains of Big data namely Big Data Engineering (BDE) and Big Data Analytics (BDA) (Bilal et al., 2016). Furthermore, BDE is supporting data storage and processing activities, needed for analytics, while Big Data Analytics (BDA) try to discover the latent patterns buried inside Big Data and extract the knowledge from the BDE facilitated storage to drive decision-making (Bilal et al., 2016).

3.5.6 Wireless Monitoring and Connected Equipment

Wireless monitoring and connected equipment is a method of utilizing the rising concept of internet of things (IoT). IoT is a network of connected physical units communicating with each other over internet without human interaction (Øverby, 2018). This concept facilitates great opportunities for logistics and industrialized construction. Hence Chen et al. (2014) there are four types of cloud deployment models: public, private, community, and hybrid clouds. Each cloud has it own specific domain within different logistic enterprises. The public cloud is sharing information provided by a third-party service, whereas the private cloud is sharing limited data within a certain organization. The hybrid cloud is a combination of private and public clouds.

3.5.7 Cloud and Real Time Collaboration

The term real time collaboration is used for software and technologies that facilitate simultaneous work on a project in real time (Varma& Kumar , 2003). The key to real time collaboration is transparency in sharing of files with availability for multiple users without delays regardless of location. There are several different tools that are utilized with the various real time collaboration technologies to accommodate groups to connect. Messages, file sharing or real time editing are examples of technologies that enhance the opportunities of real time collaboration (Techopedia, 2018). A cloud in this context is a connection of online servers, with potential of storing and sharing information (Hagen, 2017). Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) are the three main domains of cloud deviation which provide various services (Zhong et al., 2017). Zhong et al. (2017) descries the clouds as:

- IaaS - provides processing power, storage, operating system and firewalls.
- PaaS - provides a hosting environment for different applications.
- SaaS - provides an application.

3.5.8 3D Scanning and Photogrammetry

3D scanning is a process of making a 3D virtual model as a replication of a real world physical object or environment by the use of various scanning technologies (SNL, 2018). Visualization of objects and implementation of scanned objects or environments gives opportunities for detailed information that later could be utilized for necessary analysis. Photogrammetry is a process of making measurements based on photographs. If the scale of the photography is known, measurements on the photography is easily obtained.

3.5.9 Building Information Modeling

BIM is defined as the process of generating, storing, managing, exchanging, and sharing building information (Eadie et al., 2013). A BIM process could involve several of the previous mentioned technologies and tools to enhance the best result of a project. Development of BIM technology in resent years has evolved BIM from being a digital 3D model representation of a construction project, to entail several processes within the same model. This has resulted in the development of ever more Ds of BIM for including ever more applications and tools related to the construction process.

Chapter 4

Q1 Result: Potential Effects of Innovative Technology

In this section the results from several comprehensive literature reviews and interviews with pioneers within the industry are presented. First some general findings from the industrialized construction and logistics are presented. Secondly applications and benefits when utilizing the innovative technologies, described in the theory section, are elaborated. Potential effects of innovative technology results for this thesis are based upon interviews with representatives from Vediekke and their experience with implementation of innovative technologies in recent projects. More about these projects and Veidekke in the Appendix.

4.1 General

The literature review conducted on industrialized construction found several industrialization concepts e.g. mentioned by Gibb (1999): Off-site Fabrication, Pre-assembly, Pre.fabrication and Modularization. Prefabrication has been identified as the first degree of industrialization, followed by mechanization, automation, robotics and reproduction (Jaillon & Poon, 2009). Findings indicate industrialization in construction is a continuation of the principles from the second industrial revolution. Traditional precast slabs, modulation or other industrialized elements in construction have been produced more or less in the same way for 20 years. Nevertheless, the industrialized construction industry meets barriers with utilizing strategies and platforms related to the industrialized construction process as described by (Gibb, 1999; Eriksson, 2010; Moum et al., 2017; Bonev, Wörösch & Hvam, 2015). Moum et al. mention the key to success for an industrialized construction process is preliminary planning, but also the on-site logistics and delivery flow. Moreover, Schmenner (2015) implies supply chain management and a continuous flow are the main contributors to evolution in industrialization. Logistics therefore seems to be a key factor for industrialized construction to reach it's promised potential.

Findings from literature about logistics in industrialized construction focus on logistic frameworks (Wegelius-Lehtonen, 2001; Bonev, Wörösch & Hvam, 2015) and tools (Sullivan, Barthorpe & Robbins, 2010; Erikshammer et al., 2013) to handle logistics. However, there are several identified problems causing limitation created by transportation, lifting equipment, site dimensions and lack off on-site storage (Jaillon & Poon, 2009; Gan, Chang & Wen, 2018; Thuesen & Hvam, 2011; Bonev, Wörösch & Hvam, 2015). To enhance better performance for logistic in industrialized construction new framework and tools, hence the literature review, seems to simply not keep up with the construction industries evolving complexity and the growing customer demands. Through history industrial revolutions have been solutions for generations of technology on the brink to evolve by innovation of new technologies. Innovative industries like the automotive or mechanical engineering sector have managed to integrate new technologies (Oesterreich & Teuteberg, 2016), related to the 3rd and 4th industrial revolution whereas the industrialized construction industry has not. As an effect of the lack of implementation and prevaling conservatism in the construction industry, the industry has one of the lowest research & investment intensity of net sales, 1% according (Hernández et al., 2015).

Table 4.1: Main technologies and concepts in stat of the art construction industry adapted from Oesterreich & Teuteberg (2016)

Cluster	Technologies and concepts
Smart Factory	Cyber-Physical systems/Embedded systems/RFID Internet of Things/Internet of Services Automation Modularisation/Prefabrication Additive Manufacturing Product-Lifecycle-Management (PLM) Robotics Human-Computer Interaction (HCI)
Simulation and modelling	Simulation tools/Simulation models Building Information Modelling Augmented Reality (AR)/Virtual Reality (VR)/Mixed Reality (MR)
Digitisation and virtualisation	Cloud Computing Big Data Mobile Computing Social Media Digitisation

A third literature review of "Future of construction" and "Industry 4.0" were then conducted. Findings from a review article by Oesterreich & Teuteberg (2016) summaries the "state of the art" in construction logistics within three clusters, Table 4.1. Nine of the concepts described by Oesterreich & Teuteberg (2016) as the leading state of the art technologies in the construction industry in general were selected for further investigation separately regarding effects on logistics in the industrial construction industry. These findings entail innovative technologies for improvement and change of the logistics in industrialized construction.

Oesterreich & Teuteberg (2016) comprehensively illustrates impact phases of the clusters with technologies listed in Table 4.1. throughout the construction supply chain in Figure 4.1.

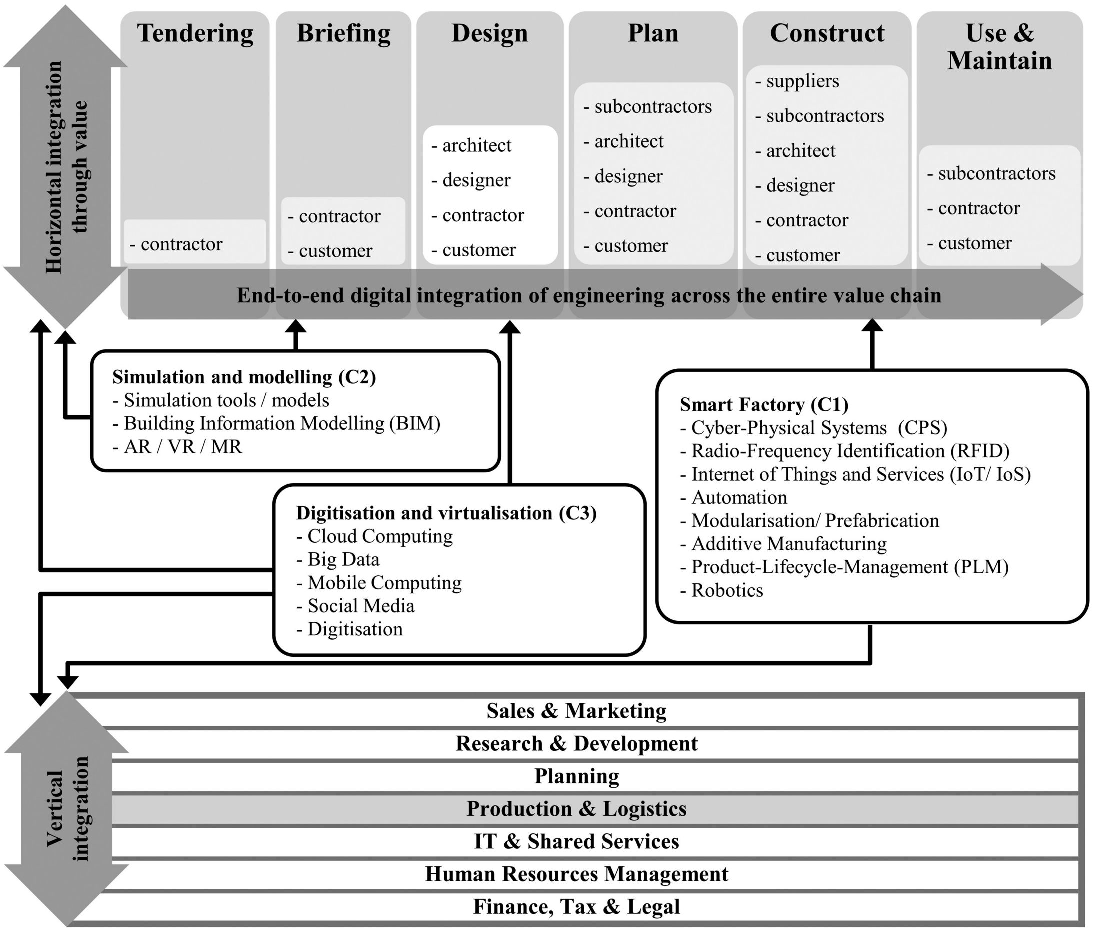

Figure 4.1: Construction value chain with adapted technologies from Oesterreich & Teuteberg (2016)

4.2 Innovative Technologies

Interviews with representatives from Veidekke provided approximate revenues on standard projects compared to innovative "light house" projects, Figure 4.2.

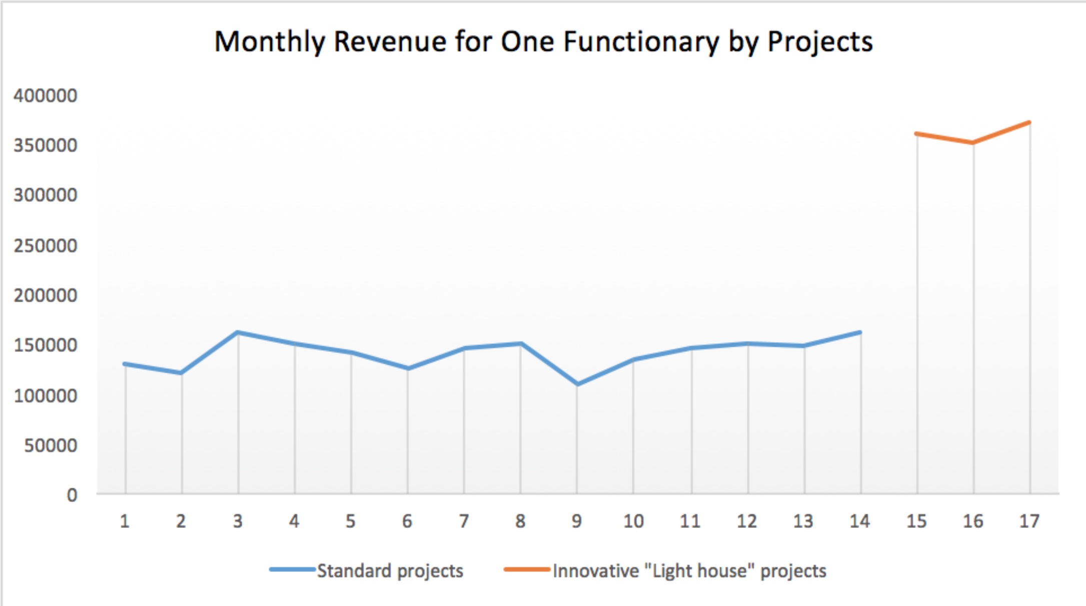

Figure 4.2: Monthly revenue [NOK] for one functionary by projects in Veidekke

4.2.1 Pre-fabrication and Modular Construction

Pre-fabrication has been identified as the first degree of industrialization, followed by mechanization, automation, robotics and reproduction (Jaillon & Poon, 2009). Literature reviewed mention major benefits of using pre-fabrication techniques compared to conventional construction (Gibb, 2001; Jaillon & Poon, 2009; Moum et al., 2017; Bonev, Wörösch & Hvam, 2015). When bringing the construction site into a factory of a controllable environment, the safety, productivity and quality could all be improved. Other advantages connected with pre-fabrication are notably faster build time, reduced costs and less environmental impacts in the construction process (Molavi & Barral, 2016). However, coordination of factory and on-site activities are concerns to consider when utilizing pre-fabrication.

Pre-fabrication and modular construction are frequently used in the Norwegian building sector, but mainly for bathroom cabins, half-fabricated "plattendekker", recesses for suspensions, sprinkler heads and electric wiring (Veidekke Representative, 2019). Stairs, shafts and cornices may also be pre-fabricated in some construction projects.

Figure 4.3: Modul of an EBS-PBU SYSTEM (EBS PRECAST, 2019)

Figure 4.4: Prefabricated wall panel (ResearchGate, 2019)

CII's differentiation of the terms prefabrication, pre-assembly and off-site production are important when searching for specific results connected to the industrialized construction industry. An off-site production implies a certain distance between the production location and construction cite. Hence Moum et al. (2017), there are problems with an increased transport route, because of the need for depot and storage. Berg (2008) also mention logistics and transportation as vital elements for an efficient industrialized construction process. Hence Sullivan, Barthorpe & Robbins (2010) transport-related cost contributes to 10 - 20% of all construction cost. Other issues with off-site construction are mentioned by Gan, Chang & Wen (2018), and are related to the adaption of the concept. A solution to the transportation problem is discussed by Sullivan, Barthorpe & Robbins (2010), with utilization of different consolidation centers (CC) as a logistic distribution platform. By using the best suited CC for an industrialized construction project, a best practise of construction logistic management could be achieved. Hence Sullivan, Barthorpe & Robbins (2010) logistics involves strategic and cost-effective, storage handling, transportation and distribution of resources, and CCs have the potential to contribute for fulfillment of these logistic requirements.

Another issue regarding pre-fabrication and modular construction is the degree of standardization. Jaillon & Poon (2009) concludes with repetition of pre-fabricated components as essential in order to meet quantity for cost effectiveness. The trending industrial construction term has gone from Make-to-Stock (MTS), Assemble-to-Order (ATO) and Engineer-to-Order (ETO) to "mass customization". However, to avoid a trade-off between mass customization and high levels of product/process standardization, companies must utilize platform concepts hence Bonev, Wörösch & Hvam (2015). Gibb (1999) mentions that standardization in industrialized construction must ensure accurate and interchangeability of components. Gibb (1999): "Thus, the most important area for standardization is actually the interfaces between the components rather than the components themselves."

4.2.2 Advanced Building Materials

Moum et al. (2017) differentiate between the industrial construction process and industrial construction production process. They claim the industrial construction production process is preliminary to the construction process and entail the constructors priorities, environment, lifetime of the project and customization. However, an industrialized construction process rely on an efficient industrialized construction production process to be successfull. Advanced building materials are the components a effecting both the industrialized construction process and the industrialized construction production process, hence the material properties.

Standard construction materials consist of metals and alloys, concrete, bituminous materials, brickwork, polymers and fibre composites (Illston & Domone, 2001). Advanced construction materials like advanced composites enhance sound logistics by unique properties mentioned by Agarwal, Broutman & Chandrashekhara (2018) like: "reducing weight strength ratio, outstanding mechanical performance, design versatility, corrosion and impact resistant and excellent fatigue strength of the materials." In other words, the material properties facilitates better logistics. The reason for this is elaborated by Moum et al. claiming the key to a success for an industrialized construction process is the on-site logistics and delivery flow. Light weight materials will often enhance better logistics, as weight will decrease volume of materials transport, make it cheaper and more sustainable. In this case it also decrease the workload for on-site construction where manually handling of these materials is needed.

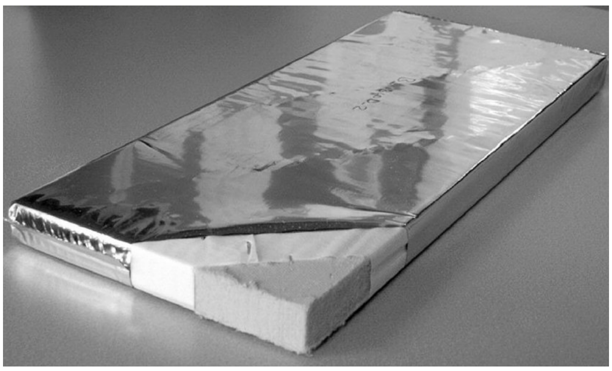

Figure 4.5: Vaccum insulation(ResearchGate, 2019)

According to interviews conducted advanced building materials are not a key priority and is not a specific focus for innovation or improving efficiency on site by Veidekke's contractors. Innovations are used if proven to be beneficial, but there are small incentives for the contractor to develop these by themselves, elaborated in *Implementation Theory*.

4.2.3 Autonomous Construction

One technology with promising attributes to the industrialized construction industry is additive manufacturing (AM), also known as 3D printing. Early applications of AM technologies have been utilized in the aerospace, automotive, and health care industries, but now hence Camachoa et al. (2018) investigations suggest potential benefits also in the construction industry. Hence Camachoa et al. (2018) AM technologies have the potential to decrease labor costs, increase safety, reduce material waste and transportation, and create complex geometries that are almost impossible to shape with normal construction techniques. Veidekke has tried 3D printing to some extent. The technology of 3D printing is a technology for the future. They have tried it, but the real project benefits of utilizing this are not expected in the short term, a Veidekke representative says. Special competence to get the full potential of the technology is also needed, the representative ads. They do not have these competencies, the representative ads.

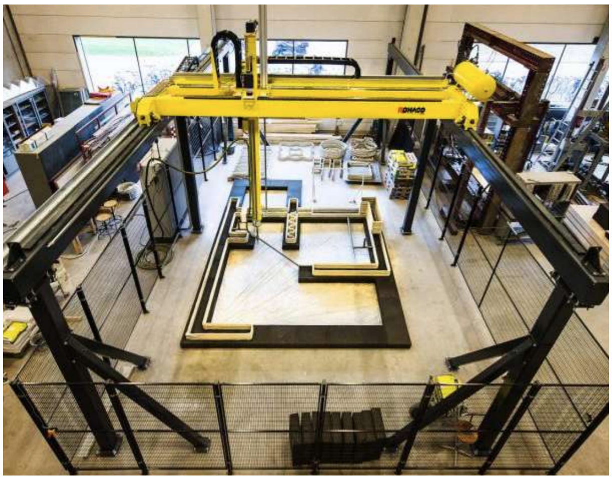

Figure 4.6: 3D printing facility (Geospatial World, 2017)

The proposed potential substantiate on different opportunities AM brings. By manufacturing special or customized parts with a normal delivery time/lead time will be reduced dramatically with the AM's capability of producing the part immediately on demand at the location of need (Camachoa et al., 2018). This is an example of shrinking the supply chain and reducing what LEAN philosophy calls *waste* (Vrijhoef & Koskela, 2000). However, as a Veidekke representative claims the competence needed to 3D print a customized part is then needed. For many construction firms the time it takes to bring in the adequate competence for the job takes longer than waiting for delivery of a new part.

Another benefit of AM rises in times of labour shortage of specifically skilled workers (Camachoa et al., 2018). AM will here provide the necessary skills to manufacture or construct the part. With a standby reserve as AM represent, there will be fewer stops of production in a project and better logistic solutions are obtained. Formwork and other temporary structures are also a potential cut off when utilizing AM (Camachoa et al., 2018). Hence Camachoa et al. (2018) formwork related labor and material costs contributes between 35 to 60% of the construction cost of a concrete slab. AM could potentially construct the same concrete structures without formwork or produce the formwork in a more sustainable and cost effective way.

Figure 4.7: Robot (New Atlas, 2018)

Some projects try to fully automate the construction process like described by Petersen, Nagpla & Werfel (2012) with their autonomous robot system TERMES. Other robot systems are e.g. the shotcrete robot described by Kochan (2000). Robots and other autonomous systems could perfection specific jobs, and do so in a harsh climate, dangerous environments, efficient and cost effective (Camachoa et al., 2018; Kochan, 2000).

In Veidekke an innovative "champion" is developing a scientific project to develop a robot. This robot's goal is to facilitate an environment for e.g. the carpenters. By drawing a full scale blueprint for e.g. the carpenters to use when constructing. The innovative "champion" in Veidekke claims this robot would perform this task within two years.

4.2.4 Augmented Reality and Viritualization

Augmented reality (AR) used in industrialized construction processes have many potential benefits found in literature. Defects and rework are primary causes of project schedule delays and cost overruns to occur, and an AR-based Defect Inspection System proposed by Park et al. (2013) is a tool for minimizing rework and enhance better performance. This is also supported by Jacobson & Dray (2018) who claim the increasingly complex construction industry will profit from adopting AR and VR to detect design errors. Moreover, the Innovate UK consortium wants to speed up the digitization of the construction industry by enhancing AR development to improve efficiency during every step of the construction process (Mansour, 2018).

Another effect of AR implementation is a transformation of the industry in terms of BIM visualization. Repercussions of this hence Mallinger (2018) will by utilizing the applications of modern smart phones contribute to collaboration between different on-site disciplines with real-time visualization of BIM-mapped buildings. Smart phones, tablets or other devices applicable for AR technology facilitates identification of mechanical, electrical and plumbing (MEP) clashes faster than conventional inspections (Mortice, 2017). Utilization of AR through phones are also claimed by Veidekke as useful to gain instant value in the implementation phase. Predicted release of the technology is set to 2019. The potential direct effects of AR are improved efficiency, cost and rework reductions, collaboration and on schedule enhancement as stated by Mallinger (2018); Mansour (2018); Park et al. (2013).

Figure 4.8: HoloLens 2 (Microsoft, 2019)

Veidekke claims to be on track regarding implementation of HoloLense an AR technology. The development of these applications are happening fast, and they believe it is possible to facilitate the use of the AR technology for all project participants in near future. An example is from the project Portalen, were the technology was used for inspection of the end product and what should be produced on specific locations on site. The problem with the HoloLense was the location awareness of the system itself. The system did not automatically know were on the construction site it was. A calibration of the HoloLence was therefore necessary. Moreover, the data capacity of the HoloLense was poor, resulting in fragments of the BIM model could only be downloaded for each session. This system flaw forced the location of inspection with the HoloLense to be specifically selected and uploaded to the HoloLense before the inspection. This level of inspection requires experts, a Veidekke representative says. Just a BIM specialist could utilize the potential of the system today. However, interviewees claim the potential for the technology is greater than internet. HoloLens is a information platform which facilitates real-time collaboration between all participants. The communication and interaction would be enhanced just not for the project team members but also the stakeholders, neighbours etc., a Veidekke representative says.

The next step for AR/VR systems are to recognize surfaces on a construction site, and then give an assumption of where they are. Direct upload of the necessary information about that location could then be automatically transmitted and utilized without a specialist within BIM technology.

4.2.5 Big Data and Predictive Analysis

The construction industry handles a vast diversity of construction data in various formats (Bilal et al., 2016). The complexity and the volume of the data in the construction industry is the reason why *Big Data* is relevant to optimize the industrialized construction logistics.

Table 4.2: An extraction of other potential opportunities of Big Data in construction addressed by Bilal et al. (2016)

Domains	State of the art	Opportunities
Resource and waste optimization	- Construction waste estimation - Waste generation benchmarking, by comparative analysis of waste management performance	- BIM tools to actualise circular economy for sustainability, green supply chains, waste estimation and minimisation
Clash detection and resolution	- BIM approaches to resolve conflicts in MEP design	- Big Data Analytics (BDA) based MEP design checker that uses prescriptive analytics to identify conflicts and best action to resolve the problem
Visual analytics	- 4D BIM Visualisation , energy user classification, using VA - Cloud-based BIM system for design visualisation and exploration	- Visual analytics driven Big Data framework for BIM model visualisation - Visual analytics driven design optimiser for energy reduction and comfort maximisation
Big Data with BIM	- BIM models for building designs, construction process documentation, GIS data and MEP conflict resolution	- BIM platform for IoT applications - Open data platform for linking BIM models with external sources
Big Data with cloud computing	- Cloud based energy data management, BIM design data storage and exploration - SaaS platform for structural MEP analysis - Cloud based BIM system for SMEs	- A BDA platform to store and process BIM models on cloud for developing domain specific applications
Big Data with Internet of Things (IoT)	- Radio frequency identification (RFID) based construction document retrieval & assets management system - IoT based energy monitoring and analysis system - Urban IoT	- Big Data driven IoT platform for smart buildings
Big Data with Augmented Reality (AR)	- BIM2MAR, a platform to integrate BIM, mobile and AR - Web3D-based AR system for BIM and social networking services (SNS)	- Big BIM Data visual exploration system - Big Data and AR based virtual site exploration - Big Data and AR enabled proactive dispute identification and resolution system - Big Data and AR enabled As-planned vs. As-built comparison system

Bilal et al. (2016) mention several positive outcomes of utilizing Big Data: "(i) Detecting causes of construction project delays, (ii) Detecting cost overruns and have quality control in construction projects, (iii) Learning from past projects, (iv) Identifying and coordinating spatial conflicts in MEP design, (v) Presenting occupational injuries, (vi) Construction data integration for enhanced productivity, (vii) Querying partial BIM models in information systems, (viii) Decision support systems for construction litigation, (ix) Structural damage detection in buildings, and (x) Identifying workers and heavy machinery actions towards site safety."

Bilal et al. (2016) summaries some potential applications of Big Data utilization illustrated in Table 4.2. The table categorizes opportunities of Big Data in domains. Associated state of the art utilization of Big Data together with future opportunities for these domains are listed.

4.2.6 Wireless Monitoring and Connected Equipment

Material management decisions still tend to be ad hoc and intuitive, even though manual handling and controlling of materials cause errors for the construction industry and logistics management (Xuesong et al., 2008). There are several technologies for automation and improvement in construction process performance – such as RFID, GPS, Wi-Fi, Bluetooth, Ultra-Wideband (UWB) and ZigBee (Jang & Skibniewski, 2008). Application of GIS and RFID have the advantage of providing automated tracking on a construction site (Irizarry et al., 2013; Song et al., 2007), e.g. location of suppliers, transportation, value adding, and non value adding activities. Teizer et al. (2014) describe the various applications of UWB in construction including simplifying on-site management, improving resource productivity and usage, reducing schedule and cost, and increasing work zone safety.

One example is registration of labour on site. Electronic automated registration is becoming a common sight on Norwegian construction sites. However, they are not used to their full potential at all sites. Veidekke for instance is using the technology to register new work crews. The system automatically gains knowledge of the worker, the job to be conducted, the risk of job, necessary certificates etc. The SHA, registration, instructions for the job and other required information are automatically generated and given to all parties involved in an instant. This is not only efficient, but also reduce the amount of paper storage and usages.

However, many of these applications still need manual handling for registration of deliveries to the construction site. A solution to this problem is described by (Lee et al., 2008), with installation of a sensor in the gate which communicates with logistic management systems and registering incoming material and work flow. Jang & Skibniewski (2008) concludes with that a "ZigBee-based wireless sensor network and the received signal strength indicator (RSSI) localization method are most promising to tackle on-site tracking of construction resources." Moreover, Xuesong et al. (2008) present an automated tracking and monitoring system based on ZigBee, that address the needed shift from the "time-and-labour-intensive legacy systems into sensor-and-network-based tracking and monitoring systems" for construction materials. Benefits stated by Jang & Skibniewski (2008); Omar & Ballal (2009) for wireless monitoring are: tracking of material properties - like level of humidity, and real-time information about construction activities including material, workers and equipment flow. Other benefits mention by Zhengxia & Laisheng (2010) is quick response to safety hazards, automatic as-built documentation, promotion and development of intelligent transport with e.g. three-dimensional integrated transport systems. Moreover, it can provide accurate information flows of products to provide reliable logistics market analysis, forecasting and decision-making.

4.2.7 Cloud and Real Time Collaboration

Cloud manufacturing (CM) and Internet of things (IoT) are interlinked (Qu et al., 2016), with respective advantages of real-time data capturing and dynamic resource management. In collaboration cloud and IoT systems managing wide-range, various-resource service capability together with the IoT's advantages of performing real-time and accurate adaptive control (Qu et al., 2016). Moreover, Zhong et al. (2017) underline the importance of real-time collaboration between prefabrication manufacturers, transport and on-site assembly as crucial for the logistics in an industrialized construction process. Provided by a cloud this real-time information and status of materials' location, properties and delivery time will be available for relevant managers. However, Zhong et al. (2017) claim that e.g. clouds for BIM servers fed with real-time data do not utilize it's potential if the data input is manual. To utilize the full potential, other technologies must be used concurrently with cloud technology as a facilitator for the real-time collaboration.

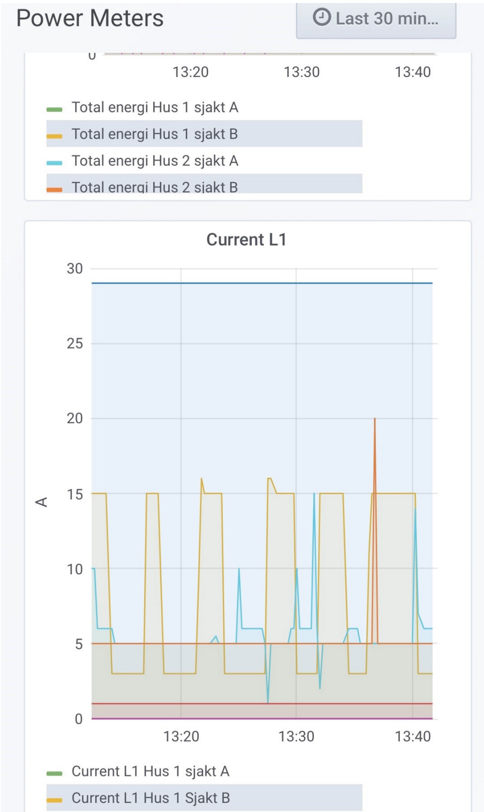

Figure 4.9: Power capacity and usages (Veidekke, 2019)

Another prominent aspect of IoT is the possibility for the construction industry to minimize reactive maintenance, since the machines and equipment are under surveillance and real-time information of the status could predict maintenance need. This allows repairs before potential damage or hazards could occur.

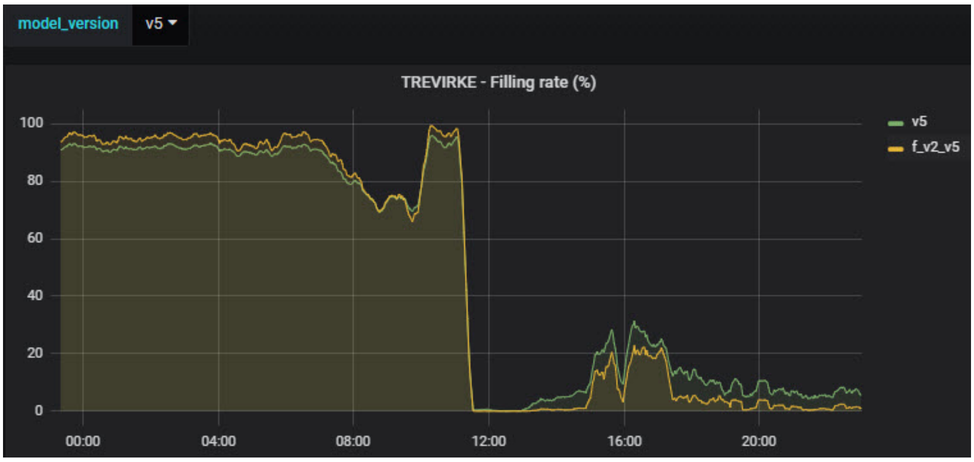

Figure 4.10: Filling rate (Veidekke, 2019)

Veidekke has developed an IoT monitoring system, see Figure 4.9. Sensors which could monitor utilization of the capacity of the electric grid on a construction site. They are not used to monitor the electric consumption, as a Veidekke representative says is a common mistake. They are set out to map the utilization of the capacity to avoid shortage. As a representative from Veidekke said, a shortage on a construction site is frequent and creates an unnecessary buzz and distraction for the site in general. Delays regarding a shortage would effect the logistics. With these monitors installed, the system could easily generate a report concluding where the shortage is located. Another opportunity this system brings is the possibility to plan the capacity of the electric grid. The monitors displays the capacity and the site manager could avoid an unnecessary shortage comparing the real capacity and the needed capacity for a job even before starting that job. The system predicts and prevent an undesirable event and maintains the work flow on-site.

Figure 4.11: Waste management app (Veidekke, 2019)

Another example of an IoT system used by Veidekke is a waste management system. A sensor with an AI (Artificial Intelligence) camera is installed on each container on the construction site. The smart sensors and AI cameras communicate directly with the waste management company. The system is trained to know when a container is full based on preset settings. Veidekke is using a preset maximum trigger at 95% as "full" for the containers, see Figure 4.10. When the system triggers this maximum an email is sent automatically to the waste management company. The real-time container status could at any time be checked in an app, see Figure 4.11. The graph in Figure 4.12 illustrates potential savings if the IoT-based waste management system was implemented. The x-axis represent number of projects and the y-axis savings in NOK.

Figure 4.12: Waste management savings in NOK by quantity of projects

When storing sensitive information concerning a construction project in a cloud several security challenges occur. A leak of information could have big consequences for employees integrity, security of the construction site or business secrets. Advanced access control, intrusion detection, firewalls, surveillance mechanisms, and the generation of exception reports are therefore necessities when utilizing clouds (Chen et al., 2014). Another challenge is lack of competence or willingness to adopt new technologies. A comprehensive training course is mentioned by Chen et al. (2014) as a solution to overcome implementation of the technology, but is not overcoming the potential skepticism.

4.2.8 3D Scanning and Photogrammetry

There are several applications found in literature regarding 3D scanning and photogrammetry. The foremost application identified by findings seems to be facilitation or "a first step" for generating models or drawings, e.g. documentation of historical sites (Remondino, 2011) or as-built drawings. The use of

3D scanning when establishin a site, could also be used for e.g. generating D4AR – A 4-dimensional augmented reality model, creates geographic information system (GIS) maps or robotic control (Larsson, Sören & Kjellander, 2006; Dorn et al., 2003). This data is vital in planning of logistics in industrialized construction, due to the opportunity to do a detailed mapping of the on-site logistic. All of these scans create a foundation for application of other innovative technologies. A scan could be saved as a 3D model and then used to create BIM models or compare as-built with designed construction to discover deviation.

It is also possible to utilize 3D scanning and photogrammetry regardless of supplementing technologies. Subsurface laser scanning (Murphy, 2012), payload monitoring (Bewley, 2011) and forensic documentation (Leica, 2018) are examples of utilization of the technology for it's sole purpose. Payload monitoring for instance could survail a bridge to predict maintenance and reduce risks of further damage.

4.2.9 Building Information Modeling

BIM is one of the most central innovative technologies to support the evolution of Indusrty 4.0 in the construction industry (Oesterreich & Teuteberg, 2016). Traditional site planing for logistic best practise has been performed manually by site plans. Building information modeling (BIM) together with geographic information systems (GIS) have revolutionized site management and enhanced better logistic (Hardin & McCool, 2015). Moreover, Hardin & McCool (2015) say a BIM model of a planned project enables the project management to plan earlier, to design safe buildable constructions with on-site logistics as well as e.g. transport logistics planning of modular prefabricated elements. The BIM enables keeping track of the supply chain status and delivery of materials.

BIM is as mentioned in previous sections interlinked with other innovative technologies to utilize the full potential and benefits of the system. Figure 4.13. illustrates an example of how BIM, IoT and cloud technologies are interlinked in an industrialized construction project. The cloud is here divided in three different layers of operation: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). They are all connected within the cloud and have a real-time concurrent connection with the BIM centered systems. This connection together with IoT enable senors, smart construction objects, in the prefabrication production, transport and on-site assembly generate a system for handling some parts of industrialized construction logistics.

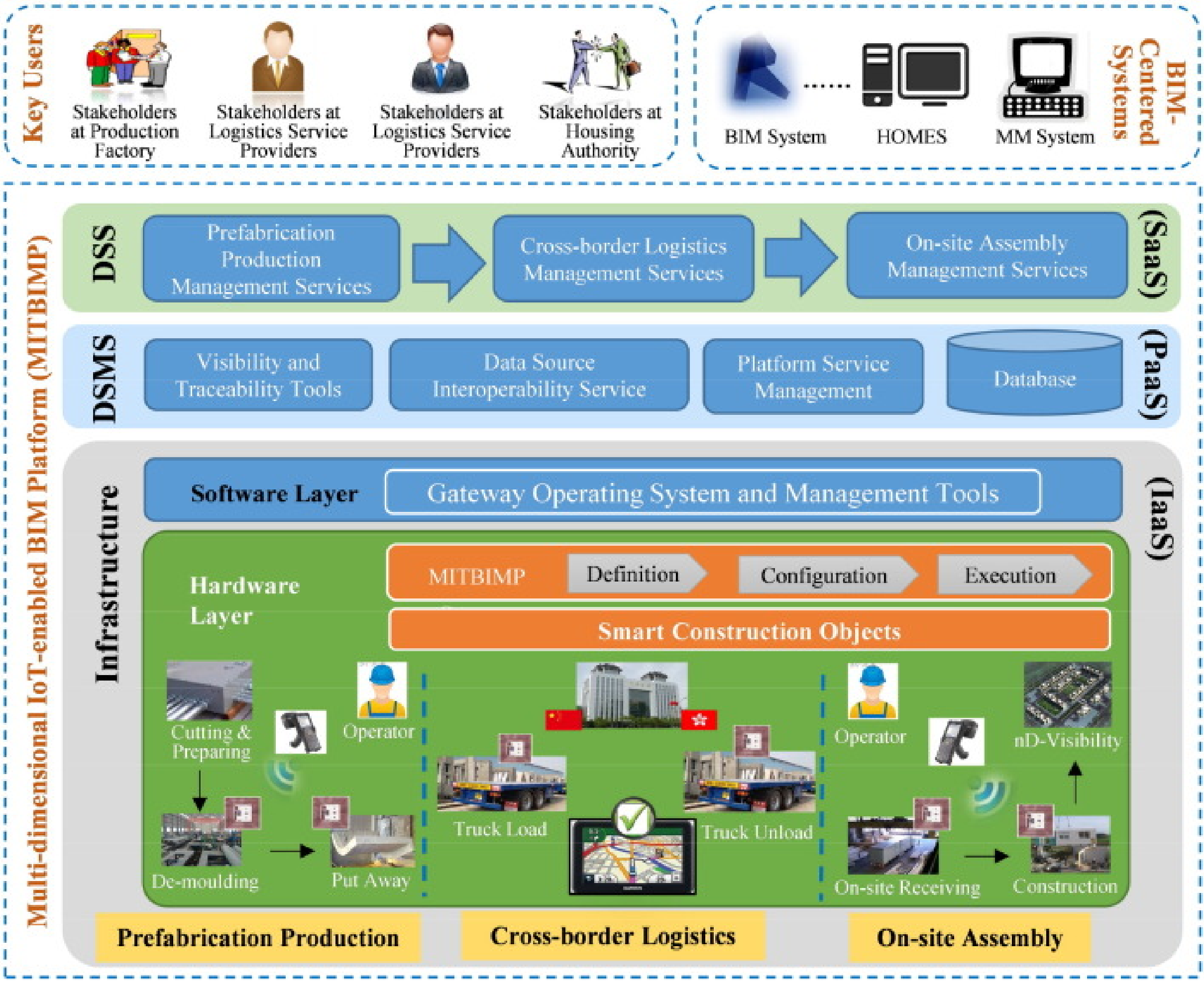

Figure 4.13: Overview of multi-dimensional IoT-enabled BIM platform (MITBIMP) (Zhong et al., 2017)

Zhong et al. (2017) propose a production process of prefabrication utilizing BIM and real-time information. Whereas standard BIM provides 3D models, a combination of technologies integrates additional dimensional information.

BIM is vital for supporting prefabrication in construction, but there are several challenges regarding it's use in prefabrication projects (Zhong et al., 2017). Paper-based manual operations and traditional methods of communication are mentioned by Zhong et al. (2017) as resulting in incomplete, inaccurate, inadequate data, lost information, ineffective communication and risk-aversion. To achieve successful implementation of BIM in industrialized construction project, accessibility and system performance of the BIM model is key (Wu & Issa, 2012). Moreover, when utilizing BIM models it is essential to provide concurrent access real-time.

Chapter 5

Q1 Discussion

In this chapter a discussion of the findings presented in the result part is conducted. First a general discussion of the development in the construction industry and industrialized construction is conducted. This is continued with discussions of findings regarding innovative technologies and their potential benefits. In the end some future perspectives and thoughts are elaborated. An attempt to discuss the innovative technologies that exist and what they entail is presented in this section.

5.1 General

The industrial revolution from the 18th to 19th century was the catalyst of it's time. The rural societies in Europe and America became industrial and urban, with machinery, factories and mass production. Through history technological innovation has enhanced efficiency and brought development further. The integrated mass production with the assembly line is an early example of this. In the recent years the development has become ever more rapid in growth and complexity. This is due to the increasing globalization and urbanization the world faces today. Repercussions of the enlarging population and urbanizational development of smarter and more sustainable solutions are enhanced by all industries to comprehend this growth without compromising the ability of future generations to meet their own needs.

The construction industry with a large influence on consuming and waste producing has a huge responsibility to comprehend the current development of urbanization. One solution discussed in literature findings is industrialized construction. To enhance better performance in this process, logistic in industrialized construction is key. The literature review support that the construction industry has an ever evolving complexity and a growing customer demand. There are several tools and frameworks for handling of logistics in industrialized construction. However, there are still several identified problems with limitation created by transportation, lifting equipment, site dimensions and lack off on-site storage. The traditional handling of logistics and even the use of LEAN or just-in-time principles does not seem to solve the current logistics problems in the industrialized construction industry.

Through history industrial revolutions have been catalysts for generations of technology on the brink to evolve by innovation of new technologies. An evolution of technology innovation is pointed out as solution for the current world problems. Some innovative industries like the automotive or mechanical engineering sector have managed to embrace the opportunities new technologies have given, related to the 3rd and 4th industrial revolutions. This is also called Industry 4.0. However the industrialized construction industry has yet to fully embraced these opportunities to the same extent. Some argue this comes as an effect of the prevailing conservatism in the construction industry, and the lowest research & investment intensity of net sales among all industries. Other argue the industry is to optimistic regarding innovation and the construction industry is implementing innovations too frequently. On the other hand barriers of implementing the same technologies as used by automotive or mechanical engineering sectors are tremendous.

5.1.1 Innovative Technologies

The first question to ask is whether the innovative technologies for handling logistic challenges exist or not?

This question may seem corny, but in the real world few questions comes with one answer. As a part of industrialized construction, pre-fabrication has been identified as the first degree of industrialization, followed by mechanization, automation, robotics and reproduction. It is obvious that pre-fabrication is a technology that could facilitate better handling of logistic challenges, but what are the barriers? How does it help? Which effects are expected? Is the potential effect good enough for implementation?

Autonomous construction is a technology with promising attributes to the logistics of the industrialized construction industry. Within this term additive manufacturing (AM) is yet again an example of a technology that is utilized in the aerospace, automotive and health care industries, but not actualized in the industrialized construction industry. On the other hand this technology is on a low maturity level. The described benefits could be realized in the future, but exactly when is difficult to predict. Even though AM one day is realized on a large scale in construction, the processes towards the goal of implementation involves large investments in innovation. History proves that this is not a plausible initiative coming from the construction industry. Augmented reality (AR) is in contradiction to autonomous construction a technology the industry already is investing in. Despite the investments, the use seems to be on an early stage. The potential benefits are positively spoken of, but the actual use and implementation hardly exist. Some of the investigated technologies are gathering and storing data for review in future projects to evaluate and form best practice. Big Data is one of these. By storing large amounts of data in one system that has the possibility to connect these data and create coherence between the data, it is possible to optimize the industrialized construction logistics in several ways. To store such information in a transparent manner with real-time updates, will facilitate the extraction of most relevant data to be used in monitoring or predictive analysis. One technology of such machinery is cloud systems. Both of these technologies are in an early stage of implementation. Pre-fabrication is on the other hand an example of a technology with high maturity in the industry. The problem seems to be lack of development regarding the facilitation of the mentioned innovative technologies.

In other words there are several existing innovative technologies, some used more than others. All come with different barriers and degree of TRL (Technology Readyness Level) or maturity in the market. As a result, it is important to differentiate innovative technologies that exist within construction projects. In the section *Potential Effects of Innovative Technology* examples of potential use of innovative technologies are presented, some with examples of actual use. Even when the innovative technologies are used, the use may not be for commercial reasons. The reasons for lack of implementation or degree of usage vary and are further discussed in the section *Implementation of Innovative Technology and Experiences.*

The second question to ask is what the effect of the bespoken innovative technologies will have on logistics if implemented?

Project managers often have profit of a project as a major goal. As found in the literature reviews, logistics are key for cost effective delivery of a project. Innovation implemented by Veidekke in their innovative "Light house" projects, which are projects pioneering in innovative technology implementation, present significant revenues compared with their standard projects. Monthly revenues ranging 210 000 NOK pr. employee for an innovative "Light house" project over standard projects, substantiate this claim. The reason behind the leap in revenues could have many explanations, and does not necessarily involve innovative technologies effecting the logistics. However, the effect is clear. Innovation tends to substitute excess tasks done by personnel with effective machinery or computer driven technologies. Innovation implemented by Veidekke such as IoT-driven waste management could be one of the contributors to the increased revenues presented. The waste management system by it's own provide a huge saving. As mentioned, effective systems of innovative technologies lead to a decreased dependency of personnel. A project team of five in a "Light house" project could do the same job as 12 in a standard project. This might not necessarily be the full truth, hence as the "Light house" projects could be specially facilitated for an effective project delivery regardless of the innovations. The project teams competence, experience, methods of work, chemistry, capacity and coordination could vary between the innovative "Light house" projects and the standard projects. Moreover, financial resources could be allocated differently between the two types of projects. However, the results presented illustrate an obvious advantage of revenues regarding innovative "Light house" projects.

Literature reviewed mentions major benefits of using prefabrication techniques compared to conventional construction, regarding logistic performance.

However, coordination of factory and on-site activities seems to be a concern when utilizing pre-fabrication. Moreover, transport is another issue to consider when producing elements on an off-site production facility. Transport related cost contributes to 10 - 20% of all construction cost. In spite of the transportation problem, consolidation centers (CC) as a logistic distribution platform is found as one of the solution to the transport problem. CCs however, do need space and investments. As many contractors, Veidekke mostly utilize prefabrication in bathroom cabins. Indeed other prefabricated elements are used, but not embraced as a total prefabricated package. A transformation from standard construction to fully prefabricated elements seems unlikely for an already established firm. The potential of prefabrication is embraced by e.g. Veidekke, but just within some areas. This approach seems common when evaluating all the innovative technologies, but yet again there is room for improvement. Other areas of construction could seemingly benefit from prefabrication, as for the bathroom cabinets. A thorough investigation of construction parts that seamlessly could be replaced by prefabricated parts should be conducted. The measures to handle the eventual replaced construction parts should also be taken into account, e.g. utilizing CCs. Yet again, another issue regarding pre-fabrication and modular construction is the degree of standardization. Nevertheless, some claim that repetition of prefabricated components as a necessity in order to obtain cost effectiveness. While other say interchangeability of components is key for standardization in industrialized construction. Even though prefabrication and modulation are mentioned as potential technologies to solve the logistics in industrialized construction, they represent only a fragment of the total technological environment that must be in place to achieve best performance. Careful consideration of needs and value on a strategic level for a firm should make a foundation for decisions regarding prefabrication implementation. The effects are definitely positive, but as mentioned it comes with several other barriers to overcome. The ability to utilize the technology is based on the various criteria stated, and strategic decisions are key for a prefabrication revolution to happen.

One of the technologies that could be interlinked with modular construction and prefabrication is the use of advanced building materials. The standard construction materials could be good for it's purpose, but innovation also in this field allow e.g. reducing weight strength ratio. Transport benefit from the reduced weight of the materials, in increased capacity, environmental foot print etc. However, materials with special attributes usually come with a higher cost. The potential savings done by transports could be lost through production. In spit of this, light weight materials will enhance better logistics on-site, due to the decrease in the workload where manual handling of these materials is necessary.

AM is to some degree implemented in the construction industry. The proposed potential is substantiated due to the different opportunities that AM brings. Furthermore, by manufacturing special or customized parts with a normally long delivery time/lead time, will be reduced dramatically with the AM's capability of producing the part immediately on demand at the location of need and will reduce what LEAN philosophy calls *waste*. However, AM requires necessary skills to manufacture or construct an object that usually would be considered a job for a high-cost skilled labourer, at least in the Scandinavian countries. A higher degree of automation is therefore a way to capitalize on innovation and simultaneously enhance better logistics performance in the industrialized construction process. Incentives for investments should be assessed based on cost benefit analysis and return of investment (ROI) calculations. Even though the potential effects are there, the underlining question for every project team or firm is; what could we gain from the technology now? As Veidekke mentions 3D printing technology is only been used on a small scale, and it is not likely for them to use it for commercial reasons in the near future. However, other projects pioneers use it for printing full scale buildings. The effects do vary and benefits from the technology seem to depend on the R&D stakes in firms. As with pre-fabrication, a specific focus regarding the technology is key to reach the level of TRL and realize the potential gains.

Utilizing the advantages of AR on-site contribute to detection of errors e.g. pre-fabricated elements mounted on-site. A quick detection facilitated by e.g. AR goggles could identify the problem, and the project could continue on schedule maintaining the logistics flows. In spite of the advantages AR brings, the technology is not fully implemented, even though some in the industry are experimenting with the technology. Veidekke's HoloLens implementation is an example. The potential effects are clear, but the commitment to the technology is in an early phase. The real effects are therefore hard to come by. Real-time BIM model visualization to compare as-built with 3D drawings, is not by knowledge obtained from the literature review tested full scale. However, some test prove the technology readiness. Either AR unveils deviations or confirms the right construction, it allows the contractors to immediately correct the error or continue to the next task. Buffers in e.g. tact time planning could be reduced with aids like AR. However, there is a lack of scientific research of these potential benefits, and this could be the reason of investment shortage.

Nevertheless, these positive effects are dependent on coherence with other technologies like BIM, cloud technology and IoT to utilize it's full potential.

Big Data integrated with other innovative technologies is key in order to utilize most out of the potential benefits to the logistics of industrialized construction. A combination of Big Data with connected equipment and wireless monitoring to generate data results is a possibility. However, the problem is the lack of implementation of these wireless monitoring systems like IoT facilitates. Dependency of coherence between different technologies therefore becomes a barrier for implementation, due to multiple investments needed in several technologies to utilize their potential. The benefit of the coherence comes to light after the investment, a seamless interaction between the different systems then facilitates for optimizing the logistic processes. An example is digital real-time data monitoring of e.g. material flows, which gives an overview of all materials positions and movement for creating better logistics decisions.

Despite the potential of wireless monitoring, materials management decisions still tend to be ad hoc, which could cause errors for the logistics management. The construction industry consists of many medium to small scale companies. Technologies for automation of monitoring processes, such as RFID, GPS, Wi-Fi, Bluetooth, Ultra-Wideband (UWB) and ZigBee, require expensive investments relative to the size of companies' business. Even though this investment most likely generates profits by developing the logistics in a long term perspective, a small to medium scale firm does not have the liquidity to handle the investment short term.

Cloud and Internet of things (IoT) are interlinked with respective advantages of real-time data capturing and dynamic resource management. In collaboration the cloud and IoT systems manage the construction logistic process in detail. Literature findings indicate the importance of real-time collaboration between prefabrication manufacturers, transport and on-site assembly. Cloud technology is in contradiction to most of the other presented technologies implemented in most construction projects.

The implementation also brings some disadvantages. The disadvantages of storing information in a cloud is the security aspect. Even with firewalls and other cyber security systems, data leaks could occur. A leak could have big consequences for employees integrity, security of the construction site or business secrets. These outcomes are not wanted, but is hard to prevent.

However, prominent aspects as the possibility to minimize reactive maintenance, hence machines and equipment are under surveillance by real-time updates, might compensate for the security risk of cloud storing.

Another important technology is photogrammetry and 3D scanning, which the foremost application according findings the facilitation is "a first step" for generating models or drawings, e.g. documentation of historical sites or as-built drawings. This allows creation of 3D models or maps of constructions or sites to develop sound logistics management. In prefabrication and modular construction it is particularly important to maintain flows between manufacturers, transport and on-site assembly, and all of these scans create a foundation for application of other innovative technologies. As already mentioned, a scan could be as mentioned saved as a 3D model and then used to create BIM models or to compare as-built with designed construction to discover deviations.

Hence literature findings, BIM is one of the most central innovative technologies to support the evolution of Industry 4.0 in the construction industry. BIM collaboration with other innovative technologies like IoT, Big data, cloud technology, 3D scanning and AR revolutionizes site management and enhance better logistic, hence findings.

BIM is vital for supporting industrialized construction logistics, but there are several challenges regarding it's use. To achieve successful implementation of BIM in industrialized construction projects, accessibility and system performance of the BIM model are key. Moreover, when utilizing BIM models it is essential to provide concurrent access real-time. If these principles are forgotten or left undone, utilization of BIM will not be as successful. Moreover, the design process of creating the BIM model is another issue that need to be considered. Project size or repetition of the construction is vital when deciding whether or not a time consuming design of a BIM model is necessary and brings enough benefits to make up the costs. BIM seems to be a mature technology, but the implementation has not yet succeeded for all. Elaborated further in the chapter is *Implementation of innovative technology and experiences.*

5.1.2 Future Perspectives

In general implementation of all the innovative technologies and the benefits they present comes with a cost. A cost-benefit analysis and discussions whether the technology improvement is applicable for the engaged industrialized construction project should be conducted. If the company manly is in prefabrication and modulation, a long term investment analysis of a transition to utilize a combination of technologies such as RFID tags on produced elements, ease the transformation for a construction company with the technology ready to use.

Future research should focus on measuring effects and present data of lead times, waste reduction, cost savings etc. to account for the potential benefits described in this paper. More specific data of improved results in handling of logistics for industrialized construction are probably what the industry needs to commit to a real transformation. The potential effect of one or several technologies discussed need to be analyzed in the context of the specific process and the business environment of the company.

Chapter 6

Q1 Conclusion

In this thesis, one of the primary aims was to explore what kind of innovative technologies for handling logistic challenges in industrialized construction exist and what effect these entail. Based on a comprehensive investigation by several literature reviews and interviews a conclusion can be drawn.

a) What kind of innovative technologies for handling of logistic challenges in industrialized construction exist?

Existing innovative solutions for handling logistic challenges in industrialized construction are: Prefabrication and modular construction, Advanced building materials, Autonomous construction, Augmented reality and viritualization, Big data and predictive analysis, Wireless monitoring and connected equipment, Cloud and real time collaboration, 3D scanning and photogrammetry, and Building information modeling. These technologies have different maturity levels, some are used daily, while others just influence the industry too some degree.

Table 6.1: Innovative technologies and their existence

Innovative technologies	**Maturity level**	**Implementation**	**Use**
Pre-fabrication and modular construction	High	High	High
Advanced building materials	Medium	Medium	Low
Autonomous construction	Low	Low	Low
Agumented reality and virtitualization	Medium	Low	Low
Big data and predictive analysis	Medium	Low	Low
Wireless monitoring and connected equipement	Medium	Low	Low
Cloud and real time collaboration	High	Medium	Medium
3D scanning and photogrammetry	Medium	Low	Low
Building information modeling	High	High	High

b) How do innovative technologies and Industry 4.0 effect logistics in industrialized construction?

These innovative technologies effect logistics in industrialized construction by optimizing different processes. The technologies found are interlinked, and as described, this is key for optimization of the illustrated benefits the innovation brings. The potential effects of full utilization of interlinked technologies for logistics in industrialized construction are: Increased safety, productivity, quality, notably faster building time, reduced costs and less environmental impacts, shrinking the supply chain and reducing waste, delivery time/lead time will be reduced, minimizing rework, enhance better performance, detect design errors, collaboration between different disciplines real-time, identification of mechanical, electrical and plumbing (MEP) clashes faster, improved efficiency, on schedule enhancement, quick response to safety hazards, automatic as-built documentation, promotion and development of intelligent transport, provide reliable logistics market analysis, forecasting and decision-making.

However, the main dependencies related to training, competence, investments, coherence, collaboration and mindset prevail. The effect of innovation will therefor also affect organization investment strategies, employment, resource allocation and capability of change.

Chapter 7

Q2 Theory: Implementation

This chapter explains the different forms of innovation, basic strategies of implementation of innovative technology and mindset of implementation.

7.1 Innovations

There are several forms of innovations in the construction industry. Some described in detail under the section *Q1: Potential effects*. The main forms of innovations regarding Slaughter (2000) are:

- *Incremental innovation* - Small improvement in current practice with minimal impact on other components or systems
- *Architectural innovation* - Small improvement within a specific area that requires significant modifications in other components or systems
- *Modular innovation* - Significant improvement but does not require changes in components or systems
- *System innovation* - Complementary innovations which work together to gain significant advance of knowledge or practice
- *Radical innovation* - Completely new concept

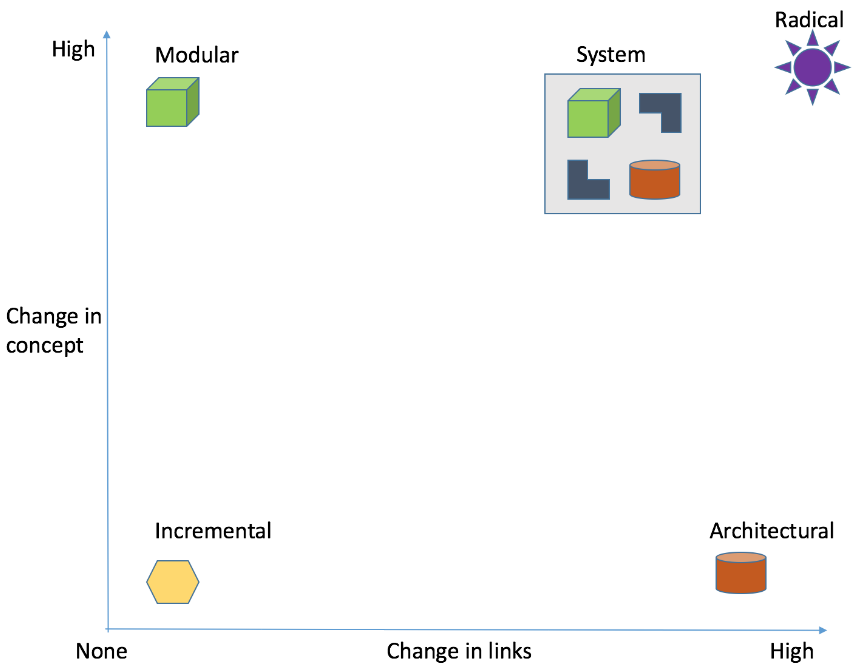

Figure 7.1: Categories of innovations by changes in concept and links to other systems based on Slaughter (2000)

The innovations investigated in this paper are associated with technology. The table below is a suggestion for categorizing the innovative technologies from Q1 in the different innovation categories as described in Figure 7.1.

Table 7.1: Innovation types

Innovative technologies	Change of concept	Change in links	Innovation category
Pre-fabrication and modular construction	High	Low	Modular/Incremental/Architectural
Advanced building materials	High/Low	High/Low	Radical/Incremental/Architectural
Autonomous construction	High	High	Radical
Agumented reality and virtitualization	High	-	Radical
Big data and predictive analysis	High	-	Radical
Wireless monitoring and connected equipement	High	-	System
Cloud and real time collaboration	High	-	System
3D scanning and photogrammetry	High	-	System
Building information modeling	High	-	System

7.2 Implementation

Implementation of innovation in construction is often described as a cycle of implementation stages, as Slaughter (2000) illustrates with the figure below. The utilization of benefits from an innovation relies on fully understanding the whole innovation process that is based on knowledge acquisition, transformation, and diffusion (Aouad, Ozorhon & Abbott, 2010).

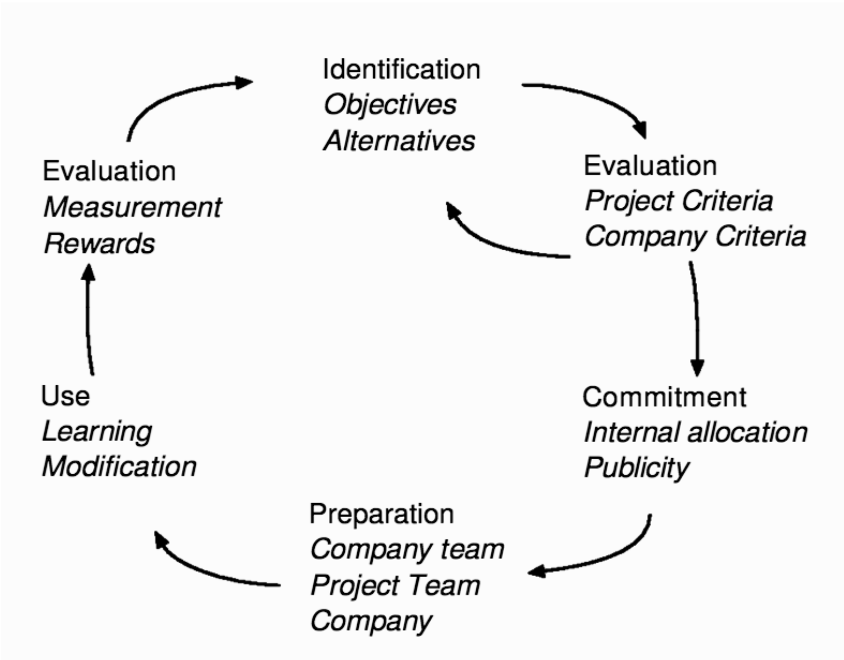

Figure 7.2: Implementation stages Slaughter (2000)

7.2.1 Identification

The first stage of the cycle is identification. The project organization will consider the objectives of a certain project and identify criteria to fulfill the initial goals of the project. This phase involves investigating several alternate opportunities to achieve the objectives. This stage are often considered by multiple stakeholders involved in the project to improve the projects outcome, process and value. However, to accomplish this, a certain knowledge about the possible innovations available, the consequences' and benefits of those are required (Slaughter, 2000).

7.2.2 Evaluation

After a selection of alternate innovations to set in use, an evaluation of these regarding the objectives of both the project and the company is conducted (Slaughter, 2000). A successful implementation could enhance a company's reputation or have a positive ripple effect through the company's performance (Christensen & Rosenbloom, 1995). There are therefore several other aspects to consider in the evaluation phase than just the individual project effects. Key criteria for both the company and the project should be considered to make a sound decision whether an innovation should be implemented or not.

7.2.3 Commitment

The third implementation phase, is a commitment to the chosen innovation(s) evaluated. Allocation of resources to implementation of the selected innovation(s) is considered as proof of the commitment (Slaughter, 2000). Moreover, these resources could consist of material, personnel or financing. Often new innovation(s) are driven by some with a more than usual belief in the benefits the innovation(s) brings (Murphy, Perera & Heaney, 2015).

7.2.4 Preparation

This phase involves the necessary preparations before an implementation. Preparation measures must be undertaken within the company's organization to meet the criteria for the intended implementation. Developing necessary skills within the company's workforce and obtaining resources to accomplish a successful implementation is key in this phase (Murphy, Perera & Heaney, 2015). Small scale implementation of a system or innovation is one way to prepare for a full scale implementation. A test could provide experience regarding an innovation. However, information gained by a small scale tests is not always a perfect representation of a real environment and full scale testing.

7.2.5 Use

When preparations are completed, adequate skills are obtained by personnel and resources are allocated to push the innovation through, use of the innovation could start. However, adaption of the new innovation could take time. There might be new routines, personnel, construction site layout etc. Use of the innovation can not accomplish the potential effect before the implementation is completed and successful.

7.2.6 Post-use Evaluation

In a post-use evaluation it is beneficial to do a comparison of expected outcomes of the potential effects for an innovation with the actual outcomes (Slaughter, 2000). The knowledge gained from such a comparison is crucial for future implementation of innovations.

7.3 Implementation by Innovation Type

Even though most implementation face the general implementation phases described in Figure 7.2, there are substantial differences regarding implementation of the different types of innovations.

7.3.1 Implementation of Incremental Innovations

Minor improvements to components fits under incremental innovations. The expected changes and benefits are minor, with little associated risk and uncertainty (Slaughter, 2000). This could directly lead to shorter evaluation time. As evaluation time is shortened the commitment stage does not demand extensive convincing, resources etc. to succeed. It is also important to notice that an innovation could be perceived different on- and off-site (Afuah & Bahram, 1995). A modular construction innovation could have made a large impact in preparation and R&D off-site, but on-site personnel would on the other hand handle the innovation as an incremental innovation. The same innovation could therefore act differently in the various stages in the construction value chain when implemented (Afuah & Bahram, 1995).

7.3.2 Implementation of Architectural Innovations

An architectural innovation is changes in the nature of interactions between core components, while reinforcing the core design concepts (Henderson & Clark, 1990). Architectural innovation by definition focus on exploration of new design and knowledge (Slaughter, 2000). However firms have trouble making this transition as the process of discovery and building new capabilities usually takes time and commitment. Repercussions of handling an architectural innovation as an incremental innovation could cause modifications to components with severe consequences (Slaughter, 2000). The commitment and preparation phase for this type of innovation is greater than for incremental innovation, hence an architectural innovation tends to have a more complex coordination need between the parties in a construction value chain (Slaughter, 2000). The post-use evaluation for this innovation should therefore focus on the different parties' experience with the implementation process.

7.3.3 Implementation of Modular Innovations

Modular innovations have major improvement in the core concept, but none or only minor changes in the links to other components (Slaughter, 2000). This facilitates innovation on specific components regardless of the components interaction with other components. Developers of this innovation could fully focus on innovation. Evaluation of this innovation is mostly connected to risks and uncertainties regarding the replacement of a module (Slaughter, 2000).

7.3.4 Implementation of System Innovations

If several innovations are combined to gain new attributes they are combined to a system innovation. An evaluation of a system innovation must consider the combination of the innovations to understand the real impact (Caputo,Marzi & Pellegrini, 2016), and also the category of implementation. IoT could for instant fit many of the presented categories, but the whole system must be evaluated (Caputo,Marzi

& Pellegrini, 2016). This is done by considering all of the innovations at a system level. Commitment to this innovation type involves all parties effected by the innovation. Active collaboration across the project organization is key to success with this implementation.

7.3.5 Implementation of Radical Innovations

Radical innovation involves a significant leap within an area. These innovations generate attributes of performance with large potential effects. Effect data for radical innovation is hard to come by, hence they are new. High level scientific and/or engineering research are needed to even create an opportunity for the innovation to exist. The potential is often described as huge, but the implementation process is yet to be considered. Future application of the innovation is therefore often considered without further re-due to implementation measures. Commitment to such innovation demands future perspectives and leadership on a strategic level analyzing trends of future opportunities and competition. Extensive testing and integration of the firm on all levels are required for a radical innovation to succeed (Abernathy & Utterback, 1978). Technical competence within the firm to deal with the complexity of a radical innovation is also key (Slaughter, 2000).

Chapter 8

Q2 Result: Implementation of Innovative Technology and Experiences

Here the results from several comprehensive literature reviews and interviews with pioneers within the industry are presented. First some general information about technologies with special consideration is presented. Secondly the implementation process of these innovative technologies is elaborated.

Implementation results for this thesis are based upon interviews with representatives from Vediekke and their experience with implementation of innovative technologies in recent projects. More about these projects and Veidekke in the Appendix.

8.1 General

The interviewees have participated in projects with a special focus on innovation. The persons involved have also been dealing with innovation more than average, and they have a drive towards new and innovative technology. The project Hagebyen was the first Veidekke project that enhanced VDC, the Portalen project possibly the first in the world to benefit from HoloLence (AR/VR technology) for commercial use and the Frysja project pioneers on drone technology and IoT autonomous systems. All of these projects characterized as "Light house" projects within Veidekke's portfolio. The interviewees have all participated in these projects.

Veidekke is very decentralized, with ideas that preferably have bottom - up structure. Hence Ling (2003) innovation should only happen if team members are motivated both during initiation and implementation stages.

8.2 Implementation Stages

8.2.1 Identification

Veidekke has a conscious awareness of main business areas and which potential innovative technologies in the market today that is worth implementation. The focus of identification of innovations are technology readiness levels of the innovation considered. In what way could an implemented innovation benefit the project's results. However, other interviewees request more information of recent market trends within innovative technologies. There are a lack of systems for identifying new innovative technologies, despite the newly estabilshed Business Development unit.

8.2.2 Evaluation

When Veidekke evaluates the identified innovation matching their criteria to improve segments of their main business areas several aspects come at play. A typical situation that happens in an organization with little or none innovation focus is that then continue with their old habits and neglect the potential effects of innovation, a Veidekke representative says. It is hard to evaluate new solutions in a conservative project team who might already have been disappointed by an innovation that not fulfilled the intentional positive effects. It is then hard to convince such a project team to commit. The interviewees as mentioned have been involved in innovative project teams, and mention that it is important to avoid conflicts when evaluating new innovative technologies.

8.2.3 Commitment

The commitment stage is a continuation of the evaluation stage. The best way to secure resources to a new implementation is by convincing the project team that the potential effects will benefit the project. As mentioned by interviewees, the benefits must be easy to capture and be instantly, in order to convince the project members and leaders to commit to the implementation. Project teams are much in power by their own resource management. As an interviewee said: "With resources come mandate." The decentralized structure facilitates project teams to commit to their own innovation. There seem to be little involvement with Veidekke's top management or any strategic innovation plan. The plans seem to be non existent. However, development of new departments in Veidekke like a Business Development unit is a step in the right direction.

A commitment at the project level is important, especially for an organization with a decentralized structure. Interest for the innovation and enthusiasm of relevant players are crucial (Ling, 2003).

8.2.4 Preparation

The preparation phase mix with the commitment phase in Veidekke's experience. To ensure commitment, a preparation phase with testing and training is in some cases crucial in the implementation of an innovative technology. The project Hagebyen is an example where the implementation process relied on a training period involving project participants to gain experience and get comfortable with the new innovation. This innovation was BIM technology. Each participant in the project was asked what BIM could do for them. This helped the different participants to develop their own needs and ways to utilize the innovation. The results showed that some were at a visualization stage, and others were on a more advanced utilization stage. Moreover, each participant got a sense of potential benefits and effects brought by the technology for their specific task straight away. The preparation phase in this case helped to stick with the commitment.

However, when implementing AR the BIM implementation process was investigated. Investigations found the BIM implementation process not to be efficient and cost effective. Veidekke is learning from the BIM implementation process when implementing AR.

Preparations are important to not implement innovations in a haphazard way (Ling, 2003).

8.2.5 Use

The use of the different innovations depends on the readiness level of the implemented innovations. 3D printing for instance was used to some degree, but more for the fun of it than for commercial use. HoloLense, first used in the Portalen project, gave value to the project, but not quite adequate. The technology displayed potential, but competence and readiness were not on an adequate level for full utilization. The IoT waste management systems in the Frysja project, however, was rolled out and used to the full extent. By these examples representatives from Veidekke concluded that the key for successful use of a new innovation must either be implementation in a fashion that compliments the projects main area of business or could replace manual systems of binary decision taking.

Investigations also found BIM to be used as a supplement. This discovery was done after investigating the BIM utilization after implementation in Veidekke. When characterizing an innovation as a supplement, the utilization will never be optimal. The solution for this, found by Veidekke, was to integrate one specific task and the management system in one. With HoloLens this could be done with an application. The down side is resource allocation, and the need for an all-in mentality in the commitment phase to push the innovation through.

The use of an innovative technology is connected to where in the project organization the innovation is implemented. AR in Veidekke for instance has several potential applications, but these applications are different for each participant in the project. The managers of the carpenters could use the technology to control and get an overview. On the other hand virtual meetings could be used to communicate with non present stakeholders.

8.2.6 Post-use Evaluation

Evaluation of use of the implemented technologies tends to be after the projects are finished. Evaluation and the implementation tact are therefore different from project to project in Veidekke. Post-use evaluation of BIM has proven to benefit implementation of AR in Veidekke. Use of the innovation was restrained by the earlier phases of evaluation, preparation and commitment. Interviewees propose that some of the errors come from the industry's newly developed "cowboy" tendencies. Processes should be carried out gradually rather than abruptly (Benešová & Tupa, 2017). Despite assumptions of the industry to be conservative, interviewees claim the industry is too eager to jump on the new innovative technology trends, before evaluating the actual effects for the project. The mindset of the current industry is fixed on value generation from innovations day one after implementation. The projects do not gain from an innovation that just look cool.

Chapter 9

Q2 Discussion

In this chapter a discussion of the findings presented in the result section is conducted. First discussion of the organizational structure is conducted, then strategic plans, experiences and implementation learnings are discussed. An attempt to discuss best practise within the implementation process is also done in this section.

A decentralized structure relying on a bottom-up structure as Veidekke has, creates a harsh environment for innovation implementation. A decentralized structure might be nice for an employee, but without a direct commitment and push from the top management in Veidekke the will to push innovation through for a project team could be minimal. There is in other words lack of incentives from the top leaders in the firm. As a result, the project team must take the risk of an innovative technology implementation. If the implementation goes wrong the project result will then be directly hit, and salaries, bonuses etc. could be withdrawn from the project team whom took their chances when implementing a new technology. Moreover, the lack of direct management over project teams in Veidekke moves the responsibility of implementation to the project team members. Typically an implementation of an innovative technology depends on a "champion" within the project team whom push the innovation trough. Without a "champion" innovations are often neglected in a decentralized structure. On the other hand Veidekke's Business Development department are recently created. This is an unit within the firm with a special focus on innovation. Resource allocation for dedicated projects is more comforting for the firm and project teams, than relying on revenues to fund innovation. Resource allocation seems to be the best way for commitment.

Moreover, the structure of Veidekke facilitates for innovation if the project team members have an innovative mindset. Based on the interviews project teams of innovative mindsets are often younger than less innovative project teams. This might be due to the competences within new technology and more curiosity displayed by younger employees.

Competence or willingness to adopt new technologies is also an issue. Conservatism is mentioned as one of the major barriers for implementation and integration of new technology advancements in the construction industry as well as for the industrialized construction industry. A mindset change and an illustration of the potential benefits of enhancing the current innovation are necessary for the industry to change. The construction industry is facing an ageing workforce, which could explain the skepticism and conservatism that innovation face. Old habits die hard, but sooner or later the benefits of enhanced logistics through the discussed technologies will prove to be vital for facing the current and future sustainability and efficiency demands.

The competence within these technologies could be a problem, but findings indicate that comprehensive training courses will overcome implementation of the technology, but will not guarantee overcoming the skepticism.

Strategic planning in innovative technologies has not been a major part of Veidekke's business plan until now. The Business Development department together with innovative project teams are leading a push for innovation in Veidekke. However, the department is in a start-up phase and the long-term innovation plan is still vague. One of the reasons for this is the uncertainty of the potential values of an innovation implementation, but also because of an innovation tact every ca. two years. The innovation tact follows the construction time of a project. While this may seem logic, short term needs will always be overshadowing potential gain in the future following this tact. Instant value seems to be more attractive than development and potential business advantages in the future. This could be the reason for the low R&D investments in the construction industry. Moreover, the resources are therefore not allocated to develop or implement innovation. Without a strategic plan or department for development, the resources will never be allocated to implement innovative technologies. This includes all phases; identification demands resources to spot market trends in technology, evaluation demands resources to find the best fit technologies etc. However, as mentioned, project teams could take innovation in their own hands. This is due to the decentralized structure of Veidekke. Both alternatives have it's pros and cons. Anyway, a unified commitment is crucial for implementation. An implementation will never work if only the board in a firm is convinced or the contractors only use the innovations as supplements to their preferable methods, or if project teams with a innovative mindset have no resources to make the implementation. A strategic plan for implementing innovative technologies is important together with collaborative innovative mindsets in project teams.

Key to implementation of innovations seems to be convince the decision taking unit of a project to commit. There are several ways to do this presented in the previous sections. From interviews innovations with immediate and instant effects seem to be preferred. Documented effects overrule potential barriers and ease aspects of the implementation process. The end do not justify the means in the implementation setting. The risk of neglecting important steps in the implementation process is that innovation will not reach its full potential. Even through the effects in the project in itself is beneficial. The implementation process is therefore important to consider, even with a short term investment possibility. Of course a long term vision is preferable, however this do not seem to be the case when implementing innovations in the construction industry.

Experiences from BIM implementation in Veidekke is an example of an implementation process that is not optimal. BIM has not been utilized to it's potential due to lack of investment in evaluation, preparation and commitment. The value for the industry is obvious, but the ways to utilize it effectively was not described before the commitment phase. As a result the resource allocation went directly to the commitment phase to implement, but evaluation of full utilization did not receive sufficient resources.

Learning from the BIM implementation phase is used in Veidekke for implementation of AR. The process now focuses on evaluation and preparation phases. The Business Development department has designated resources to thoroughly investigate the possibilities of the technology, and how to maximize the utilization when put to use. This is important in order to gain knowledge of the full potential of the technology and how to gain the preferable value in the end. Such a process will also facilitate a long term investment plan for the technology and strategic implementation measures to secure sound implementation. The key for the AR implementation is to develop a system where an integrated system could preform a task without no further rework.

9.1 Future perspectives

More investigation processes of implementation should be conducted to get a better understanding of the process as a whole. Implementation of innovative technologies has already affected the industry, but the impact seen so far is just the start. The implementation of innovative technologies presented is just a fraction of the vast opportunities facing the industry. More innovate technologies will be implemented rapidly as the maturity of the technology rises. The concluded measures of strategic long term planning, ability of mindset change, resources allocation and to see the implementation process as a whole are more important than ever for future implementation of innovative technologies.

Chapter 10

Q2 Conclusion

Exploration of implementation of innovative technologies for handling logistic challenges in industrialized construction was one of the aims of this thesis. Based on a comprehensive investigation by several literature reviews and interviews, a conclusion can be drawn.

a) How are innovative technologies implemented?

Innovative technologies are implemented through various processes leaning on the basic implementation process steps. Mature technologies, e.g. BIM, have been implemented in a haphazard way. The implementation process phases are not prioritized, and there are lack of resource allocations to critical evaluation phases. The best way to implement innovative technologies seems to be by development of a long-term strategic plan for implementation including a thorough investigation of evaluation, preparation and commitment phases. Resource allocation must facilitate sound decision making in every step of the process. These new strategies of implementation are used in recent implementation processes by Veidekke's Business Development department.

b) What are the experiences with the implemented innovative technologies?

An important experience is to not be blinded by new innovative technologies' potential effects before evaluating the main business area of the firm and the outcome of the implementation. Moreover, instant value of an implemented innovation seems to be key for commitment underlining the importance of the early phases of the implementation phase. Innovative technologies are existing, but not necessarily used fully for every task within construction industry or to enhance industrial construction logistics. Innovations implemented are used as supplements rather than performing a certain task. Innovative "champions" and a innovative mindset is a plus in order to push an innovation through, but the most important is the ability to change.

Chapter 11

Post Evaluation of Method

Participants in the interviews were selected within one firm; Veidekke. As mentioned in the *Method* section, interviewing several different managers in one specific construction company to analyze how different sites under the same logistics framework operate was chosen. However, the outcome after selection of interviewees was broader than expected. Project managers with experience implementing and using several of the innovative technologies presented were interviewed. Moreover, strategic leaders and Business Development managers within Veidekke were interviewed. This gave a better than expected representative coverage of the firm regarding implementation and use of innovative technologies across various projects. However, there could always have been more interviews and a greater data gathering span. More interviewees could have made an impact and brought to light other perspectives within effects and implementation of innovative technologies. Nevertheless, an adequate quantity of data was gathered to generate a comprehensive thesis.

The findings from the literature review showcase a large pool of opportunities to benefit for technological advancements in industrialized construction, but few references are from Norway. It was not an original goal or intent to focus on the industrialized construction industry in Norway, so the review presents relevant results based on the search criteria. Nevertheless the result could vary from geographical areas, market conditions, workforce, cost of labour, etc.

Interviews were conducted in Norwegian and then transcribed. The translation of speech could have influenced the transcribed material and slightly changed some of the Norwegian formulations.

Literature review was conducted as a start-up or the thesis. The literature review became the foundation for further investigation. Findings were interesting and useful, but did not shrink the research area specifically. A post evaluation of the research process enlightens the limitations of the chosen approach. If conducted again, interviews would be conducted earlier in the process to gain knowledge the literature review did not present. This approach could have resulted that the research process had targeted a more specific research area.

Another issue with the research method was lack of quantitative data. However, the maturity of innovative technologies investigated leads to few or no measured real effects. The effects were therefore presented as potential with some exceptions.

Bibliography

Abernathy, W.J. & Utterback, J.M. (1978) *Patterns of industrial innovation* Publisher: Technology Review, pp. 40-7.

Afuah, A.N. & Bahram, N. (1995) *The hypercube of innovation* Publisher: Research Policy, 24, pp. 51-76

Agarwal, B.D., Broutman, L.J. & Chandrashekhara, K. (2018) *Analysis and Performance of Fiber Composites* Publisher: John Wiley & Sons, Inc.

Aouad, G., Ozorhon, B. & Abbott, C. (2010) *Facilitating innovation in construction: Directions and implications for research and policy* Publisher: Construction Innovation, Vol. 10 Issue: 4, pp.374-394

Ball, K. (2015) *The Dawn of the Programmable Logic Controller (PLC)* Publisher: PULSE URL: https://www.automation.com/automation-news/article/the-dawn-of-the-programmable-logic-controller-plc

Ballard, G. (2008) *The Lean Project Delivery System: An Update* Publisher: Lean Construction Journal 1 2008: pp. 1-19

Benešová, A. & Tupa, J. (2017) *Requirements for Education and Qualification of People in Industry 4.0*, Publisher: Procedia Manufacturing 11, pp. 2195–2202

Bewley, A. et al. (2011) *Real-time volume estimation of a dragline payload* Publisher: IEEE International Conference on Robotics and Automation.pp. 1571–1576.

Bilal, M., Oyedele, L.O., Qadir, J., Munir, K., Ajayi S.O., Akinade, O.O., Owolabi, H.A., Alaka, H.A. & Pashac, M. (2016) *Big Data in the construction industry: A review of present status, opportunities, and future trends* Publisher: Advanced Engineering Informatics Volume 30, Issue 3, August 2016, Pages 500-521

Bonev, M., Wörösch, M. & Hvam, L. (2015) *Utilizing platforms in industrialized construction: A case study of a precast manufacturer* Publisher: Construction Innovation Volume 15, ISSUE 1, pp.84-106, Emerald Group Publishing Limited

Bowen, G.A. (2009) *Document Analysis as a Qualitative Research Method* Publisher: Qualitative Research Journal, Vol. 9 Issue: 2, pp.27-40, URL: https://doi.org/10.3316/QRJ0902027

Boysen, N., Emdea, S., Hoeck, M. & Kauderer, M (2015) *Part logistics in the automotive industry: Decision problems, literature review and research agenda* Publiser: European Journal of Operational Research, Volume 242, Issue 1, Pages 107-120, Elesevier

Camachoa, D.D., Clayton, P., O'Brien, W.J., Seepersad, C., Juenger, M., Ferron, R. & Salamone, S.(2018) *Applications of additive manufacturing in the construction industry – A forward-looking review* Publisher: Automation in Construction Volume 89, May 2018, Pages 110-119

Caputo, A., Marzi, G. & Pellegrini, M.M. (2016) *The Internet of Things in manufacturing innovation processes: Development and application of a conceptual framework* Publisher: Emerald Group Publishing Limited, Business Process Management Journal, Vol. 22 Issue: 2, pp.383-402

Chen, Chen & Hsu (2014) *A New Approach to Integrate Internet-of-Things and Software-as-a-Service Model for Logistic Systems: A Case Study* Publisher: Sensors 2014, 14(4), 6144-6164

Christopher, M. (2016) *Logistics & Supply Chain Management* Publisher: Pearson UK

Christensen, C.M. & Rosenbloom, R.S. (1995) *Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network* Publisher: Research Policy, 24, 233-57.

Designing Buildings Wiki (2018) *Logistics management in construction* URL: https://www.designingbuildings.co.uk/wiki/Logisticsmanagementinconstruction

Dorn, M. et al. (2003) *Landmark detection by a rotary laser scanner for autonomous robot navigation in sewer pipes* Publisher: Proceedings of the ICMIT 2003, the second International Conference on Mechatronics and Information Technology, pp. 600- 604, Jecheon, Korea

Eadie, R., Browne, M., Odeyinka, H., McKeown, C. & McNiff, S. (2013) *BIM implementation throughout the UK construction project lifecycle: An analysis* Publisher: Automation in Construction Volume 36, December 2013, Pages 145-151, Elsevier

Elsevier (2018) URL: https://www.eu.elsevierhealth.com/

Erikshammer, J., Weizhou, L., Stehn, L. & Olofsson, T. (2013)*Discrete event simulation enhanced value stream mapping: an industrialized construction case*Publisher: Lean Construction Journal, ISSN 1555-1369, E-ISSN 1555-1369, Vol. 10, pp. 47-65

Eriksson, P.E. (2010) *Improving construction supply chain collaboration and performance: a lean construction pilot project* Publisher: Supply Chain Management: An International Journal, Vol. 15 Issue 5, pp.394-403, Emerald Group Publishing Limited

Gan, X., Chang, R. & Wen, T. (2018) *Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis* Publisher: Journal of Cleaner Production Volume 201, pp. 735-747

Galetta, A. (2013) *Mastering the semi-structured interview and beyond* Publisher: New York University press

Gibb, A.G. (1999) *Off-site Fabrication – Pre-assembly, Prefabrication and Modularisation* Publisher: Wiley-Blackwell A John Wiley & Sons, Ltd., Publication

Gibb, A.G. (2001) *Standardisation and pre-assembly – distinguishing myth from reality using case study research* Publisher: Construction Management and Economics, Vol. 19, pp.307-315

Google Scholar (2018) URL: https://scholar.google.no/

Hagen, A.N. (2017) *Strømmetjenester* Publisher: SNL URL: https://snl.no/strC3B8mmetjenester

Hardin, B. & McCool, D. (2015) *BIM and Construction Management: Proven Tools, Methods, and Workflows* Publisher: John Wiley & Sons, Inc.

Henderson, R.M. & Clark, K.B. (1990) *Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms* Publisher: Administrative Science Quarterly Vol. 35, No. 1, Special Issue: Technology, Organizations, and Innovation, pp. 9-30 (22 pages)

H. Hernández, F. Hervás Soriano, A. Tübke, A. Vezzani, M. Dosso, S. Amoroso, N. Grassano, A. Coad, P. Gkotsis (2015) *EU R& D SCOREBOARD* Publisher: The Industrial R&D Investment Scoreboard European Commission – Joint Research Centre, Luxembourg (2015)

History (2009) *Industrial Revolution* Publisher: A&E Television Networks URL: https://www.history.com/topics/industrial-revolution/industrial-revolution

Galetta, A. (2013) *Mastering the semi-structured interview and beyond* Publisher: New York University press

Illston, J.M. & Domone, P. (2001) *Construction Materials Their Nature and Behaviour* Publisher: CRC Press, London

Irizarry, J., Karan, E.P. & Jalaei, F. (2013) *Integrating BIM and GIS to improve the visual monitoring of construction supply chain management* Publisher: Automation in Construction Volume 31, May 2013, Pages 241-254

Jacobson & Dray (2018) *Reducing design coordination errors with VR, AR* Publisher: ConstructionDive URL: https://www.constructiondive.com/news/reducing-design-coordination-errors-with-vr-ar/525645/

Jaillon, L. & Poon, C.S.(2009) *The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector* Publisher: Automation in Construction Volume 18, Issue 3, pp.239-248, Elsevier

Jang & Skibniewski (2008) *A wireless network system for automated tracking of construction materials on project sites* Publisher: Journal of Civil Engineering and Management, 14:1, 11-19

Kochan, A. (2000) *Robots for automating construction – an abundance of research* Publisher: Industrial Robot: An International Journal, Vol. 27 Issue: 2, pp.111-113,

Kommunal- og moderniseringsdepartementet (2012) *Gode bygg for eit betre samfunn* Meld. St. 28

Larsson, Sören, Kjellander, J.A.P. (2006) *Motion control and data capturing for laser scanning with an industrial robot* Publisher: Robotics and Autonomous Systems. 54 (6): 453–460. doi:10.1016/j.robot.2006.02.002.

Lee, Song, Kwon, Choi, Kim & Chin (2008) *A gate sensor for construction logistics* Publisher: ISARC 2008

Leica (2018) *forensic* URL: http://www.leica-geosystems.us/forensic/

Ling, F.Y.Y. (2003) *Managing the implementation of construction innovations* Publisher: Construction Management and Economics, 21, pp. 635–649

Lorange, A.L. (2018) *Finn kilder* URL: https://innsida.ntnu.no/wiki/-/wiki/Norsk/Finne+kildersection-Finne+kilder-Hvordan+velger+jeg+ut+kilder Downloaded: 04.10.18

Mansour, S. (2018) *AR, VR and 3D Modelling: Technology in the construction industry* Publisher: Construction Global URL: https://www.constructionglobal.com/equipment-and-it/ar-vr-and-3d-modelling-technology-construction-industry

Mallinger, K. (2018) *How Augmented Reality Will Innovate BIM Visualization* Publisher: Forbes URL: https://www.forbes.com/sites/forbescommunicationscouncil/2018/05/14/how-augmented-reality-will-innovate-bim-visualization/14ca00dc6fb5

Malt, M. (2015) *Kvalitativ* Publisher: Store norske leksikon URL: https://snl.no/kvalitativ.

Molavi, J. & Barral, D.L. (2016) *A Construction Procurement Method to Achieve Sustainability in Modular Construction* Publisher: Procedia Engineering, Volume 145, 2016, Pages 1362-1369

Mortice, Z. (2017) *Augmented Reality in Construction Lets You See Through Walls* Publisher: Autodesk URL: https://www.autodesk.com/redshift/augmented-reality-in-construction/

Moum, A., Høilund-Kaupang, H., Olsson, N. & Bredeli, M. (2017) *Industrialisering av byggeprosessene status og trender* Publisher: SINTEF akademisk forlag, SINTEF Byggforsk

Murphy, M.E., Perera, S. & Heaney, G. (2015) *Innovation management model: a tool for sustained implementation of product innovation into construction projects* Publisher: Construction Management and Economics, 33:3, 209-232.

Murpy, L. (2012) *Case Study: Old Mine Workings* Publisher: Subsurface Laser Scanning Case Studies. Liam Murphy.

Oesterreich, T.D. & Teuteberg, F. (2016) *Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry* Publisher: Computers in Industry Volume 83, December 2016, Pages 121-139

Omar, B. & Ballal, T. (2009) *Intelligent wireless web services: context-aware computing in construction-logistics supply chain* Publisher: ITcon, 14 (Specia). pp. 289-308.

Oracle (2018) *What Is Big Data?* Publisher: Oracle URL: https://www.oracle.com/big-data/guide/what-is-big-data.html

ORIA (2018) URL: https://bibsys-almaprimo.hosted.exlibrisgroup.com/primolibrary/libweb/actio/search.do

Park, Lee, Kwon & Wang (2013) *A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template* Publisher: Automation in Construction Volume 33, August 2013, Pages 61-71

Petersen, K., Nagpla, R. & Werfel, J.(2012) *TERMES: An Autonomous Robotic System for Three-Dimensional Collective Construction* Publisher: Robotics: Science and Systems VII Pages 257-264

Price, P.C., Jhangiani, R. & Chiang, I.A. (2015) *Reliability and Validity of Measurement* Publiser: Creative Commons Attribution-NonCommercial-ShareAlike 3.0 License

Prosjekt Norge (2018) *Om Prosjekt Norge* URL: https://www.prosjektnorge.no/om-prosjekt-norge/

Qu, T., Lei, S.P., Wang, Z.Z., Nie, D.X., Chen, X. & Huang, G.Q.(2016) *IoT-based real-time production logistics synchronization system under smart cloud manufacturing* Publisher: The International Journal of Advanced Manufacturing Technology, April 2016, Volume 84, Issue 1–4, pp 147–164 | Cite as

Remondino, F. (2011) *Heritage recording and 3D modeling with photogrammetry and 3D scanning* Publisher: Remote Sensing 3.6: 1104-1138.

Said, H. & El-Rayes K. (2010) *Optimizing material logistics planning in construction projects* Publiser: Construction Research Congress

Sander (2014) *Reliabilitet* URL: http://estudie.no/reliabilitet/.

Sarja, A (1998) *Open and industrialised building* Publisher: E& FN Spon, London, UK.

Scopus (2018) URL: https://www.scopus.com/search/form.uri?zone=TopNavBarorigin=NO20ORIGIN20DEFINEDdispla

SINTEF (2018) *Om SINTEF Byggforsk* URL: https://www.sintef.no/byggforsk/om-oss//

Slaughter, E.S. (2000) *Implementation of construction innovations* Publisher: Building Research & Information, 28:1, 2-17

Sobotka, A., Czarnigowska, A. & Stefaniak, K. (2005) *LOGISTICS OF CONSTRUCTION PROJECTS* Publisher: Poznan University of Technology

Song, Lee, Yoon, Kwon, Chin & Kim (2007) *Material tracker for construction logistics* Publisher: ISARC 2007

Sullivan, G., Barthorpe, S. & Robbins, S. (2010) *Managing construction logistics* Publisher: Wiley-Blackwell A John Wiley & Sons, Ltd., Publication

Tanenbaum, M. & Holstein, W.K. (2016) *Mass production* Publisher:Encyclopedia Britannica, inc. URL:https://www.britannica.com/technology/mass-production

Techopedia (2018) *Real-Time Collaboration* URL: https://www.techopedia.com/definition/15608/real-time-collaboration

Teizer, J., Venugopal, M. & Walia, A. (2014) *Ultrawideband for Automated Real-Time Three-Dimensional Location Sensing for Workforce, Equipment, and Material Positioning and Tracking* Publisher: Journal of the Transportation Research Board, Volume 2081

Thuesen, C. & Hvam, L. (2011) *Efficient on-site construction: learning points from a German platform for housing* Publisher: Construction Innovation Volume 11, Issue 3, Emerald Group Publishing Limited, pp.338-355.

Thuesen, C. L., & Claeson-Jonsson, C. (2009) *The Long Tail and Innovation of New Construction Practices: Learning Points from Two Case Studies.* Publisher: Open Building Manufacturing: Key Technologies, Applications, and Industrial Cases. (pp. 51–64), ManuBuild

Thunberg, M., Rudberg, M. & Gustavsson, T.K. (2017) *Categorising on-site problems: A supply chain management perspective on construction projects* Publisher: Construction Innovation, Vol. 17 Issue: 1, pp.90-111, Emerald Publishing Limited

Tranøy, K.E. (2019) *Metode* URL: https://snl.no/metode

Varma, P. & Kumar, S. (2003) *Shared and independent views of shared workspace for real-time collaboration* Publiser: US6564246B1, US Grant

Veidekke (2019) *Fakta om Veidekke* URL: http://veidekke.no/om-oss/article8949.ece

Vrijhoef, R. & Koskela, L. (2000) *The four roles of supply chain management in construction* Publisher: European Journal of Purchasing & Supply Management Volume 6, Issues 3–4, pp.169-178, Elsevier

Wegelius-Lehtonen, T. (2001) *Performance measurement in construction logistics* Publisher: International Journal of Production Economics Volume 69, Issue 1, pp. 107-116, Elsevier

Wohlin, C. (2014) *Guidelines for snowballing in systematic literature studies and a replication in software engineering* Publisher: EASE '14 Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering Article No. 38

Wu, W. & Issa, R.R.A. (2012). *Leveraging Cloud-BIM for LEED Automation* Publsiher: Journal of Information Technology in Construction (ITcon), Vol. 17, pg. 367-384

Xuesong, Wu & Ming (2008) *Wireless Sensor Networks for Resources Tracking at Building Construction Sites* Publisher: Tsinghua Science & Technology Volume 13, Supplement 1, October 2008, Pages 78-83

Yin, R.K. (2003) *Case study research: Design and Methods* Publisher: Sage publications Inc

Zhengxia, W. & Laisheng, X. (2010) *Modern Logistics Monitoring Platform Based on the Internet of Things* Publisher: 2010 International Conference on Intelligent Computation Technology and Automation, Changsha, 2010, pp. 726-731.

Zhong, Peng, Xue, Fang, Zou, Luo, Ng, Lu, Shen & Huang (2017) *Prefabricated construction enabled by the Internet-of-Things* Publisher: Automation in ConstructionVolume 76, April 2017, Pages 59-70

Øverby, H. (2018) *Tingenes internett* Publisher: SNL URL: https://snl.no/tingenesinternett

Appendix

A – Reference Evaluation

Examples of some references and how they have been evaluated.

Reference 1

Authors: A. Moum, H. Høilund-Kaupang, N. Olsson and M. Bredeli(2017)

Title: Industrialisering av byggeprosessene status og trender

Publisher: SINTEF akademisk forlag, SINTEF Byggforsk

Moum et al. (2017) summarize the recent trends in the industrialized construction process. Moreover, they explain the concept, historic background and the implementation of industrialized processes in the construction industry. The paper gives an overlook and discussion of topics like supply chain management, logistics and principles in a "state of the art" industrialized construction process.

Credibility: The authors A. Moum, H. Høilund-Kaupang, N. Olsson and M. Bredeli are all scientists at SINTEF Byggforsk, NTNU and SINTEF Raufoss Manufacturing. SINTEF Byggforsk is a research institute focusing on sustainable development in construction, infrastructure and mobility (SINTEF, 2018). SINTEF is a recognized institute of research and knowledge in extensive topics. The institution and authors involved are therefore considered trustworthy. The presentation of the work is done in a professional manner, and follow the standards of academic writing. Moreover, the structure makes it easier to backtrack sources and contact information. The paper is trustworthy.

Objectivity The project is divided in two phases. Phase one was conducted on demand and sponsored by the BAE-program. The BAE-program tries to substantiate a research foundation for long term growth in the construction industry (Prosjektnorge, 2018). The second phase was a peer-review process through the Bygdin network. This phase was also sponsored by the Bygdin network. The Bygdin Network is a joint industry and R&D initiative for manufacturing and industrialization in the Norwegian construction industry (SINTEF, 2018). These phases and their sponsoring do not rise any concern considering conflict of interest. The report is written to benefit the industry, and does not try to convince the reader, but enlighten them in a factual manner. The report is therefore considered objective.

Accuracy: The level of detail and technical language in this paper is understandable, even for a reader with just some knowledge about the construction industry. There is no need for an expert to grasp the topics discussed in the paper. The paper was published in 2017, therefore up to date with recent observations of the industry trends.

Relevance: The information is relevant for the research done in the specialization project, hence the topics discussed are summed up with the keywords: Construction process, construction project, efficiency, quality, logistics. All of the keywords are relevant and the paper is too.

Reference 2

Author: T. Wegelius-Lehtonen (2001)
Title : Performance measurement in construction logistics
Publisher: International Journal of Production Economics Volume 69, Issue 1, pp. 107-116, Elsevier

Wegelius-Lehtonen (2001) introduces a framework for measuring construction logistics and how application of improvement measures and monitoring measures could secure sound logistics in construction. Wegelius-Lehtonen (2001) concludes with “If you want to improve something – Measure it”.

Credibility: The International Journal of Production Economics has an Impact Factor of 4.407 (Elsevier, 2018). The Norwegian Register for Scientific Jorunals, Series and Publisher (NSD) has rated the journal to a scientific level of 2 (NSD, 2018). Hence the rating from NSD and the impact factor given, the ratings support trustworthiness of the paper. The paper is cited 154 times (Google Scholar, 2018), and implies sound links to other scientific research conducted in more recent time.

Objectivity: The author works for the Department of Industrial Management, Helsinki University of Technology. Moreover, the paper is conducted as a research project with an aim to find new solutions and improve productivity of logistics in the construction industry (Wegelius-Lehtonen, 2001). There is no reason to believe a conflict of interest or one sided subjective views are at play to convince readers.

Accuracy: The paper implies a certain level of competence and expertise to understand the subjects discussed. This could complicate abstraction of relevant information. The paper was published in 2001, and could therefore be outdated. However, documentation of facts in a precise and comprehensive context will always be useful even just to see development in the industry.

Relevance: The paper's keywords are: Performance, Measurement, Measuring tools, Logistics, Construction industry. These words comply with the research in this paper. Moreover, the literature gives important information about performance measurement in construction logistics, which could be relevant for further writing of the specialization project.

Reference 3

Authors:G. Sullivan, S. Barthorpe and S. Robbins (2010)
Title: Managing construction logistics
Publisher: Wiley-Blackwell A John Wiley & Sons, Ltd., Publication

This paper discusses the use of different consolidation centers (CC) as a logistic distribution platform. Sullivan, Barthorpe & Robbins (2010) divide consolidation centers in three different categories - Concealed consolidation center, Communal consolidation center and Collaborative consolidation center, underlining different strategies of construction logistic management.

Credibility: Hence to John Wiley & Sons (2018) website Gary Sullivan is co-founder of Wilson James Ltd, which provides a range of support services to industry, commerce and government. Stephen Barthorpe is the Corporate Responsibility Manager for MITIE Group PLC, a major strategic outsourcing and asset management company. Stephen Robbins works at Laing O'Rourke Plc, as Off-Site Production Manager where he utilizes his knowledge in the development and implementation of logistics strategies for a number of challenging projects, both at tender and at contract stage. The authors has experience with logistics in the construction industry, with records of approval. The trustworthiness is sustained.

Objectivity: The book is written to the industry professionals, academia and students with an objective view on construction logistic, hence a quote from the Australasian Journal of Construction Economics and Building (2010).

Accuracy: "Practical, clear and accessible. First book to address logistics in construction. Written by the industry-recognized logistics experts..." (Medicaster, 29 October 2010) This quote from a review by Medicaster claims the book is neat and understandable. Extraction of facts is easy, hence a good structure throughout the book. Terms like industry-recognized and logistics experts imply accuracy in the information provided in the respective book.

Relevance: Just the title *Managing construction logistics* implies a relevance for the research conducted in this paper. The book aims to inform readers about construction industry logistics and how to run them smoothly. This entails major topics of the research relevant for the specialization project.

Reference 4

Authors: R. Vrijhoef, L. Koskela (2000)

Title: The four roles of supply chain management in construction

Publisher: European Journal of Purchasing & Supply Management Volume 6, Issues 3–4, pp.169-178, Elsevier

Vrijhoef & Koskela (2000) illustrates initiatives to advance the construction supply chain, through emphasizing practical objectives for specific roles in the construction industry. The present status and problems regarding the supply chain are presented. Furthermore, conclusions based on findings of waste and problems found in the supply chain are drawn.

Credibility: Norwegian Register for Scientific Journals, Series and Publisher (NSD) rates the European Journal of Purchasing & Supply Management to a scientific level of 1 (NSD, 2018). This implies that the paper is not published through a journal in the top 20% within the field. However, the article is quoted 772 times (Google Scholar, 2018). L. Koskela is a recognized scientist with different expertise: Lean construction, construction management, project management, operations management and design science. Moreover, R. Vrijhoef the co-writer works at Delft University of Technology (Google Scholar, 2018). The authors appears with trustworthiness, hence their work experience and previous published papers.

Objectivity: The paper aims to present the four roles of supply chain management (SCM) in construction. There is no bias towards a certain supply chain, manufacturer or influential third party. This is a objective research paper.

Accuracy: The publishing date of 2000 gives the article an implication of old research, but the frequent citation of the paper proves otherwise. The paper appear as factual and clear. The structure of the paper provides information comprehensive and within academic standards. A consistency in argumentation and presentation provides neat and easy reading.

Relevance: The research highlights the roles of a SCM in construction in 2000, this is still relevant today at least as a comparison to future systems. Vrijhoef & Koskela (2000) identify important contributions to the construction industry, through different sides of SCM, empirical observation that leads to potential improvements of SCM methodology and discussion of SCM's limitations and new roles. This is relevant for the specialization project.

Reference 5

Authors: M. Bonev, M. Wörösch, L. Hvam (2015)

Title: Utilizing platforms in industrialized construction: A case study of a precast manufacturer

Publisher: Construction Innovation Volume 15, ISSUE 1, pp.84-106, Emerald Group Publishing Limited

Bonev, Wörösch & Hvam (2015) mentions a framework with five domains: customer, functional, physical, process and logistics. These domains are analyzed and discussed in a case study of a precast manufacturer. The paper concludes a trade-off between mass customization and high levels of product/process standardization utilizing platforms is not necessarily the truth, but rather an enhancement of optimum cost and value creation.

Credibility: The authors Martin Bonev (Department of Operations Management, DTU Management Engineering, Technical University of Denmark, Kongens Lyngby, Denmark), Michael Wörösch (Department of DTU Mechanical Engineering, Technical University of Denmark, Kongens Lyngby,) and Lars Hvam (Department of Operations Management, DTU Mechanical Engineering, Technical University of Denmark, Kongens Lyngby,) are all PhDs with respective knowledge in their field. The publishing journal Construction Innovation is ranked to scientific level of 1 (NSD, 2018). However, the research links to other scientific results and is based on an acceptable methods of research.

Objectivity: Bonev, Wörösch & Hvam (2015) wrote the paper with the purpose to explore the development of a platform-based project in the industrialized construction sector. The facts are presented in a sophisticated way, where all sides are described and discussed. A holistic view on platforms within the precast sector with an in-depth exploration of how practitioners from the industry' management sector handle these platforms to generate value creation is discussed and conclusions drawn without any bias towards a specific result. There is no reason to believe the research excludes crucial information to benefit the outlined result.

Accuracy: The level of detail in the paper is professional in-depth analytics with a strict structure. However, insight and experience regarding discussed themes are prerequisite for abstracting information efficient. A tendency of abbreviations and technical glossary contributes to difficulties regarding the understanding of certain topics discussed. On the other hand the technical vocabulary is explained preliminary in the paper, so the precondition is set, a reviewer needs to read the prerequisite information to get the full benefit. If the reader of the paper reads through the article chronologically the prerequisite vocabulary is explained and the information provided in further reading is understandable.

Relevance: Different terms and notions conveyed simplifies further research and resolve issues regarding glossary and concepts. The explanation and exemplifications of the precast industry is a necessity to understand parts of the industrialized construction industry. Therefore this paper clarify relevant topics related to the initial work commenced.

Reference 6

Authors: C. Thuesen, L. Hvam (2011)
Title: Efficient on-site construction: learning points from a German platform for housing
Publisher: Construction Innovation Volume 11, Issue 3, Emerald Group Publishing Limited, pp.338-355.

Findings from Thuesen & Hvam (2011) identify central learning points from the German platform such as "off-site manufacturing" that this is not necessarily the most optimal production method, and points out vital organizational matters and target costing as more important.

Credibility: The publishing journal Construction Innovation is ranked to a scientific level of 1 (NSD, 2018) as explained earlier. L. Hvam is also discussed in the previous reference review and is concluded to be a recognized researcher. His co-writer C. Thuesen's publishing record is also of significance within Project Organizing and Management, and Construction Management. Moreover, the research is referred to 39 times (Google Scholar, 2018). Trustworthiness is obtained.

Objectivity: The case study was enabled by a close collaboration with NCC Germany (Thuesen & Hvam, 2011). Findings could be biased in a way that benefit NCC Germany and their strategy and methodology. By promoting good results from methods described as NCC's, a beneficial outcome of the research could be gained. However, the goal was to find learning points from the German platform, but nevertheless statements such as: "platform does not imply that "off-site manufacturing" is the most optimal production method", could be biased towards the sponsored industry. This is something to be aware of when abstracting information from this paper.

Accuracy: Dividing the different sections of research in phases like the development phase and production phase clarifies and simplifies the information given in a structured manner. Abstraction of information comes easy with the paper's set-up.

Relevance: The paper illuminate topics around off-site production and learning points from a German platform industry. Different analogies and examples could be drawn from this paper, and be relevant for further work. Barriers found in this paper could identify logistic problems relevant for the specialization project on similar topics. A Notion from Thuesen & Hvam (2011) is a market comparison of the German and Nordic markets, where the German market is much bigger than the market in the Nordic countries. An implementation of platform based models is therefore easier in Germany. They also mention the cultural and societal deviations, where Germany has a long tradition in industrial production where other regions might not have the same foundation. This information and more has relevance for further work.

Reference 7

Author: P.E. Eriksson(2010)
Title: Improving construction supply chain collaboration and performance: a lean construction pilot project
Publisher: Supply Chain Management: An International Journal, Vol. 15 Issue 5, pp.394-403, Emerald Group Publishing Limited

The paper aims to improve the construction supply chain collaboration and performance through awareness of lean thinking. Nevertheless, the pilot project with application of lean thinking states an example of the effects the adaption celebrates for continuous improvements and development.

Credibility: P.E. Eriksson works for Department of Business Administration and Management, Luleå University of Technology, Luleå, Sweden. He has written several papers about SCM and barriers to partnering. The author and the representing university seem credible. The presentation of the work follows the standards of academic writing, and it is a pleasure to read the paper's structure.

Objectivity: Eriksson (2010) claims the lean-related aspects from his literature review were utilized in the case study conducted. Scientific results from previous research were utilized to improve the construction supply chain and it is therefore hard to find any bias regarding the scientific approach.

Accuracy: The method of research is described, whereas the author was engaged in the case study with an action research approach. Eriksson (2010) describes action research as a suitable approach since it enhances a solution of practical problems and at the same time creates new knowledge. The author is convincing, and the method of search seems trustworthy. The paper was published in 2010, which could mean the findings are outdated. However, the information provided is useful for description of concepts and basic theory in the field, rather than the state of the art research.

Relevance: Keywords from the paper: Lean production, Construction industry, Partnership, Procurement, Supply chain management. The keywords implies relevance to any research projects aiming to improve SCM or understand implementation of lean-aspects to construction industry.

Reference 8

Authors: M. Thunberg, M. Rudberg and T.K. Gustavsson (2017)
Title: Categorising on-site problems: A supply chain management perspective on construction projects

Publisher: Construction Innovation, Vol. 17 Issue: 1, pp.90-111, Emerald Publishing Limited

Thunberg, Rudberg & Gustavsson (2017) identify on-site problems from a supply chain management (SCM) perspective. Furthermore categorizing the problems and concluding with the construction industry's supply chain orientation as inadequate to comprehend with the revealed problems.

Credibility: The authors M. Thunberg (Department of Science and Technology, Linköping University, Norrköping, Sweden), M. Rudberg (Department of Science and Technology, Linköping University, Norrköping, Sweden) and T.K. Gustavsson (Department of Real Estate and Construction Management, Royal Institute of Technology, Stockholm, Sweden) are all from respectable universities in Sweden. They seem credible based on publications and previous work experience.

Objectivity: The paper was funded by "The Development Fund of the Swedish Construction Industry" (SBUF). Hence, SBUF's own website the organization host members of 3,000 affiliated companies in Sweden, which funds different research projects to benefit the industry. The research done in this paper seems to be a resource for development in the construction industry, rather than a promotion of certain techniques of SCM to benefit a specific supplier.

Accuracy: A recent publication date (2017) implies current practices and problems discussed might be very similar to the problems faced by the industry today.

Relevance: Thunberg, Rudberg & Gustavsson (2017) categorize problems with both material flows, internal communication, external communication and complexity in the construction industry. All of these themes are relevant for the specialization project, where one of the goals is to find current logistics problems in the industry. They also conclude that on-site problems often is supply chain related, because of the orientation in the supply chain.

B – Interview Guide

The interview guide is in Norwegian.

Hvem er jeg:

Jeg skriver en masteroppgave for NTNU innenfor retningen prosjektledelse, som er en avsluttende oppgave for studentene ved Bygg- og miljøteknikk i Trondheim. I den forbindelse samler jeg inn data som forhåpentligvis kan brukes i sluttproduktet som skal leveres våren 2019.

Oppgaven:

Innledende arbeider har fokusert på innovative teknologier som kan utnyttes i byggeindustrien for å effektivisere logistikkprosesser, særlig med fokus innenfor industrialisert bygging. Resultater av dette arbeidet ga innblikk i ulike effekter en eventuell implementering av teknologien kan gi.

1. Generelt

a. Kan jeg ta opp intervjuet?

b. Hvilken stilling/ansvarsområde?

c. Hvilket prosjekt?

d. Har prosjektet/bedriften et innovasjonsfokus?

2. Teknologi

a. Til hvilken grad har bedriften oversikt over teknologitrender, hva de kan brukes til og hvilke som allerede blir brukt? (Verktøy og systemer)

b. Er det satt av ressurser til avdelinger som jobber med innovasjon og implementering av teknologi? (Egen avdeling for forskning og innovasjon/ teknologikompetanse internt i bedriften)

c. Hvilken av disse teknologien brukes i prosjektet evt. blir brukt i prosjekter bedriften nå utfører?

i. Prefabrikasjon og modulbasert bygging

ii. Avanserte byggematerialer (Ressurseffektive, resirkulerbare) Ikke så sentralt

iii. Automatisert bygging (3D printing, konstruksjonsprosseser styrt av maskiner)

iv. Augmented reality (Virtuell representasjon av virkeligheten med overliggende informasjon lag)

v. Big data og prediktive analyser Detter er ideen. Maskiner som passer på i sted for folk.

vi. Trådløs overvåking (IoT)

vii. Cloud systemer og sanntids kommunikasjonssystemer

viii. 3D Scanning og fotogrammetri

ix. BIM

d. Om en eller flere teknologier blir brukt. Til hvilken grad brukes den og til hva?

3. Prosess

a. Til hvilken grad har bedriften oversikt over kjerneprosesser og arbeidsoppgaver i nåværende og framtidig drift som kan påvirkes av innovasjon i teknologi?

b. Hvilke problemer (flaskehalser) hindrer arbeidsflyt i dagnes prosesser, og hvilke skritt er gjort for å i møte komme disse i nåværende og framtidige prosjekter?

4. Kompetanse

a. Til hvilken grad er kompetanse for nåværende og fremtidig prosjekt innad i bedriften kartlagt og på hvilken måte?

b. Er denne kompetansen tilstrekkelig? Og hva gjøres for å tette eventuelle hull for å i møte komme fremtidig implementering av innovativ teknologi?

I forbindelse med teknologien nevnt er det interessant å finne ut hvorfor de er brukt eller hvorfor de ikke er benyttet i like stor grad.

5. Implementering

a. Hvorfor/hvorfor ikke er teknologien(e) brukt/ikke brukt?

b. Hva skal til for at de implementeres?

c. Hvilke utfordringer knyttes til allerede implementerte teknologier?

d. Hva er utfordringen med implementering av nye?

e. Er det noen av teknologiene som er implementer bare i spesielt kompliserte prosjekter? Hvorfor?

f. Hvordan implementeres innovasjoner i dag?

i. Identifisering, evaluering, stå ved valget (Commitment), forberedelser, bruk, slutt evaluering. Andre faser.

ii. Er fasene ulike for forskjellige type innovasjoner?

Tidligere arbeider har gitt en pekepinn på potensiell effekt ved implementering, men faktisk effekt i norsk byggebransje er det lite konkrete svar på i nåværende forskning.

6. Effekt

a. Hvilken effekt har implementering av teknologien gitt?

b. Hva kommer denne effekten av?

7. Noe mer å legge til?

C – Veidekke

Description of Veidekke from their own websites (Veidekke , 2019), translated:

Veidekke is one of the largest contractors in Scandinavia. The firm conducts everything from construction, development of projects, road and asphalt maintenance, gravel. Veidekke is recognized from it's involvement and local knowledge.

Facts about the firm from their own website (Veidekke , 2019), translated:

- Largest contractor in Norway
- Yearly revenue of 36 billion NOK (2018), 63 % Norway, 31 % Sweden and 6 % Denmark
- 8 600 employees
- Involvement of stakeholders secures effective production and value for customers
- Employee co-ownership is an important factor of success Profits since 1936

The projects within Veidekke's portfolio are charachterized as "Light house" projects utilized for abstraction are described under. The project presentations are taken from Veidekkes websites. The descriptions are in Norwegian.

Portalen

Totalentreprisen består av et kontorbygg (ca. 17 000 m2), to boligblokker, en næringsetasje med underliggende parkeringskjeller, samt et hotell. Prosjektet er på totalt ca. 55.000 kvm, og ligger like ved jernbanestasjonen på Lillestrøm. Skisse - LPO

Kontorbygget i Portalen er det første BREEAM-NOR prosjektet i Distrikt Oslo. Veidekke har vært med i en utviklingsfase av prosjektet, og har kunnet påvirke hvilke poeng som skal tas helt fra starten av. Dette gjør at vi selv har hatt kontroll på at også de tidlige poengene har blitt gjennomført og dokumentert.

Å sitte i førersete for utviklingen av et BREEAM-prosjekt har gitt oss erfaring og kunnskap rundt hvordan ulike BREEAM-krav kan påvirke et prosjekt og hva man må tenke på i tidligfasen. Det har også skapt økt bevissthet i teamet rundt ulike kvaliteter i et prosjekt, og ikke minst kvaliteter som ikke krever annet enn litt fokus for å oppnå. Frysja

Hagebyen

Hagebyen ligger sentralt på Fornebulandet med Nansenparken som nærmeste nabo og er det nyeste boligprosjektet på Fornebulandet. Totalt er det planlagt 345 boliger i fordelt på fire byggetrinn.

- I Hagebyen har vi boliger til førstegangsetablereren, barnefamiliene og de voksne som vil bytte ut eneboligen med en mer praktisk leilighet. Sammen med flotte private og felles utearealer og unik beliggenhet nær sjø og natur bare en kort busstur unna byen, har dette vært Hagebyens suksessformel, sier prosjektleder for Hagebyen Anders Holmlund i Veidekke Eiendom.

Frysja

Veidekke Entreprenør AS har fått oppdraget med å bygge første trinn av Frysjaparken i Oslo, som består av 169 leiligheter i tre boligblokker. Frysjaparken er eid av OBOS Nye Hjem AS, Stor-Oslo Eiendom m.fl. Stor-Oslo Eiendom har stått for prosjektledelse og utvikling av det nye boligprosjektet, som ved ferdigstillelse vil bestå av over 900 leiligheter og noe næringsvirksomhet. Kontrakten er en totalentreprise med en kontraktsverdi på NOK 413 millioner ekskl. mva. I tillegg er det inngått en intensjonsavtale om utvikling og gjennomføring av neste trinn, som består av ca. 220 leiligheter.

Haakon Skar

Industry 4.0: Potential Effects and Implementation

NTNU
Kunnskap for en bedre verden