Master's thesis

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

Marte Helle Schia

The Introduction of AI in the Construction Industry and its Impact on Human Behavior

Master's thesis in Civil and Environmental Engineering
Supervisor: Ola Lædre and Bo Christian Trollsås
June 2019

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AF GRUPPEN

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Professor in charge/supervisor: **Ola Lædre**				
Other external professional contacts/supervisors: Bo Christian Trollsås (AF Gruppen)				

Abstract:

The digital shift has arrived in the construction industry, with the aim of increasing production efficiency. However, how should the industry implement digital tools? And how should a human-technology relationship work? The purpose of this thesis is to illuminate how the construction industry can close the gap between the potential benefits and the harvested benefits of implementation of AI. The research is based on a comprehensive literature review, a case study of a construction project in Norway, and three external interviews. The case study consists of a document study and eighteen semi-structured interviews.

The findings indicate that it is possible to gain experience from the implementation of basic digital technology when implementing advanced technology, such as artificial intelligence (AI). However, human-AI trust is considered the most decisive factor for successful implementation of AI. This thesis constitutes a piece of pioneer work, as it investigates the implementation of how humans and AI technology should work together.

This research is limited by one case study and three digital tools. Further research is recommended to discuss the adaption of AI on the users' premises, collect more empirical data and to look into experiences done by other industries and other countries.

Keywords:

1. Artificial Intelligence
2. Digitization
3. Implementation
4. Collaboration
5. Trust

Preface

This master thesis is written as a closure of the five-year master program in *Civil and Environmental Engineering* at the Norwegian University of Science and Technology (NTNU). The thesis is written as part of a specialization towards *Building and Material Engineering* at the Department of Civil and Environmental Engineering and Faculty of Engineering during spring 2019, and counts toward 30 credits.

I was introduced to the topic by Bo Christian Trollsås in AF Gruppen, in August 2018, in connection with my project assignment (7.5 credits) autumn 2018. Bo is a former colleague through summer jobs and has also been my external supervisor during this thesis.

My choice of writing about the implementation of Artificial Intelligence (AI) in the construction industry was mainly based on three factors. Firstly, the motivation provided by Bo's engagement and interest in the topic. Secondly, the fact that I found the combination of writing about humans, technology, and how they can best work together fascinating, and thirdly that I found it especially exciting to immerse myself in such an unexplored topic.

I hardly knew what AI was, and I had little knowledge about the digitization of the construction industry. Today it is approximately ten months since I was introduced to the topic. The last ten months have provided me with new knowledge and experiences, and the motivation to continue learning more about AI and how it can be successfully implemented in the construction industry. Knowledge, experiences, and motivation I hope will be beneficial and useful for the construction industry as well as my own future career.

The structure of this master thesis differs from the traditional thesis as it contains three parts: (1) Master thesis report, (2) Conference paper, and (3) Appendix.

Trondheim, June 10, 2019

Marte Helle Schia

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The work involved in this master thesis has been demanding, interesting, and educational. In connection with the thesis and conference paper, I would like to give special thanks to the following persons:

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Secondly, I want to give acknowledgment to my supervisor at NTNU Ola Lædre (Associate Professor, dr.ing., Department of Civil, and Environmental Engineering). Thanks for your guidance, feedback, and support with the master thesis as well as the conference paper. The idea of submitting a conference paper to the International Group of Lean Construction Conference (IGLC) 2019 can be credited to you.

Thirdly, I want to thank Håkon Fyhn (Senior Researcher, Department of Social Research, NTNU) for informative and useful inputs to and feedback on the conference paper as well as the master thesis.

I would also like to thank all members of the case study, Team Bispevika, for being generous and welcoming. Interview participants deserve special recognition for taking time out of their busy schedules to make the study a possibility.

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Lastly, a big thank should be directed to my fellow students at Civil and Environmental Engineering and Torjus. Thanks to you guys, I can look back at five unforgettable years at NTNU in Trondheim.

Abstract

Even though the construction industry has developed a long way since its beginnings, the technology that can remold the industry has not yet found a place. The digital switch has now arrived in the construction industry, aiming to increase production efficiency. Artificial Intelligence (AI) is a subfield of computer science and can be seen as the ability of a machine to mimic intelligent human behavior, seeking to use human-inspired algorithms to approximate conventionally challenging problems. AI differs from lower degrees of digitization due to its complexity. The complexity of AI results in new prerequisites concerning trust and collaboration with humans. This thesis constitutes a piece of pioneering work, as it investigates the implementation of AI and how humans and AI-based technology should work together.

The purpose of this thesis is to illuminate how the construction industry can close the gap between the potential benefits and the harvested benefits of the implementation of AI. The gap has been identified by looking into the possible benefits of implementing AI and today's harvested benefits of and barriers to implementing AI in the construction industry.

This thesis presents research based on a comprehensive literature review, a case study of Team Bispevika, a construction project in Oslo, Norway, and three external interviews. Eighteen case-specific interviews have been conducted in addition to a document study. The case study is restricted to looking at three digital tools, which represent three different levels in the implementation process as well as three levels of digitization.

The findings of this study reveal that AI's ability to analyze millions of datasets, continuously learn from the data generated, and the fact that AI-based technology acts on statistics, can result in several possible benefits in the construction industry. AI has come to stay, and a successful implementation of AI can result in increased productivity, increased safety, and constructions with higher quality.

The construction industry is currently on the start-line of the implementation of AI-based technology. However, this study shows that it is possible to gain experience from the implementation of basic digital technology when implementing advanced technology, such as AI. User-friendly tools, a well-defined training strategy, willingness and motivation to learn, and trust and respect between contractors are factors that are decisive for a successful implementation of basic digital technology and can also be considered decisive when implementing AI-based technology.

In order to close the gap between the future and current situation a strategy for collecting a sufficient amount of high-quality data must be developed. However, human-AI trust is concluded to be the most decisive factor in exploiting the benefits brought by AI-based technology. Essential factors for obtaining human-AI trust are concluded to be the following: transparent AI-systems, human-AI interaction, education, time, and experience.

Further work should investigate projects abroad, in addition to looking at other industries to learn from their experiences. It is also recommended to follow the implementation of AI in Team Bispevika and see how the implementation takes place in practice. This work should involve looking into a potential strategy for collecting data and mapping how much transparency and interaction is needed in the AI-system to obtain a sufficient level of Human-AI trust.

Sammendrag

Teknologien som kan revolusjonere byggebransjen har enda ikke funnet sted. Det digitale skiftet har nå ankommet med ambisjoner om å effektivisere byggebransjen. Kunstig Intelligens (AI) er et underfelt av datavitenskap og kan defineres som en maskins evne til å etterligne intelligent menneskelig adferd. Det gjøres ved bruk av menneskelig inspirerte algoritmer for å løse utfordrende problemstillinger. AI basert teknologi skiller seg fra andre digitale teknologier grunnet dens kompleksitet. Den teknologiske kompleksiteten resulterer i nye forutsetninger relatert til tillit og samarbeid med mennesker. Denne masteroppgaven er en pilotoppgave, som undersøker implementeringen av AI, og hvordan mennesker og AI-basert teknologi bør samarbeide.

Formålet med oppgaven er å belyse hvordan byggebransjen skal lukke gapet mellom de potensielle fordelene og de høstede fordelene ved implementering av AI. Gapet er blitt identifisert ved å se på mulige fordeler ved å implementere AI og dagens høstede fordeler og barrierer ved implementeringen av AI i byggebransjen.

Denne oppgaven presenterer forskning basert på en omfattende litteraturstudie, en case-studie av Team Bispevika, et byggeprosjekt i Oslo, Norge og tre eksterne intervjuer. Atten case-spesifikke intervjuer er utført i tillegg til en dokumentstudie. Case studiet har blitt avgrenset til tre digitale verktøy, som representerer tre ulike faser i implementeringsprosessen, samt tre nivåer av digitalisering.

Studien viser at det er flere potensielle fordeler ved å implementere AI i byggebransjen, gjennom evnen til å analysere data, kontinuerlig læring, og avgjørelser basert på statistikk. AI har kommet for å bli, og en vellykket implementering av AI kan føre til økt produktivitet, økt sikkerhet og konstruksjoner med høyere kvalitet.

Byggebransjen befinner seg på startstreken når det gjelder implementeringen av AI−basert teknologi. Studien viser imidlertid at en kan dra nytte av erfaringene gjort ved implementeringen av mindre komplekse digitale verktøy ved implementeringen av avansert teknologi, som AI. Brukervennlige verktøy, en veldefinert opplæringsstrategi, vilje og motivasjon til å lære, tillit og respekt mellom entreprenører er faktorer som er avgjørende for en vellykket implementering av mindre komplekse verktøy. Disse faktorene kan også betraktes som avgjørende ved implementering av AI-baserte verktøy.

Sett i betraktning av de potensielle fordelene og dagens situasjon kan det konkluderes med at det må utvikles en strategi for innsamling av en tilstrekkelig mengde data av høy kvalitet. Imidlertid er tillit mellom mennesker og AI-basert teknologi å anse som den mest avgjørende faktoren for å høste fordelene AI-basert teknologi muliggjør. Sentrale faktorer for å oppnå tillit mellom menneske og AI-basert teknologi kan konkluderes med å være følgende: Gjennomsiktighet i AI-systemet, interaksjon mellom menneske og AI, opplæring, tid og erfaring.

Videre arbeider bør undersøke prosjekter i utlandet, i tillegg til å se på andre næringer å dra nytte av deres erfaringer ved implementeringen av AI. Det anbefales også å videre studere implementeringen av AI i Team Bispevika, for å se hvordan implementeringen utarter seg i praksis. Videre arbeider bør også innebære å se på en potensiell strategi for innsamling av data, samt kartlegging av hvor mye gjennomsiktighet og interaksjon som er nødvendig i AI-systemet for å oppnå tilstrekkelig tillit.

PART 1: MASTER THESIS REPORT

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Acronyms

AI Artificial Intelligence

BIM Building Information Modelling

CS Computer Science

DL Deep learning

DS Data Science

FLS Fuzzy Logic System

HSE Health safety and environment

IGLC International Group of Lean Construction Conference

IT Information technology

LIME Local-interpretable-model-agnostic

LPS Last Planner System

ML Machine learning

NTNU Norwegian University of Science and Technology

OSU Oslo S Utvikling

PPC percentage of assignments completed

ROAA reliability-objectivity-accuracy-aptitude

TFV Transformation-flow-value theory

Chapter 1: Introduction

This chapter presents the background for the topic to investigate and analyze, why this is a topic of interest, the research's limitation and the structure of the thesis.

1.1 Background

The construction industry is one of the world's oldest industries, beginning with the building of stone houses and the carpenter felling trees, drying them and cutting his boards from the raw timber. For centuries the building industry and its culture were advanced and probably superior in comparison with other industries (Kristensen, 2011).

However, like almost every other industry the construction industry has developed significantly over time, as illustrated in Figure 1.1. The list of changes that have shaped the modern world of work is long and technology forces change upon companies and people. Although the industry has developed significantly the industry has maintained its old craft-based traditions and culture (Kristensen, 2011).

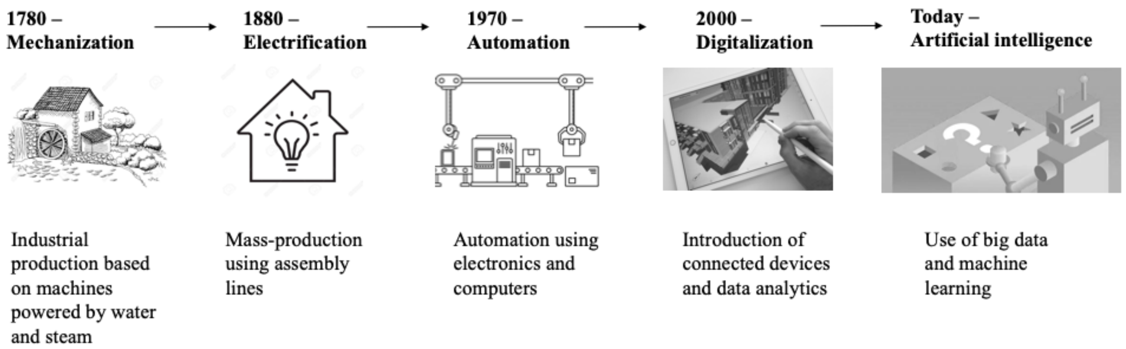


Figure 1.1: Stages of development in the construction industry

In a period when virtually all other industries have increased their productivity [1] owing to industrialization [2], the productivity of the construction industry has decreased or stagnated (Kristensen, 2011). Surveys show that the construction industry is the third-to-least digitized industry in the world, only ahead of agriculture and hunting (Agarwal, Chandrasekaran, and Sridhar, 2016). However, the construction industry differs from other industries with its relatively high share of the work taking place on the construction site, its more or less uniquely defined objectives, its set deadlines, the non-routine character of its tasks, and its complexity, which requires effort from several different kinds of specialists (Kristensen, 2011).

[1] A productivity measure is expressed as the ratio of output to inputs used in a production process. With other words: Output per unit of input. Source: http://www.businessdictionary.com/definition/productivity.html

[2] Industrialization is the process by which an economy is transformed from primarily agricultural to one based on the manufacturing of goods. Individual manual labor is often replaced by mechanized mass production, and craftsmen are replaced by assembly lines. Source: https://www.investopedia.com/terms/i/industrialization.asp.

The German-American architect Ludwig Mies van der Rohe defended the following in 1924 (Futagawa and Pawley, 1970):

Industrialization is about fundamentally remoulding the whole building trade and NOT about rationalizing existing working methods

Futagawa and Pawley (1970)'s statement has remained valid for the construction industry until today, but something is about to change. The construction industry is currently experiencing a transformation from traditional, hierarchically organized construction sites to digital and more autonomous ones. With the aim of increasing the production efficiency of the construction industry, AI-based technology is now entering the industry (Salehi and Burgueño, 2018). Many digital tools have simplified human-related work, but a key reason for building AI systems is not just to match human performance, but to exceed it. AI could be the technology that will fundamentally remold the construction industry. However, the complexity of AI results in new challenges compared to less complex technology, challenges such as new prerequisites concerning trust and collaboration with humans.

There is plenty of published literature concerning the implementation process and AI as two separate fields of research. However, there is a lack of published research regarding the implementation of AI; and this area is especially under-explored within the field of construction. By addressing the above-mentioned this thesis contributes toward pioneering work. It investigates the implementation of AI in the construction industry, with a main focus on how humans and AI can form an effective collaboration that can achieve innovative breakthroughs that the industry would never have achieved with humans and AI working separately (McCaffrey and Aceves-Fernandez, 2018).

1.2 Purpose and research questions

The purpose of this master thesis is to illuminate how the construction industry can close the gap between the potential benefits and the harvested benefits of the implementation of AI-based technology.

In order to find a way of closing this gap, the following two research questions have been developed:

1. *What are the potential benefits of implementing AI in the construction industry?*
2. *What are the harvested benefits of and barriers to the implementation of AI in the construction industry today?*

1.3 Scope of the study and limitations

Time frame
This thesis is conducted by one student in spring 2019 at NTNU. It counts towards 30 credits and was conducted over the course of *20 weeks*. It is reasonable to assume that a longer time frame would lead to a more representative and valid result, unveiling a larger and more valid image of the implementation of AI-based technology in the construction industry. The limited time frame has made it challenging to follow the whole implementation process throughout every phase.

Knowledge level
Before starting the thesis, the author had *limited knowledge* of AI, as it has not been a part of the learning objectives of other courses. However, the author acquired some general knowledge concerning the implementation processes and AI during the autumn 2018 project assignment, in addition to the knowledge acquired during the master thesis.

Industry
This thesis is limited to considering the implementation of AI-based technology in the *construction industry*. This is a natural limitation since the thesis constitutes the author's final work of the five-year master program in Civil and Environmental Engineering.

Country
The research in this study will be carried out in a *Norwegian context*, while bearing in mind that specific Norwegian development trends and solutions might deviate from those found in other countries.

Construction phase
In construction, the scope of implementation of AI can be fairly broad, encompassing all stages of the construction life-cycle, from the initial design, through to the actual construction of the building or structure on site. Even after the structure has been completed. This study is limited down to look at the implementation of AI in the *construction phase*, the building of structure on site. This is considered the phase that is less digitized (Mahbub, 2008), which strengthen the relevance of this assignment.

Literature study
The literature search has been limited to mainly consisting of *eight searching phrases*. The limitation of searching phrases may result in the exclusion of relevant information. The literature search has also been limited to *English and Norwegian literature*.

Single case study
This master thesis is mainly based on a *qualitative single-case study*, further described in Chapter 2, Methodology. Furthermore, the author decided to only look into the *operating department* at the case study. This decision was based on the time frame and the fact that the operating department is most suitable considering the study of digital tools. In addition, it was decided to focus on *three digital tools* in the project.

Conference paper
Part 2: Conference Paper, is limited in size, and thus there is a potential information loss. The potential information loss resulting from this limitation is evened out in *Part 1: Master thesis Report*, which is longer and more detailed in all stages.

1.4 Structure

The structure of the master thesis differs from traditionally thesis as it contains of three parts. (1) Master thesis Report, (2) Conference Paper, and (3) Appendix.

1.4.1 Structure Part 1: Master thesis report

Chapter	Description
Introduction	Chapter 1 presents the assignment's background, the purpose, problem description, the limitations of the study and its structure.
Methodology	Chapter 2 consists of a thorough description of how the author has gone forward to answer the primarily purpose and accompanying research questions. The methods used are literature study, case study and external interviews.
Theoretical framework	Chapter 3 presents a selection of relevant theory and research considering the topics implementation and human behavior, AI, and human-AI collaboration.
Findings	Chapter 4 presents the findings from the empirical data collection: external interviews and case study.
Discussion	Chapter 5 discuss the findings from the empirical data towards the already existing literature stated in Chapter 3, Theoretical Framework. The discussion does also contain personal opinions and views of the author. The aim is finding corresponding contexts, moments and elements of interest to the study's problem statement.
Conclusion and Further Research	Chapter 6 carries out the purpose of the assignment by answering the primary purpose and accompanying research questions, in addition to recommendation for further research on the topic

Table 1.1: Structure of the master thesis report, inspired by Olsson (2011)

1.4.2 Structure Part 2: Conference Paper

Part 2: Conference Paper presents a scientific article, in the form of a conference paper. The conference paper is compiled as a contribution to the IGLC, which will take place July 1-7 2019, Dublin, Ireland. The article was approved by two independent reviewers and were published in proceedings for the conference during the summer 2019. The conference paper follows the guidelines given by the conference of IGLC 2019, thus a page limitation of ten pages excluded reference list. The structure of the paper is illustrated in Figure 1.2.

Figure 1.2: Structure Part 2: Conference Paper

1.4.3 Structure Part 3: Appendix

Part 3: Appendix consists of the following supplementary documents:

1. Description of the search engines used in the literature study
2. Interview guide
3. Explanation of AI's human level performance milestones
4. Planning structure, Project Bispevika, Department of Operation

Chapter 2: Methodology

The methodology contains the methodological choices the author have made, why, and the consequences of the election. The purpose is to give the reader a good insight into the assignments underlying work, so the research is transparent and able to verify (Everett and Furseth, 2012; Tjora, 2017). At the beginning of this chapter, a description of methodological concepts will be presented, followed by the choice of method. Finally, a stepwise explanation of the author's strategy of collecting data, analyzing data and an evaluation of the collected data's validity, reliability, and generalizability.

2.1 Research Methodology

Correctly research begins with a deeper look into the already existing research and literature. Based on the already existing literature, a knowledge gap is identified. Further, with the aim of closing the knowledge gap, research questions are developed (Eisenhardt and Graebner, 2007). In order to conduct research of high quality and reliability several choices regarding the research method must be made. All choices are related, and one choice will further impact the remaining choices (Busch, 2013). This section presents methodological concepts that will be used throughout this thesis.

2.1.1 Intensive and extensive design

Busch (2013) distinguishes between an *extensive* and *intensive* research design. An extensive design is characterized by information collected from many sources, for example through a survey. An intensive research design collects data from fewer sources compared to an extensive design, for example through interviews. An intensive design is preferable if it is desirable to look into a complex problem with many variables. In the case of a more limited formulation it is more practical to choose an extensive design. The results of an intensive research design are often based on a smaller amount of data compared to an extensive research design, which makes it harder to transfer the results to, for example, other projects. However, the choice between an extensive and intensive research design should be seen in the light of the purpose of the assignment and its research questions (Busch, 2013).

2.1.2 Qualitative and quantitative methods

Busch (2013), Dalland (2017), and Yin (2009) distinguish between *qualitative* and *quantitative* research methods. The question of whether to use a qualitative or quantitative method or a combination of qualitative and quantitative methods is closely related to the choice of an extensive or intensive research design (Busch, 2013). Qualitative methods collect data in the form of text, and the analysis stage consists of interpreting the text. This method is suitable for analyzing complex phenomena and is often combined with the choice of an intensive research design. Quantitative methods are used with data that is quantified, such as numbers, and the analysis consists of the evaluation of statistics (Dalland, 2017). Quantified data is easy to collect and analyze compared to data that is gathered using a qualitative method (Busch, 2013). Quantitative methods are often used when choosing an extensive research design. A quantitative design makes it easier to handle a great amount of data, but in order to perform advanced analysis clearly defined limitations are required, in some cases at the expense of the quality of the research. A qualitative design will, on the other hand, make it easy to look into a complex problem, but it can be difficult to generalize the results to other situations. A combination of the two designs is also an option. The researcher will then get the opportunity to exploit the benefits of both methods, but on the other hand, this approach will require considerably more time. In any case, the method chosen, whether a single method or a combination, should depend on the study's purpose and its research questions (Yin, 2009; Busch, 2013).

2.1.3 Triangulation

Triangulation consists of using more than one method to illuminate a topic (Bryman, 2004). Different methods may give different data and different findings, which again will impact the interpretation of the findings. The purpose of using triangulation is to study the topic from several angles and by doing so increase the research's validity and reliability (Yin, 2009). Surveys, case studies, literature studies, document studies, interviews, and observations are methods that are often combined.

2.1.4 Validity, Reliability and Generalizability

All methods used during the research will impact the quality of the results. Validity, reliability, and generalizability are concepts related to the quality and trustworthiness of the research. Research should aspire to high validity and reliability (Busch, 2013).

The *validity* of the research is an indication of how well the data aligns with the theory. In other words, how representative the data is (Samset, 2015). The information given has no value without validity, as it does not contribute to the purpose of the research. It is therefore important that the researcher formulates questions that substantiate the possibility of fulfilling the research's purpose. *Reliability* is linked to the consistency of the data, i.e. how well different findings confirm each other (Samset, 2015). The reliability is also linked to the verifiability of the results. Would another researcher be able to verify the results if the study was repeated? *Generalizability* indicates the possibilities of transferring the results to other situations. Whether generalizability is beneficial or not will depend on the purpose of the research (Busch, 2013).

2.1.5 Data Analysis

Unit of analysis are concepts that describes the frame of what is being analyzed in the study, while *level of analysis* point of the location, size, or scale of the research target (Yin, 2009). Unit of analysis considers which data needs to be collected, measured and analyzed. Level of analysis defines the level on which the phenomena should be studied. Should the phenomena take into account a whole industry, a firm, a project, a team or only one individual?

2.2 Choice of method

For this study, an *intensive research design* is chosen, due to the broad formulation of the research questions presented in Section 1.2, Purpose and research question, and based on the knowledge gap discovered through the literature search.

Further, a *qualitative method* was chosen for this study. The choice of qualitative research methods corresponds to the choice of an intensive research design (Busch, 2013). The topic is unexplored, which makes it challenging using a quantitative method, as it requires a significant amount of data. Compared to quantitative methods, qualitative methods are more based on subjective interpretation. The author's interpretation of the collected data can therefore be considered a possible source of error. *Triangulation* of the methods literature study, interviews, and document study has been used, in order to illuminate the subject from several approaches, and increase the research's validity and reliability.

With the intention of finding already existing research on the topic, identifying knowledge gaps and increasing the author's knowledge level on the subject, a *literature study* was chosen as a method. The literature search revealed a lack of published literature on the implementation of AI in construction, which emphasizes the choice of an intensive research design and qualitative methods. Based on the lack of existing research on the topic, it was necessary to collect empirical data. The fact that little or none projects in Norway have started the implementation of AI-based technology made the use of quantitative methods difficult, as these methods require a significant number of informants. The *level of analysis* was therefore restricted to a case study of one project, in addition to three external companies with expert knowledge of AI. Considering the lack of knowledge regarding AI among the project members, the current stage of the implementation of the digital tools, and the research's purpose, it was decided that *interviews* and *document study* would be suitable methods for data collection.

Three *external companies* were contacted due to the lack of implementation of AI-based technology in the construction industry. The aim of contacting external companies was to learn from and take advantage of the experiences of other industries. *Interviews* were chosen as a suitable method for collecting data, due to the possibility of asking follow-up questions, and having a conversation.

In addition to the systematic research conducted, has the author's presence at the case study for two weeks made it possible to conduct several *informal* conversations and observations. The author did also participate in a workshop with and about the implementation of one of the digital tools (ALICE). To increase the author's level of knowledge considering AI, have the author conducted an AI online course, named *Elements of AI* [1]. The impression and information given from the presence at the case-study, workshop, and AI course have been beneficial for the master thesis, even though they were not carried out according to a systematic research methodology.

[1]https://course.elementsofai.com/

2.3 Literature study

Science is about further developing what researchers have already developed (Busch, 2013). Two literature searches [2] and literature studies [3] were conducted to get an overview of the already existing literature and research. The first was conducted during the project assignment, autumn 2018. The first literature search and literature study mapped basic literature regarding the implementation process and general digitization of the construction industry. Based on the literature search and literature study of autumn 2018, the chosen case study and the author's interest in AI, the master thesis was limited to looking into the implementation of AI-based technology. Due to this limitation, the second literature search and literature study, conducted spring 2019, were focused on the implementation of AI.

Both literature studies are based on the procedure written in Bloomberg and Volpe (2012). The following sections will be structured as follows:

1. Identification and collection of literature
2. Review of the literature
3. Critique of the literature
4. Conceptual framework

2.3.1 Identification and collection of literature

The literature search and literature study was carried out using several acknowledged databases, journals, conference articles, articles, books, and snowballing in addition to recommendations from supervisors. The recommended literature was recommended through discussions and supervision and established a starting point for finding literature in the search engines. The search engines used was Oria, Scopus, Ei Compendex, Science Direct, Google Scholar and Google. Further description of the databases is given in Appendix 1, Search engines. The broad spectrum of databases used, increased the probability of finding relevant literature. However, in order to identify relevant literature in all the databases it was necessary to develop a *search strategy*. The author first searched widely in order to get an overview of the available and most acknowledged literature. Later, the search was more specific, in order to find literature of high quality and relevance. The following questions were asked when evaluating the relevance and quality of the sources:

- Does the literature fit the subject?
- Where is the literature published?
- Which year was the literature published?
- Is the literature peer-reviewed?
- Does the literature follow the IMRAD [4] format?
- Is the research method of high quality?
- Has the author made use of relevant and reliable sources?
- What is the h-index [5] of the author?

[2]A literature search is a systematic, thorough search of all types of literature concerning the relevant topic.

[3]The literature study should enumerate, describe, summarize, objectively evaluate and clarify the previous research. It should give a theoretical base for the research and help the author determine the nature of his/her research.

As illustrated in Figure 2.1, considering each subject separately (implementation/human AND behavior and AI), there was plenty of available literature. However, a lack of literature was found when combining the subjects. The lack of literature on the topic strengthens the relevance of this assignment.

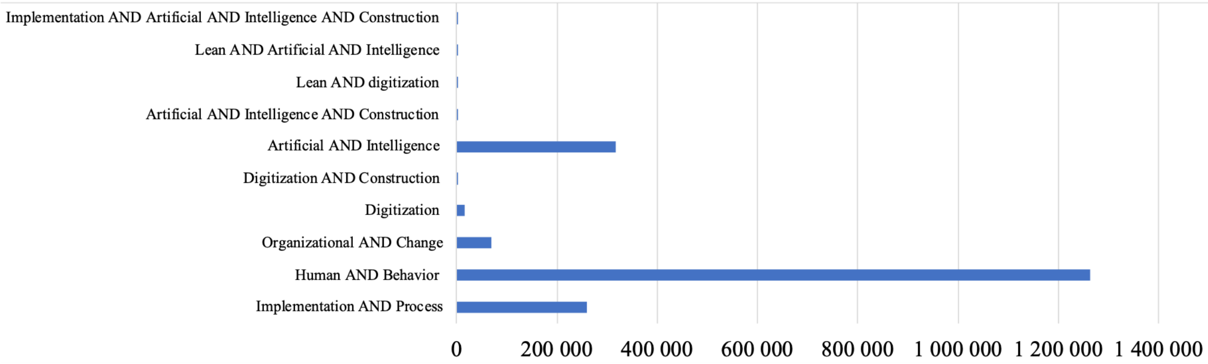


Figure 2.1: Searching phrases and number of hits on the searching engine Scopus

2.3.2 Review of the literature

Based on the minimum requirements for quality and relevance mentioned in the list above, the chosen literature was read through. In digital books and articles the searching function cmd (f) was used to find the relevant information. The literature was further evaluated after the reliability-objectivity-accuracy-aptitude (ROAA) principles described in Table 2.1 [6]. The literature that fit the bullet list above, in addition to passing the evaluation using the ROAA principle, constitute most of the sources found in the bibliography. Figure 2.2 shows the diversity in sources used.

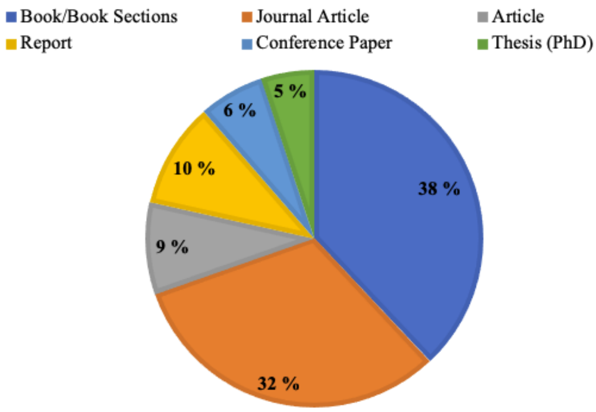


Figure 2.2: Presentation of sources

[4]Introduction - Method - Results and Discussion. Is a way of structuring a scientific article. More information can be read at: https://sokogskriv.no/category/skriving/oppgavens-struktur/imrad-modellen/

[5]H-index, or Hirsch-index, is a bibliometric measure of a researcher's scientific publication and influence in the academic literature. The number is calculated based on the number of published works and the number of times each work is cited.

[6]The information given in the table is taken from the following webpage: https://innsida.ntnu.no/wiki/-/wiki/Norsk/Finne+kilder

Table 2.1: Explanation of the ROAA principle

Criterion	Explanation of criterion. What is evaluated?
Reliability	Is the source trustworthy? The author's qualifications, acknowledgment, h-index, education, and job.
Objectivity	Is the source neutral? Lack of conflict of interest, balance in the given information, lack of exaggeration.
Accuracy	Do the reader find negligence, cheating and errors? Year of publication, scope, level of detail, matter-of-factness, bibliography, and correspondence to other sources.
Aptitude	Does the source contribute to the research's purpose? Relevance and subject area.

2.3.3 Critique of the literature

When selecting literature it has been essential to evaluate the sources' *validity, reliability, and generalizability* to ensure this study's quality. As mentioned above, a search strategy was developed and used to collect sources of high relevance and quality. This assignment aims to reveal how to close the gap between the current and future use of AI in construction. *Valid* literature is in this context the research and publications of the most known authors within the respective topics. These authors' research is assumed to be especially *reliable*.

Within the subjects implementation, organizational behavior, and organizational change John Arnold, Ray Randall, Stephen Swailes, Barbara Senior, Paal Roland and Elsa Westergaard are known internationally and nationally. All are professors and researchers within their field of knowledge. For the field of AI and human-AI collaboration the work of several authors have been consulted for this study. The authors have been found through the use of the search strategy and recommendations of Professor Agnar Aamodt[7], a professor in Computer Science and Artificial Intelligence at NTNU. The majority of the sources concerning AI are taken from different journals. Journal articles present the most recent research on a specific topic, are peer-reviewed and written by experts for experts.

Due to the lack of peer-reviewed research regarding the implementation of AI in the construction industry has there also been taken in use sources that do not have all the criteria mentioned in Section 2.3.1 and Section 2.3.2. This literature is shown as reports and articles in Figure 2.2. One example, is reports and articles published by McKinsey & Company [8], which are not peer-reviewed. Although the reports and articles include the authors, their experience and published date, one must look at the literature with critical eyes. McKinsey & Company is a consulting company that wants to sell its services. Based on this are the sources not considered neutral.

The search reveals a lack of valid literature concerning the implementation of AI in the construction industry. It was therefore necessary for the author to take advantage of the experiences of other industries, such as the Information technology (IT) industry where it was reasonable to assume that these experiences could be *generalized* to the construction industry.

[7]https://www.ntnu.edu/employees/agnar
[8]https://www.mckinsey.com/

2.3.4 Conceptual framework

The findings from the two literature studies are presented in Chapter 3 as the theoretical framework of this assignment.

2.4 Empirical data

Figure 2.3 illustrates the timeline of collected empirical data. Nine of the case-specific interviews were conducted during the work with the project assignment. These nine interviews took place 7-9 November 2018. With the aim of studying and taking advantage of how other industries used AI, three external interviews were conducted at the beginning of March 2019. Experiences and new information from these interviews were further used in the nine case-specific interviews conducted between 18 and 28 March 2019. The following sections will be structured after case study and external interviews.

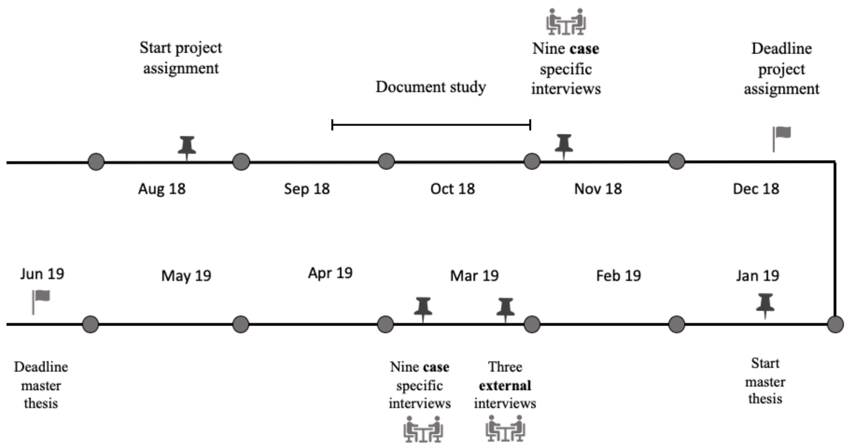


Figure 2.3: Timeline - Empirical data

2.4.1 Case study

According to Yin (2009) the choice of research method should aim to choose the method that can answer the research questions and the purpose of the assignment in the best possible way. In the domain of project management there are five main methods that are normally used: experiment, survey, archival analysis, history and case studies. The case study method is suitable when the research aims to exploit *how* and *why* social phenomena act as they do (Yin, 2009). This assignment aims to explore *how* to close the gap between the current and future implementation of AI in the construction industry. Based on the purpose of this assignment, a case study was chosen as a suitable method for collecting and analyzing data. The case specific data collection consists of document study and interviews, used to triangulate the information from the case study. The conscious and correct use of multiple sources of data collection strengthens the quality and validity of the research (Yin, 2009).

Case studies can be conducted as multiple case studies or as one single case study. Multiple case studies collect data from several cases, for example, several building projects. A single case study collects data from, for example, one building project. A single case study can be convenient when there is a lack of research on the phenomenon and its extent and situation (Yin, 2009). The two most obvious challenges related to a single case study is the possibility of low transferability of results to other cases and the effect of other variables than the ones included in the study (Tjora, 2017). A single case study was chosen, due to the lack of research considering the phenomenon. As the data collection is from a single case study, the story and context of the case study needs to be presented as a narrative, in order for the analysis and findings to be credible as part of a qualitative study (Eisenhardt and Graebner, 2007). The information presented in the following sections originate from the website of the main contractor [9], the project website [10], and from information given by the author's supervisor [11] at the project.

AF Gruppen

AF Gruppen is the main contractor for the chosen case study. Key information about AF Gruppen is presented in Table 2.2.

Table 2.2: Key information: AF Gruppen

Key information	Description
Company	AF Gruppen
Business activities	Construction, Building, Environment, Property, Energy , and Offshore
Offices	Norway, Sweden, United Kingdom, Poland, and Lithuania
Annual turnover 2018	NOK 18 767 million
Vision	Clearing up the past, building for the future. (Vi rydder fra fortiden, og bygger for fremtiden)

Project Bispevika

Table 2.3 presents key information about Team Bispevika.

Table 2.3: Key information: Team Bispevika

Key information	Description
Project name	Team Bispevika
Contractor	AF Byggfornyelse, AF Energi og Miljø and AF Anlegg
Location	Oslo, Norway
Contract	Partnership contract
Project owner/client	Oslo S Utvikling (OSU)
Contract price	NOK 4-5 billion
Type of constructions	Apartments and commercial properties (restaurants, culture, stores etc.)
Time frame	March 2017-est.2024

[9] https://afgruppen.no/prosjekter/bygg/bispevika/
[10] https://boibjorvika.no/vannkunsten
[11] Bo Christian Trollsås (Site Manager/Planner & Development VDC at AF Gruppen)

Project Bispevika was chosen as the only case, as it is the first and currently the only project in Norway that has started the implementation of AI-based technology to support scheduling. It is likely to believe that it is also the first construction project implementing any AI-based technology in Norway. Project Bispevika was a suitable case to investigating the phenomena based on its non-traditional way of working regarding innovative processes and tools and the fact that a project of its scale seems a perfect testing ground for implementations due to the possibility of learning and of having the same people improving the implementation along the way.

The project consists of several building stages, which are divided between Bispevika north and Bispevika south. Bispevika north is the area surrounded by the orange line in Figure 2.4 [12]

Figure 2.4: Illustration of Bispevika north

Bispevika north is under construction and consists of 355 apartments and 8000m^2 commercial space. The north part is planned to be finished in quarter four July 2020. The construction of Bispevika south started in March 2019. Project Bispevika's official statement states that the project is an "interaction project" between the client and the main contractor. The vision behind the collaboration between AF Gruppen and Oslo S Utvikling (OSU) is a result of the mutual goal of creating competitive advantage in order to change the industry.

[12] The picture is taken from the following webpage article: http://ostkantliv.blogspot.com/2013/02/her-er-nesten-nye-bispevika.html

Digital tools
The purpose of this thesis is to illuminate how to close the gap between the current and future implementation of AI-based technology, with Bispevika as a case study. The research has further been narrowed down to look mainly at three digital tools used in Bispevika. The three tools are chosen based on their different level in the implementation process and difference in the level of digitization, as illustrated in Figure 2.5 [13].

Touchplan represents the first level of digitization and has been in use at the project for one year. The tool is assumed in the late implementation phase. Synchro represent the second level of digitization; digitalization and is considered in the midway of the implementation. ALICE represent the third level of digitization; digital transformation and is considered in a early testing stage.

Only one of the three tools (ALICE) is based on AI-technology. The reason for studying the two non-AI based tools (Touchplan and Synchro) is to learn from the implementation of a lower level of digitization and take advantage of these experiences when implementing more advanced tools, such as ALICE. The three tools are further described in Section 3.2.1, Artificial Intelligence. The following section will introduce the procedure used to collect case-specific data.

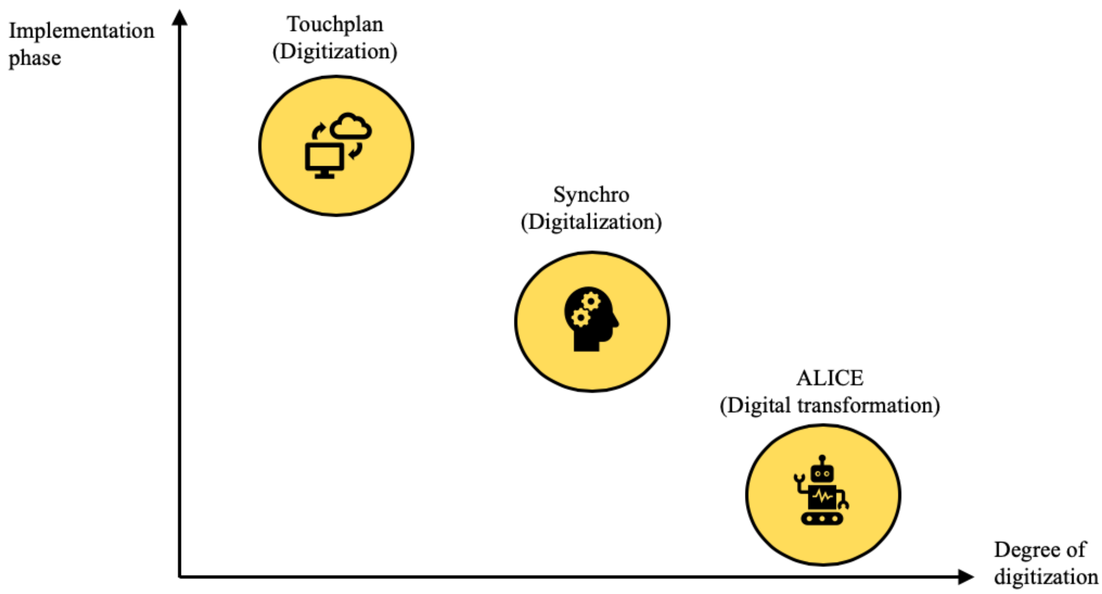


Figure 2.5: Touchplan, Synchro, and ALICE: implementation phases and levels of digitization

Interviews
Interviews are one of the most central qualitative research methods, intended to prompt the informant to reflect on their own experiences and opinions related to the topic of research (Roller and Lavrakas, 2015; Yin, 2009). As a method the interview is targeted and focuses directly on the topic of the case study. The next sections describe the data collection, data analysis and the validity, reliability and generalizability of the case-specific interviews.

[13]The figure is made by the author to illustrate the difference in the implementation process as well as the difference in the level of digitization.

Data collection
Appropriate interviewees need to be identified, as the results will depend on the chosen informants (Tjora, 2017). Choosing interviewees was done in collaboration with the external supervisor from AF Gruppen. As shown in Figure 2.3, nine of the case-specific interviews were conducted in November 2018 and the remaining nine in March 2019. The interviewees were chosen based on their experience with digital tools, their mindset concerning digitization, age, and position. An attempt was made to choose persons with different levels of experience, knowledge and age, in order to strengthen the validity and generalizability of the research. Fifteen out of the seventeen interviewees at the project represented the *main contractor*, and three represented different *subcontractors*. One of the interviewees were interviewed both during the autumn 2018 and spring 2019. Table 2.4 clearly shows the diversity of the interviewees regarding their digital skills and age. ‘Little skills’ means that they can use a computer to perform daily work tasks such as sending and responding to e-mails, and have some knowledge of the use of Touchplan, but they are dependent on the daily help of others. ‘Some skills’ means that the interviewees use a computer to perform daily work tasks and can use Touchplan more or less independently. ‘Extensive skills’ means that they can use Touchplan and Synchro or similar programs, and can do so independently.

Table 2.4: Information about the interviewees: their position, digital skills and age

Company	**Position**	**Digital skills**			**Age**			
		Little	**Some**	**Ext.**	**25-35**	**35-45**	**45-55**	**55-65**
AF	Operation Manager			X	X			
AF	Operation Manager	X				X		
AF	Site Manager			X	X			
AF	Site Manager	X			X			
AF	Site Manager		X					X
AF	Site Manager		X		X			
AF	Site Manager			X	X			
AF	Planner			X	X			
AF	Planner			X	X			
AF	BIM coordinator			X	X			
AF	Chief transformation officer		X				X	
AF	Project Manager		X			X		
AF	Project Director		X			X		
AF	Digitization and innovation chief			X		X		
Subcon.	Foreman Painting	X				X		
Subcon.	Foreman Fire protection		X		X			
Subcon.	Foreman Con-Form	X					X	

Roller and Lavrakas (2015) distinguish between three main interview designs: structured, semi-structured and unstructured. All interviews were carried out as *semi-structured* in-depth interviews and were conducted individually. A semi-structured technique was chosen to allow the interviewer to ask follow-up questions (Yin, 2009; Dalland, 2017). This method gives the interviewer the chance to pose follow-up questions, which makes the interview seem more like a conversation. Interviews can be conducted through several channels of communication such as Skype, telephone conversations, emails or face-to-face. An evaluation was made and in order to promote the quality of the interviews. *Face-to-face* interviews at Project Bispevika was chosen as a favorable method. Yin (2009) indicates the importance of observing the interviewees' reactions when asking questions and taking these reactions into account when asking further questions. The method gives and increased level of communication (Yin, 2009; Roller and Lavrakas, 2015). By sitting face-to-face, it is also easier to remember the given situation when analyzing the data.

All interviews were carried out with a prepared *interview guide*, which can be read in Appendix 2. The guide was developed in collaboration with supervisors through the brainstorming of questions related to the research questions, in autumn 2018. Furthermore, all questions were grouped into categories. These categories were named Technology, Process, and Culture. More or less the same interview guide was used during the interviews held in spring 2019. Some modifications were made to take into account ideas from the external interviews and experiences from the interviews carried out in autumn 2018. The subcategories – Technology, Process, and Culture – were used to divide the main purpose and the research questions into smaller, detailed questions, and contributed to the structure of the interview guide, as well as providing a foundation for the analysis. The interview guide served primarily as a checklist to assure that the most relevant elements were covered and discussed. A compact and explicit version of the author's interview guide was sent to the interviewees prior to the appointment, allowing them to prepare as they wished.

A *pilot interview* was conducted before the first interview in autumn 2018. The pilot interview was conducted with the external supervisor from AF Gruppen, in addition to researcher Håkon Fyhn [14] and was followed by recommendations and adjustments regarding the questions and interview technique. Researcher Håkon Fyhn was also present at the first interview to observe and give further recommendations to the author. The remaining interviews were conducted by the author alone.

All interviews, both the ones conducted in autumn 2018 and in spring 2019 were conducted using the approach of Tjora (2017). First, easy questions that contributed to making the interviewee comfortable were asked. The main core of the interview was comprised of the questions which contributed to the purpose of the research. Lastly, closing questions were asked, where the attention was drawn away from the reflective level, normalizing the situation. The interview guide in Appendix 2 follows this approach. The duration of the interviews varied from *thirty minutes to one hour and twenty minutes*. These significant variations in interview length were partly due to the interviewees' availability and their prerequisites for answering questions regarding the topic.

[14] https://www.ntnu.no/ansatte/hakon.fyhn

Data analysis

The qualitative analysis aims to generate readable data (Tjora, 2017). All interviews were *sound-recorded* after obtaining approval from the interviewees, and later *transcribed*. Tjora (2017) states that the main loss in transition from the interview to the transcription is the loss of visual cues and information about the mood during the interview. However, since the author was the interviewer it was somewhat easier to remember the given situation and mood, which increases the quality of the data. The transcribed information was analyzed with the use of Tjora (2017)'s *step-wise-deductive inductive method*. The method is based on the concept of *coding*, and has the following goals:

- Extract the essence of the empirical material
- Reduce the volume of the material
- Facilitate idea generalizability based on empirical details

The coding started by reading through the first transcribed document. While reading, the author took notes when key information, comments or phrases emerge in the text. The key information, comments or phrases were named subject knobs. The code was kept as close to the actual statement as possible, so that the link between the empirical data and the code was highly recognizable. This increases the quality of the results (Tjora, 2017). All transcribed documents were read through. Already existing information was fastened to already existing subject knobs, and new useful information formed new subject knobs. The next step is named *code grouping*. It consists of grouping the existing codes into groups that have mutual thematic connections. Irrelevant codes were separated from the others. The code grouping formed the structure of the analysis and subcategories in the presentation of the findings. Figure 2.6 illustrates the process of coding and group coding. As illustrated in Figure 2.6, every interviewee had their own color in the coding. The purpose of the color coding was to recognize which interviewee stated what information, as the interviewee's knowledge, experience, and position will impact the analysis.

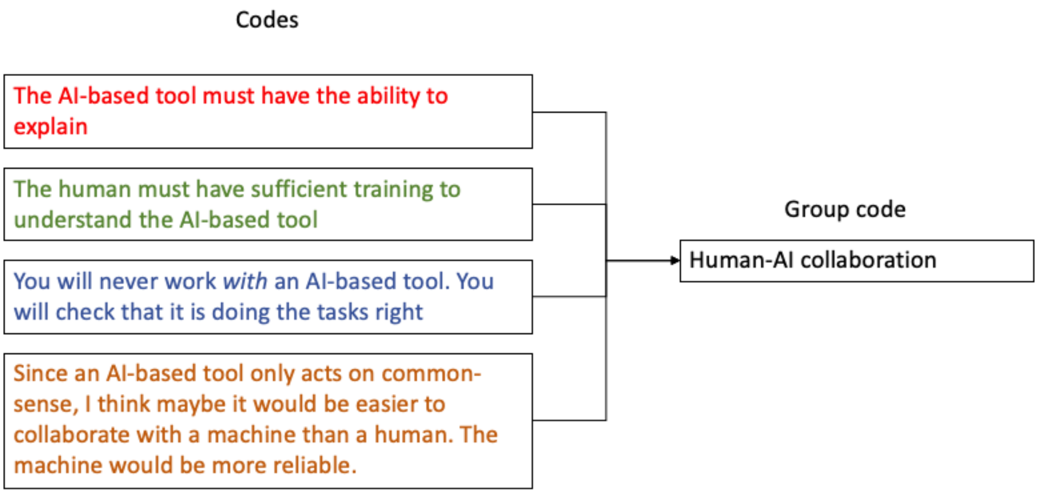


Figure 2.6: Illustration of the process from coding to group coding

The interviews as well as the analysis were conducted in Norwegian, while the quotations given in the findings are translated from Norwegian to English. The translation may lead to changes in the comprehension of what the interviewees said.

Validity, reliability and generalizability
The interviewees' opinions and thoughts relating to the current and future implementation of AI are important contributions toward answering the research question, and fulfilling the purpose of this thesis. However, there is a possibility of obtaining irrelevant results by interviewing the wrong interviewees or asking poorly articulated questions. All interviewees were chosen based on their position, skills and age. As is shown in Table 2.4, there is a diversity in positions, skills and age among the interviewees, which strengthens the *validity* and *generalizability* of the findings. The decision was made to conduct eighteen interviews to get a sufficient amount of data from which to draw conclusions.

Reliability is often considered one of the main challenges of interviews as a method. Both the interviewer and the interviewee are subjective beings, who might act differently under different circumstances. Several factors could influence the answers given in an interview; for example, the interviewer could unknowingly ask leading questions, catch the interviewee in a bad mood, or fail to correctly interpret answers. The reliability of the interviewees can also be weakened, as there is a chance of mirroring [15] occurring between the interviewer and the interviewees.

Reliability is also often connected to repeatability. The interviews should be conducted such that another researcher could use the same method and get the same results. All interviews were conducted using approximately the same interview guide, which increases the verifiability and the reliability of the interviews. However, the interview guide was only used for guidance, and follow-up questions were also asked with the aim of getting valid information. In order to ensure reliability in the research, all interviews were recorded and transcribed. The transcription makes it possible for other researchers to study the results. A repetition of the interviews will possibly not give the exact same results, but it is likely that it would give more or less the same findings.

Document study

Document study consists of studying documents that were not necessarily created for use in research. Document study can contribute towards reducing the burden on the participants involved in the research, by letting the researcher acquire information by analyzing various already existing documents (Tjora, 2017). The next sections describe the data collection, data analysis, and the validity, reliability and generalizability of the documents used.

Data collection
The process of finding the documents was quite simple, as they were provided by the author's supervisor in AF Gruppen.

Data analysis
The author acquired information by closely reading each document and marking the relevant information using color codes. Since the documents may have incomplete research and retention of sources, the information was used as a secondary source during the preparation for the interviews as well as supplementing the findings of the interviews. The analyzed documents are shown in Table 2.5.

[15] The interviewee says what the interviewer wants to hear (Yin, 2009)

Table 2.5: Documents used in the document study

Document	Purpose
LEAN in Team Bispevika	To understand how Bispevika works, considering lean and digitization, and generally acquire information about the project
Bispevika-KS-Overview digital systems	To acquire knowledge about the extent of digital tools at the project
Pilot and Implementation Week	Acquire knowledge about ALICE, and the strategies for implementation
Construction Information Model	Acquire knowledge about the technical parts of ALICE
AF Gruppen Onsite Pilot Recap Final	Acquire information about how ALICE will fits into the team structure and plan for the early testing

Validity, reliability and generalizability
The *validity* of the documents is considered to be good as the documents specifically describe how Bispevika works and how ALICE works. The fact that the documents are exact and concrete makes it hard to *generalize* the information. However, this is not considered a disadvantage, as there is no aim of generalizing this information. The authors of the documents concerning Team Bispevika are people working on the project, while documents concerning ALICE were written by people working in ALICE and AF Gruppen. The documents can therefore be considered *reliable*.

2.4.2 External companies

Due to the low implementation of AI-based technology in the construction industry three external companies, with expert knowledge within the domain of AI, were contacted. The aim was to unveil useful experiences that may be beneficial when implementing AI-based technology in the construction industry. One person from each company was interviewed. Information about the companies and the interviewees is given in Table 2.6.

Data Collection
Norwegian Open AI Lab [16] and Inmeta [17] were chosen based on their experiences with the implementation of AI-based technology within several industries. Spacemaker [18] was chosen because they are one of the few companies in the construction industry in Norway that use AI-based technology. The interviewees were chosen by the companies, based on the informa-

[16] https://www.ntnu.edu/ailab
[17] https://inmeta.no/kontakt
[18] https://spacemaker.ai/

tion given by the author. Table 2.6 presents information about the companies as well as the interviewees.

The three interviewees were carried out as *semi-structured in-depth interviews*. All interviews were conducted *face-to-face* at the companies' offices. The interviews were carried out with the same prepared *interview guide* as the one used in the case-specific interviews, to make it easier to analyze and compare them with the case-specific data. The interviews were conducted using Tjora (2017)'s interview approach, explained in Section 2.4.1. Each interview had a duration of more or less one hour. The interviews were conducted with a gap of three days between the first two interviews, and one week between the second and third interviews. The follow-up questions from the first external interview differed from those asked in the last interview, as the author's knowledge level considering AI had increased, and interesting information was thus discovered.

Table 2.6: Description of external companies and interviewees'

Company name	**Description of company**	**Description interviewee**
Norwegian Open AI Lab	Research center that brings together various research efforts within AI. Key areas of research are health, energy, ocean space, digital economy and smart environments	Professor in Computer Science (CS) and AI. Long experience within the development and implementation of AI-based systems, especially within the oil and gas industry, and fishing industry
Inmeta	One of the leading consulting companies within machine learning in Norway	Data scientist with specialization in machine learning. Experience within the development and implementation of AI-based systems, especially within the health care industry
Spacemaker	Norwegian start-up company that has developed an AI-based system that calculates and optimizes a building site during the design phase of a project	Chief Operating Officer (COO) with experience in the implementation of AI-based technology in the design phase of construction projects

Data analysis

The interviews were *sound-recorded* with the approval of the interviewees. Further, all interviews were *transcribed*. The transcribed information was further analyzed with the use of Tjora (2017)'s *step-wise-deductive inductive method*, as described in Section 2.4.1.

Validity, reliability and generalizability

The three external interviewees are all persons with extensive knowledge considering AI, and contributed much useful information related to the research's purpose. The interviewees were chosen by their firms, based on the information given by the author. However, there is a possibility that the information given by the interviewees is not transferable to the construction industry, which weakens the *validity* and *generalizability* of the findings.

As for the case-specific interviews it would be challenging to get the exact same results when verifying the results, but it is likely that the findings would be more or less the same. The same interview guide was used for the case-specific interviews, which strengthens the *reliability* of the findings.

Chapter 3: Theoretical Framework

An essential part of doing research is to read, be inspired by and be critical of others' work. The aim of this chapter is primarily to map how the assignment topics have been treated and explored in existing research and secondly to identify lack of knowledge about how the mentioned topics interact with and are dependent on each other (Blumberg, Cooper, and Schindler, 2011). The theoretical framework presented in this chapter is based on the two conducted literature studies, explained in Section 2.3, Chapter 2, Methodology.

The construction industry is claimed to be undigitized, with low productivity development compared to other industries (Blanco, Fuchs, Parsons, et al., 2018). However, research indicates that the correct implementation of digital technology will result in increased production efficiency (Barbosa, Woetzel, Mischke, et al., 2017). More advanced technology such as AI is now entering the industry. As stated in Figure 2.1 there is a lack of published literature concerning the implementation of AI in the construction industry. As a result, it has been necessary to investigate research regarding the implementation process and human behavior and combine it with research on AI. Regarding human-AI collaboration the author has looked to other industries where AI is more explored. Based on this, the theoretical framework is divided into the following three sections:

1. Implementation of change
2. Artificial Intelligence (AI)
3. Human-AI Collaboration

3.1 Implementation of change

3.1.1 Implementation models

Implementation consists of the process of putting into practice an idea, program, or a set of activities and structures new to the people attempting or expecting to change (Fullan, 2007). Implementation can be considered as a change process. Meyers, Durlak, and Wandersman (2012) divide a change process into four main phases, as illustrated in Figure 3.1.

In *Phase 1*, the evaluation of possible change, the organization must assess whether or not the change will benefit the organization. The assessment should be carried out by key persons who will follow the possible change throughout the implementation process. Systematic identification of weaknesses and opportunities provides the basis for formulating an implementation strategy in *Phase 2*, structure of the implementation (Schuh, Anderl, Gausemeier, et al., 2017). In Phase 2 it is essential to identify what is needed to succeed with the implementation work. *Phase 3* consists of the actual implementation process, where the strategies and plans made in Phase 2 are executed. *Phase 4* is the improvement phase, during which individuals should evaluate what worked, what did not work, and how the implementation process can be improved (Roland and Westergård, 2015).

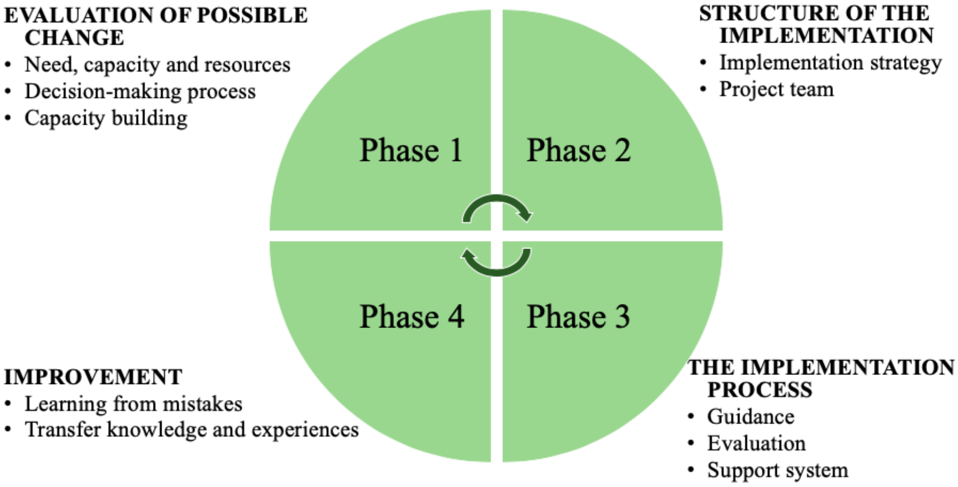


Figure 3.1: Implementation model (Meyers, Durlak, and Wandersman, 2012)

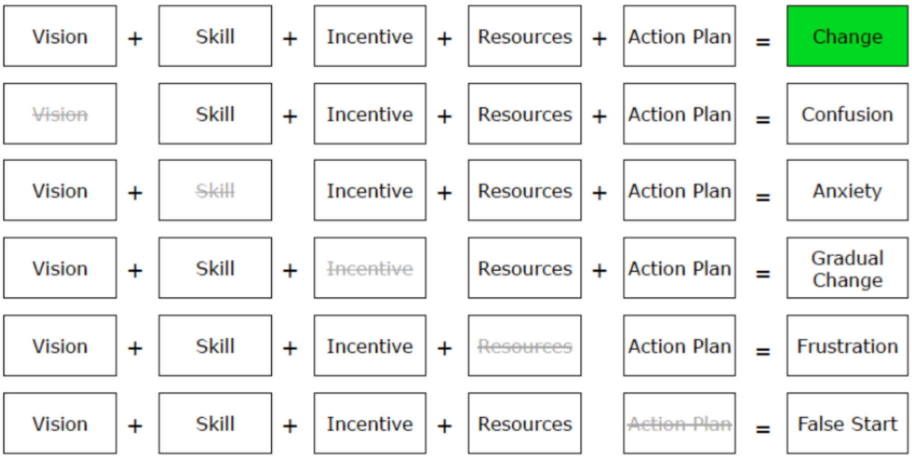


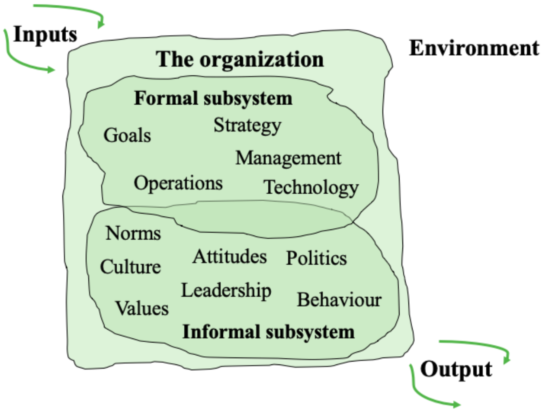
Figure 3.2: Elements for a successfully implementation of a change (Larson, 2003).

3.1.2 What is needed for a successful implementation?

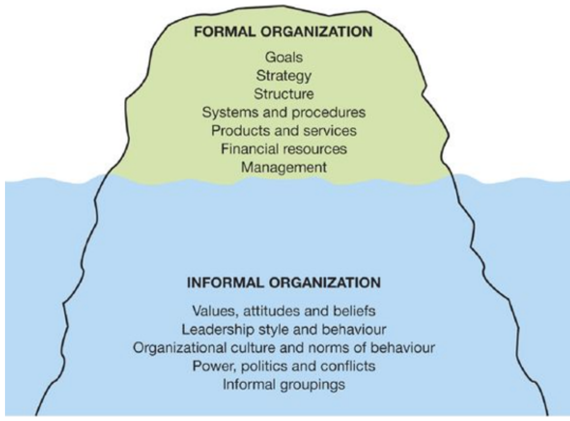
According to Blackler and Brown (1986) many companies put little effort into the specific process by which they introduce new technology. Quite a few companies are surprised when they get poor results after implementing technology because they automatically assume technology will lead them to good results. This corresponds to Senior and Swailes (2010)'s research, which shows that incomplete implementations are often a result of incomplete preliminary work, where organizations are focusing on *what* instead of *how*. To get the full benefit of a change the organization must manage both *what* and *how* (Greenberg, Domitrovich, Graczyk, et al., 2005).

Phase 2 in Meyers, Durlak, and Wandersman (2012)'s implementation model illuminates the importance of identifying the essential factors for successfully implementing a change. Larson (2003) presents in his book the five elements he believes are decisive for success when implementing a change: Vision, Skill, Incentive, Resources, and Action. As illustrated in Figure 3.2, all five factors are essential to succeed.

Larson (2003)'s five factors for a successful implementation can be related to Senior and Swailes (2010)'s organizational system, shown in Figure 3.3 (a) and (b). Incentives can be related to the informal subsystem, while resources, skills, vision, and action plan form part of the formal subsystem. An action plan can be considered the same as a strategy. As mentioned above the implementation can be considered as a change process, with inputs and the wish for a specific output, as illustrated in Figure 3.3 (a). What happens between the input and the output determines whether the implementation is successful or not. Good quality is needed both in the formal subsystem and the informal subsystem in order to succeed with an implementation (Senior and Swailes, 2010). The following sections will be structured around the formal- and informal subsystems, and their accompanying factors.



(a) Organization as a system, inspired by Senior and Swailes (2010).



(b) The organizational iceberg (Senior and Swailes, 2010).

Figure 3.3: Organization as a system: formal and informal subsystems

3.1.3 Formal subsystem

Organizations are made up of formal, tangible elements such as vision, structure, strategy, technology, goals, and financial resources. As illustrated in Figure 3.3 (b) is the visible part of the iceberg the formal part and consists of the more easy-to-see and formal aspects of an organization (Senior and Swailes, 2010).

Vision

The early establishment of the organization's *vision* for the change creates a framework that includes the goals that must be met in order to achieve the vision and the overall strategy for reaching these goals (Larson, 2003). All stakeholders involved in the change process should have a clear idea of what the goals are and how to achieve them. The lack of a common understanding of *what* the change is supposed to achieve, and *how* to achieve it, may result in several erroneous interpretations of *why* the change should be implemented. An important question to consider when a change is presented is 'why?'. A clearly defined vision makes this question easy to answer (Atkinson, 2015).

Strategy

Senior and Swailes (2010) defines *strategy* as the following:

The direction and scope of an organization over the long term: [the strategy] achieves advantages for the organization thorough its configuration of resources within a changing environment, to meet the needs of markets and fulfill stakeholder expectations.

The strategy consists of steps to take in order to fulfil the organization's vision. It is during the development of the strategy that the need for a vision of the change becomes evident. Through the strategy the vision is translated into specific, achievable goals and objectives. The plan should contain *how* the goals are to be reached, articulated, *who* is responsible for what, specify the desired results and outcomes, and set out a timeline for achieving the goals. Without a clear strategy, an organizational change will begin, lose direction, begin again, lose direction and so on. In other words, the change will fail (Atkinson, 2015).

Increased skills through training

In any organizational change, there is a cultural change, and cultural change requires a change in behaviors. One of the key ways to get people to make a behavioral change is to ensure that they have the *skills* that will be required to accomplish their work (Atkinson, 2015). Providing *training* in the required new skills is one way of eliminating a common reaction to change, namely fear. Giving the opportunity to acquire needed skills is a mitigating factor (Atkinson, 2015).

Every change will require training, but the wrong type of training, or too little or too much training can cause more problems than benefits (Arnold, Randall, Patterson, et al., 2010). A training strategy should be developed and should consist of: training needs analysis, training design and training evaluation. All three are equally vital (Arnold, Randall, Patterson, et al., 2010; Roland and Westergård, 2015). The training is likely to fail if one arrow of the triangle shown in Figure 3.4 is weak or missing. Poorly designed training strategies often result in high cost without value for the company. Spending time and money on developing good training strategies will benefit employees as well as the company in the long term (Arnold, Randall, Patterson, et al., 2010).

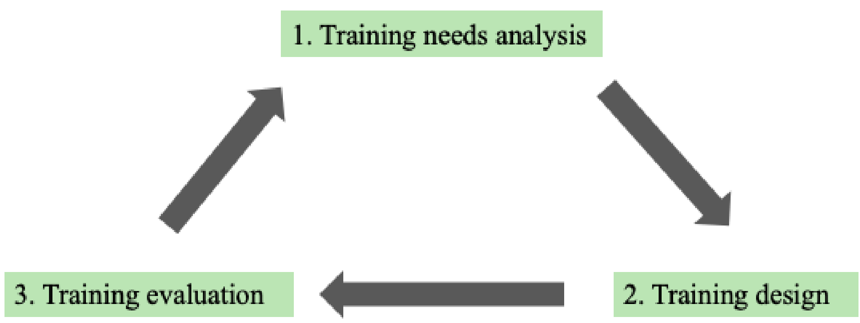


Figure 3.4: Training strategy (Arnold, Randall, Patterson, et al., 2010)

The *training analysis* should be conducted first, as it forms the basis of the training design. In order to assess the training needs, three levels of analysis should be considered: organizational analysis, task analysis, and personal analysis. The organizational analysis consists of identifying the organization's training needs. This is done through the investigation of strategic goals, and further identifying and prioritizing how the goals can be met through training, and deciding if training is indeed the right solution. Task analysis consists of identifying the training needs associated with the role or the task. This analysis is used to specify what type of training is needed to develop specific knowledge, skills, and abilities. Personal analysis has the goal of identifying who needs training and what type of training is needed (Arnold, Randall, Patterson, et al., 2010).

Based on the training analysis the *training design* is developed. According to Arnold, Randall, Patterson, et al. (2010) should a training design consist of the following elements:

- Training goals and objectives
- Determination of the training strategy
- Scheduling and implementation of training

The *training evaluation* should determine whether the training has worked or not. Survey feedback from those who are involved in the implementation process is one form of evaluation. Typical questions are (Senior and Swailes, 2010):

- Have the training goals been achieved?
- Was the investment in training worth it?
- What do the trainees thinking about the training?
- What challenges were encountered?
- What improvement could be made?

Continuous evaluation is essential for improving the training strategy, as well as the implementation process. Arnold, Randall, Patterson, et al. (2010) indicate that only 10-15% of organizations conduct a training evaluation. As a result, many organizations experience a cycle of bad training.

The right training should ensure that employees acquire the knowledge and qualities that are needed to implement a change successfully. As Roland and Westergård (2015) writes:

An organization can only learn when humans in the organization learn.

Implementation drivers an essential resource

Resources include everything – and everyone – needed to make the change happen. If teams don't have the tools, money, time, information, and people necessary to accomplish a goal, they will become frustrated (Atkinson, 2015). The people that drive the training process and develop further are essential to obtaining change and further contributing to sustainable change (Roland and Westergård, 2015). These people can be described as *implementation drivers*, and can be divided into three groups: competence drivers, leadership drivers, and organizational drivers, further described in Table 3.1.

The implementation drivers should be seen in connection with each other, as they influence each other. A weakness in one driver can be balanced by another driver's strength (Roland and Westergård, 2015). According to Senior and Swailes (2010), implementation drivers should have the following approach:

- Be consistent in the approach but be supportive, encouraging and respectful
- Train every employee in what is expected of them
- Accurate, timely communication is essential for people to understand what the driver is trying to achieve
- Stick at it and do not give up

Table 3.1: Description of the implementation drivers (Roland and Westergård, 2015)

Implementation driver	**Main task**	**Explanation**
Competence	Guidance, practice and selection	Developing, improving and maintain the belief in the implementation process, with loyalty. Essential part of the other employees motivation. Recruiting, teaching and guidance employees through the change process
Leadership	Technical support and adaption	Develops management strategies to act appropriately when it comes to decision-making challenges. Dynamic leadership is important as the different implementation stages have different challenges. Should supervise the competence drivers
Organization	Support system, administration and decisions	Create and maintain the structure during the change. Offer resources which facilitate learning, and takes care of the externally conditions such as laws and regulations

Goals

The *goal*-setting theory is strongly supported by research (Arnold, Randall, Patterson, et al., 2010). Setting performance goals that are specific, challenging and meaningful, but not impossible, and to which the person feels committed, is likely to improve employees' work performance, self-efficacy, and their motivation to commit to new challenges (Arnold, Randall, Patterson, et al., 2010). Roland and Westergård (2015) state that if one does not feel a commitment to the goal, it can be concluded that no goal exists. However, recent research (Kahneman, 2011) indicates that clear performance goals are not always beneficial. When working with simple processes, performance goals are considered beneficial, but when processes are complex, the same measures could inhibit productivity.

Implementing change can be a long-term process, and commitment to the process can weak over time. Motivation must be ensured until the change is incorporated into the employees' daily work routines, and the employees feel comfortable with the change (Senior and Swailes, 2010). The achievement of short-term goals is therefore essential, both as a motivating factor and as a mechanism for tracking the process towards the longer-term goals (Arnold, Randall, Patterson, et al., 2010; Senior and Swailes, 2010). A short-term goal should according to Senior and Swailes (2010) and Arnold, Randall, Patterson, et al. (2010) be:

- Visible
- Unambiguous
- Clearly related to the change effort

Achieving goals in teams is considered simulating for further motivation. Based on this, working in teams can be considered an important factor for motivation, and training should be adapted to provide both social gains and increased knowledge levels to the participants (Roland and Westergård, 2015).

3.1.4 Informal subsystem

The hidden part of the iceberg shown in Figure 3.3 (b) is the informal part of an organization. Like icebergs in the Arctic Ocean, the most significant and critical parts of an organization are hidden (Senior and Swailes, 2010). The informal organization is composed of the more covert aspects of organizational life. These include the values, beliefs, attitudes, incentives, motivation, leadership and norms of behavior held by the management and employees. In other words, the organization's working culture.

Incentives and motivation

"What is in it for me?" is the key question related to *incentives*. Rewards are given for accomplishments, and incentives are enticements to accomplish. If the change is perceived to increase the burden on individuals for an extended period, resistance, frustration, and anxiety will increase. If the change results in easier, better ways of accomplishing work, the change is likely to be accepted. Making each individual's work-life easier is considered the best incentive for change in the workplace (Atkinson, 2015).

In the broadest sense, incentives should spring directly from the vision of the organizational change. If a change is needed to move the organization forward, it should also move the individual forward.

Leaders have an important role when it comes to implementing change. Atkinson (2015) states that change leaders should think about the following questions when it comes to incentives:

- What benefits of the change will be felt by individuals?
- What kinds of incentives do people in this organization respond to?
- What types of incentives can and should be offered in the short-, medium-, and long-term?

Leaders should create incentives that will reinforce the positive and counterbalance the negative. At the individual level, the incentives need to be reasonable, affordable, and commensurate with the desire to change (Atkinson, 2015).

Organizational culture

Organizations are about people, and people form cultures. Duarte and Snyder (2006) defines culture as follows:

Culture is ... the hidden 'scripts' that people use to guide their behaviors. These scripts are created by repeated interactions between members of the group that creates them. Over time, they become second nature and serve as shortcuts for guiding actions and making decisions. Like an iceberg, culture is often partially or totally hidden. It can, however, affect people's assumptions, behaviors, and expectations about leadership practices, work habits, and team norms.

Culture plays an essential role in helping or hindering the process of change as it is deep-seated, illustrated in Figure 3.3 (b) (Senior and Swailes, 2010). Implementation can, therefore, be considered culture work. Korszilius (1988) illuminates the importance of establishing a unified and robust project culture for successful projects because the lack of a unified culture can be detrimental to the attainment of the overall project objectives. The following sections will present the traditional construction culture and the construction culture as it has been influenced by the lean-mindset.

The traditional construction culture
Hancock (2000) characterizes the construction industry as a culture of conflict, fragmentation, labor mobility, subcontracting, hierarchical, traditional and masculinity. What are the reasons for this bad reputation? Is the behavior on site a result of individuals' nature brought to the site, or is the behavior formed on site? The following paragraph will present possible reasons presented in the literature, which include:

- Project-based industry
- Diversity of cultures
- The economical aspect

The construction industry is a *project-based industry*, which consists of temporary teams working together for a restricted period of time. Today construction projects consist of a large number of specialized people who engage in some kind of interaction and in some level of collaborative activities that shape the construction (Skinnarland and Yndesdal, 2010). Each person and firm has its own working culture, norms, values, attitudes, and behavior which will impact the project culture. As illustrated in Figure 3.5, project culture is made up of several sub-cultures.

As new people continuously arrive on the site throughout construction, new kick-off seminars, planning meetings and training evolve in a circle more than a straight line (Skinnarland and Yndesdal, 2010). The short time frame makes it hard for people to get to know each other well, and by extension, this makes it hard for them to trust each other. McDermott, Khalfan, and Swan (2007)'s research shows that the level of trust between partners is reported to be low, as a result of a lack of keeping promises. Not keeping promises damages interpersonal trust, and further the collaboration and working culture.

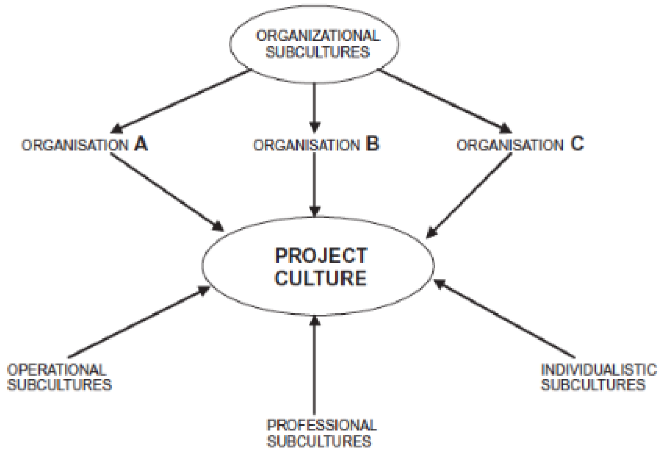


Figure 3.5: Project culture: a combination of several subcultures (Kumaraswamy, Rowlinson, Rahman, et al., 2001)

As a result of globalization and employment immigration, today's construction teams consist of team members with *different cultural backgrounds*. Different cultures bring unlike behaviors in terms of what is right and wrong, norms, values, and attitudes (Arnold, Randall, Patterson, et al., 2010). The short time frame for which people work on a project together can make it demanding to establish a common understanding of the work culture. In addition to different cultural backgrounds, people speak different languages. This makes it even harder to establish a common understanding of the work culture, the work tasks, and daily communication and collaboration. Even though most people have no intention or desire to contribute to a poor working culture, it can be difficult to contribute to a good working culture when people have different perceptions of good working cultures and when it is challenging to communicate (Quelhas, Filho, Neto, et al., 2019).

Another important aspect is *economy*. Clients, contractors, consultants, suppliers and subcontractors all work to earn money. The fact that everyone is supposed to earn money may result in people thinking and acting for their own benefit and individual objectives rather than the common goals (Zuo and Zillante, 2005). A feeling of ”us” and ”them” occur, instead of ”we” (Skinnarland and Yndesdal, 2010). All participants must cooperate loyally if the results should benefit all participants. If one contractor breaks the cooperation and sub-optimizes to his benefit, all the other collaborators will suffer. The result is usually a poor work culture (Kristensen, 2011).

Lean

Although the construction industry is still known for its poor working culture, and the defining characteristics of a project-based industry, diversity of cultures and the economic aspect are still valid, the industry has nonetheless developed in recent years.

Lean is a philosophy and methodology with the aim of delivering flawless services and products by producing value for the customer and making the process as effective as possible (Kalsaas, 2017). Lean has its roots in Henry Ford's introduction of the assembly line in 1913. The assembly line made it possible to deliver products cheaply and quickly. After the Second World War, Japan was extremely poor, and Toyota, with its base in Japan, had to rethink how to earn money.

The comprehensive methodology called *The Toyota Production System* was developed. The majority of the methodology was developed from 1948 through to 1975, with significant influence from Taiichi Ohno [1], Eiji Toyoda [2], and Shigeo Shingo [3]. By using the lean philosophy and methodology, Toyota surpassed traditional industrial production in terms of eliminating waste and maximizing the efficiency of production. Toyota's success was observed and transformed into what is today known as *lean* in the book *The Machine That Changed the World* [4]. Since then, lean has been introduced and transferred to several industries, including the construction industry.

Lean Construction
Lean entered the construction industry through Koskela (1992), and as *Lean Construction* in the late 90s, through the Transformation-flow-value theory (TFV) (Koskela, 2000). Kalsaas (2017) repeat Koskela (1992)'s lean principles as the following:

- Increased value creation through better quality and focus on customer value
- Improved productivity by removing what is not productive
- Increased satisfaction for employees by allowing them to experience their work as well organized and meaningful

Last Planner System
Lean Construction was central to the development of the Last Planner System (LPS). LPS was developed by Glenn Ballard with the aim of improving the planning of construction projects (Ballard, 2000). The procedures of LPS consist of two components: Production Unit Control and Work Flow Control.

Production Unit Control means to make plans of high quality produced by the *last planner*. The *Last Planner* should be the one to conduct the work. By choosing the workers to be the last planner, and facilitate that the last planners from the different disciplines plan and coordinate the work tasks together, is likely to result in increased workflow, predictability and further contribute to a common working culture. Ballard (2000) defines the critical quality of a task to be the following:

- The assignment is well defined
- The right sequence of work is selected
- The right amount of work is selected
- The work selected is practical or sound; i.e., can be done

Continuous learning and corrective actions are taken care of through percentage of assignments completed (PPC) and root cause analysis. PPC is the number of tasks completed compared to the number of tasks planned. It is expressed as a percentage with a range of 0-100%. Root cause analysis is targeting why the unfinished activities are not finished, with the aim of not repeating the same error twice (Ballard, 2000).

While *Production Unit Control* coordinate the execution of work *within* production units such as construction crews and design squads. *Work Flow Control* coordinates the flow of design,

[1] https://history-biography.com/taiichi-ohno/
[2] https://www.notablebiographies.com/St-Tr/Toyoda-Eiji.html
[3] http://www.process-improvement-japan.com/shigeo-shingo.html
[4] https://www.lean.org/Bookstore/ProductDetails.cfm?SelectedProductID=160

supply, and installation *through* production units (Ballard, 2000). Further information about lean, lean construction and LPS can be read at: Koskela (1992), Ballard and Howell (1998), Ballard (2000), Ballard and Howell (2003) and Kalsaas (2017).

Lean culture

Collaboration and commitment are central factors in the lean philosophy as well as essential factors for a good working culture. Montiel-Overall (2005) defines collaboration as the following:

[A] trusting, working relationship between two or more equal participants...Also, in a true collaboration, there is a commitment to shared resources, power, and talent.

With the implementation of lean in the construction industry, the focus on collaboration has increased. The increased involvement of participants, and the higher degree of respect and trust among the participants, have increased the feeling of familiarity and community and have further contributed toward a collaborative attitude (Skinnarland and Yndesdal, 2010; Zuo and Zillante, 2005). Research shows that getting to know each other is one of the most critical factors in establishing collaboration, helping build a relationship based on trust and responsibility towards each other (Arnold, Randall, Patterson, et al., 2010).

Weekly and daily meetings contribute to people getting to know each other and their understanding of themselves in a broader context. Understanding the whole context in combination with knowing each other can result in a willingness to take on others' perspectives, and the feeling of ”we” instead of ”us” and ”them” will grow among the participants. Skinnarland and Yndesdal (2010) state that willingness to commit to the totality of the project is key to success, and is in stark contrast to previous traditional projects. Lean encourages employees to make suggestions and changes in the company and take control and ownership of their work (Zuo and Zillante, 2005).

Attitudes

Any change process can be stressful and claim a higher contribution from employees' than a normal situation does. People develop a negative *attitude* toward the initiative if the implementation process is more laborious than was first assumed. As a result, implementation work is often under-prioritized (Roland and Westergård, 2015). On the other hand, resistance to change can be seen as feedback that can enhance the initiative, through the expression of clear expectations and communication with employees (Senior and Swailes, 2010). However, research shows that learning from resistors is challenging for modern managers and leaders. Another important factor is which persons have the ownership of the change. By owning the change, negative stress will be somewhat positive pressure and motivation to implement the change successfully. As a result, change can become the norm, with the adoption of innovative change-oriented behavior (Senior and Swailes, 2010).

Building a culture of trust

Much of the energy for building trust into the organization or corporate culture comes from a move towards the lean philosophy and incorporating continuous improvement into the business (Skinnarland and Yndesdal, 2010). The 'trust' approach emphasizes the commitment of employees and allows them the autonomy to self-manage and regulate their own actions (Bell and Kozlowski, 2002). Studying twelve engagement models reveals that the number one driver in *corporate culture* is *trust* (Walther and Bunz, 2005; Arnold, Randall, Patterson, et al., 2010).

Working together often involves interdependence, and people must therefore depend on other in various ways to accomplish their personal and organization goals. Skinnarland and Yndesdal (2010) state that trust is a huge driver in terms of taking personal and commercial relationships to positive conclusions (Skinnarland and Yndesdal, 2010). Atkinson (2015) writes that trust should be a central guiding value in all personal and business relationships, as a relationship without trust generates very little in terms of value.

There are several definitions of what trust is. Many researchers have agreed that risk, or having something invested, is requisite to trust. However, it is still undefined whether risk is an antecedent to trust, is trust, or is an outcome of trust. Mayer, Davis, and Schoorman (1995) state that the *need* for trust only arises in a *risky* situation. The study of Mayer, Davis, and Schoorman (1995) defines trust as the following:

The willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party.

Being *vulnerable* is associated with trust, as it implies that there is something of importance to be lost. Making oneself vulnerable is taking risk. Anyhow, trust is not *taking* risk, but rather it is a *willingness* to take risk (Mayer, Davis, and Schoorman, 1995).

As mentioned above have Montiel-Overall (2005) defined collaboration as "[A] trusting, working relationship betwen two or more equal participants...". However, Mayer, Davis, and Schoorman (1995) state that trust is not necessarily a prerequisite for collaboration, because cooperation does not necessarily put a party at risk, as it is possible to cooperate with a person who you do not really trust. On the other hand, Walther and Bunz (2005) have found that having team controls (such as goal-setting and deadlines) in place can help to increase trust because such measures reduce uncertainty and thereby risk.

Different types of trust
Trust can be divided into calculus-based trust, experienced-based trust, and identification-based trust (Lewicki and Bunker, 1996).

Calculus-based trust derived from rational calculation and relationships of exchange among partners who don't know each other but assume they will do as promised due to possible negative sanctions if they don't. Such trust is an on-going economic calculation whose values is derived by determining the likely outcomes (Newman, 2001).

Knowledge- or experienced-based trust, is formed over time, based on the experience, information, and interaction between the agents. It is based on a longer-term stake in the relationship which leads to 'give and take' and elements of reciprocity. Experienced-based trust can be related to *ability*. Ability is that group of skills, competencies, and characteristics that enable a party to have influence within some specific domain. You trust another person because you have experienced this person's ability and competence within that specific domain (Mayer, Davis, and Schoorman, 1995).

Identification-based trust is formed through common patterns of identification and the principles of mutuality and loyalty. It is implicit, affective and long-lasting (Newman, 2001). Identification-based trust can be related to *integrity*. The relationship between integrity and trust involves the trustor's perception that the trustee adheres to a set of principles that the trustor identifies with (Mayer, Davis, and Schoorman, 1995). It can be seen as the compatibility of an employee's beliefs and values with the organization's cultural values.

The three forms of trust present different forms of behavior and are associated with different costs and benefits. Calculus-based interactions tend to produce compliance, while identification-based relationships tend to produce a high level of personal engagement and commitment (Newman, 2001). Calculus-based trust and experienced-based trust can be described as *rational trust*, while identification-based trust can be described as *emotional trust*. It is normal to move from calculus-based trust to knowledge-based trust as one get to know each other, this can further develop into identification-based trust in case of human-human relationships (Lewicki and Bunker, 1996).

3.1.5 Summing up

The formal and informal factors shown in Figure 3.3 are equally important with regard to the implementation process (Senior and Swailes, 2010). The formal factors are the visible part of the iceberg and include vision, goals, strategies, and resources. Culture, including attitudes, commitment, motivation, trust, norms, and behaviors, are factors in the informal subsystem. The informal factors are the invisible part of the iceberg. They are deep-seated and considered more resistant to change than the formal factors.

Organizations are about people, and the entire organization must be prepared to support and shape any continuous changes and understand that the benefits of the changes will only be realized if they are systematically used by everyone (Schuh, Anderl, Gausemeier, et al., 2017). However, what will happen when an organization is formed of people and AI-based technology? Will the factors strategy, motivation, commitment, collaboration, and trust, which the literature claims are decisive for a successful implementation, be affected? In order to answer this question, it is necessary to look more deeply into the possibilities and limitations of AI-based technology.

3.2 Artificial Intelligence

The digital switch has now arrived in the construction industry, intending to increase productivity. Several technologies have been applied to the industry in the past 40 years, but not to the same extent as in other industries, and with a quite low impact on the production efficiency of the industry (Aziz and Hafez, 2013). Will AI be the technology that remolds the entire industry?

3.2.1 Digitization, Digitalization and Digital Transformation

Today companies are rushing to become more digital, with the hope of improving their business (Dörner and Edelman, 2015). However, what does digital mean?

Digital describes electronic technology that generates, stores, and processes data in terms of two states: positive and non-positive. Positive is expressed or represented by the number 1 and non-positive by the number 0 [5].

Is this what you think about when someone refers to the digital switch? Probably not. For some executives digital is about technology. For others, digital is a new way of engaging with customers. And for others, it represents an entirely new way of doing business. None of these definitions is necessarily incorrect, but such diverse perspectives often result in differing expectations and a lack of a shared vision. When the management team presents their digital agendas, it is worth pausing to clarify vocabulary, so that everyone has a clear and shared understanding of exactly what digital means to them, and their business (Dörner and Edelman, 2015).

Digitization, digitalization, and digital transformation are often referred to as the same phenomenon. However, the words represent different levels of the digital. *Digitization* involves creating a digital version of analog information, such as checklists on your mobile device instead of paper. *Digitalization* refers to the second level and is the process of considering how best to apply digitized information to simplify specific operations. For example, using digital data so that machines can perform human-controlled processes, such as continuously updating the Building Information Modelling (BIM) [6]. *Digital Transformation* is the integration of digital technologies in a way that makes the organization fundamentally change how they operate [7]. The implementation of AI-based technology can be seen as a digital transformation. As illustrated in Figure 3.6, digitalization is dependent on digitization, and digital transformation is dependent on both digitization and digitalization [8]. The following paragraphs will describe the three digital tools investigated in this thesis: Touchplan, Synchro, and ALICE.

[5] The information is taken from the following webpage: https://whatis.techtarget.com/definition/digital

[6] BIM is a digital multi-dimensional version of the construction. However, BIM is more than just technology: it is a process that is enabling all participants (owner, contractors, costumer, etc.) to share information and collaborate in the model. More information about BIM can be read in Eastman, Teicholz, Sacks, et al. (2011) and Harty, Kouider, and Paterson (2015)

[7] The information is taken from the following web article: https://www.i-scoop.eu/digitization-digitalization-digital-transformation-disruption/

[8] The information is taken from the following web article: https://www.i-scoop.eu/digitization-digitalization-digital-transformation-disruption/

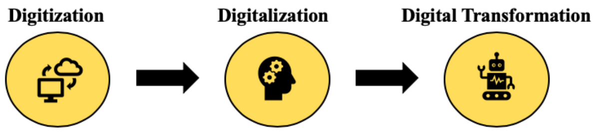


Figure 3.6: Digitization, digitalization and digital transformation (Made by the author).

Touchplan [9], as illustrated in Figure 3.7 [10], is a web-based construction collaborative tool. The tool can be seen as a digital version of the tools in the LPS (Sticky notes and physical boards). Touchplan represents the first level of digitization: digitization.

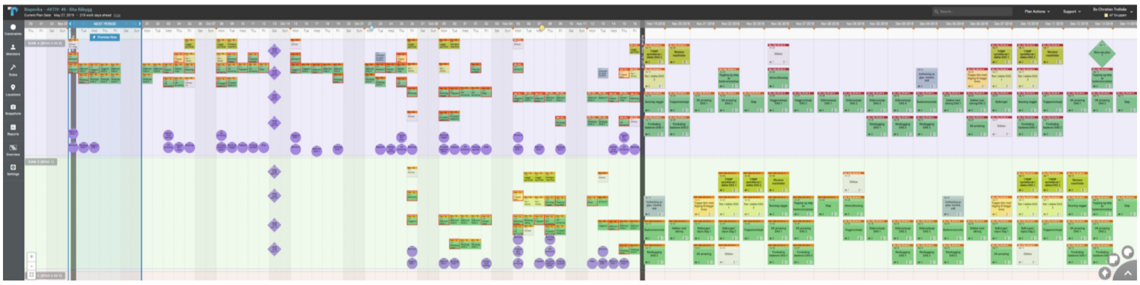


Figure 3.7: Screenshot of a schedule in Touchplan, Project Bispevika

Synchro [11] is a 4D digital construction platform, as shown in Figure 3.8. In the context of construction, 4D modelling refers to a 3D model that includes the construction schedule (Harty, Kouider, and Paterson, 2015). 4D gives the workers the opportunity to visualize, analyze, discuss, and collaborate the sequence of events on a time-line in order to find all possible constraints before executing. Synchro represent the second level of digitization: digitalization.

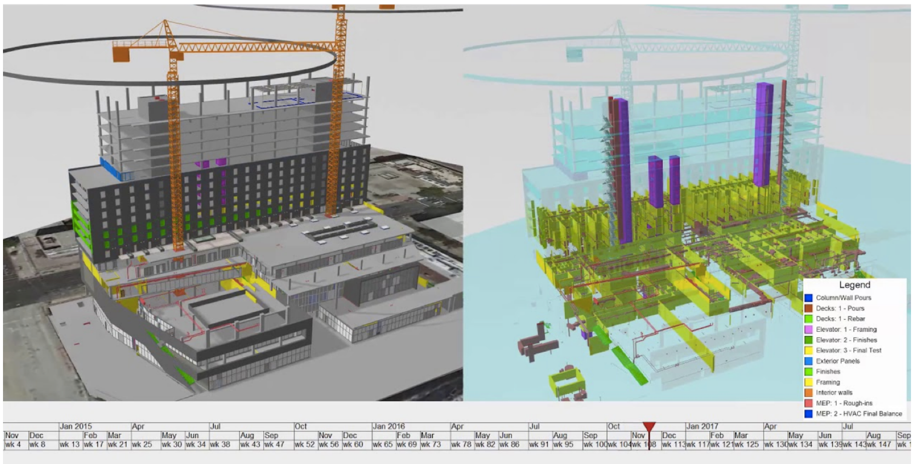
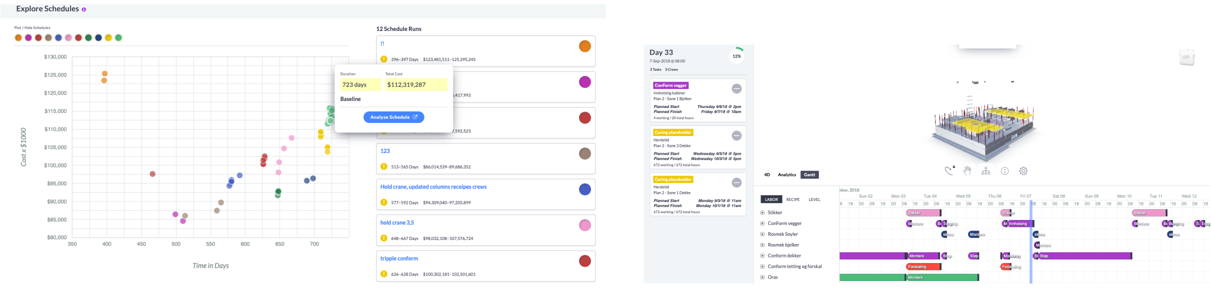


Figure 3.8: Screenshot of a construction in Synchro

[9]More information about Touchplan can be read at: https://www.touchplan.io/
[10]Screenshot from Project Bispevika
[11]More information about Synchro can be read at: https://www.synchroltd.com/

ALICE [12] is an AI planning Software which uses the input from the users and historical figures to, create and optimize schedules based on the ”recipes” created by the human. Figure 3.9 (a) [13] shows all the possible schedules provided by ALICE and the assumed time frame and cost of each schedule. Further, is the human given the opportunity to look closer into each of the schedules. Figure 3.9 (b) [14] illustrates one of the schedules and its accompanying 4D model and Gantt diagram. ALICE represent the third level of digitization: digital transformation.



(a) Possible schedules provided by ALICE

(b) One of the possible schedules illustrated in 4D and with its accompanying Gantt diagram

Figure 3.9: Screenshot of ALICE, Project Bispevika

The construction industry has partly implemented tools based on the first two levels, digitization and digitalization (Agarwal, Chandrasekaran, and Sridhar, 2016). However, the development of the digital is advancing so fast that the industry is struggling to keep up (Harty, Kouider, and Paterson, 2015). The following section presents literature regarding what AI is and the strengths and limitations of using AI in construction.

3.2.2 What is AI?

AI is a scientific discipline, like mathematics and biology. This means that AI is a collection of concepts, problems, and methods for solving problems. As Figure 3.10 illustrates, AI is based on several sub-fields and is in itself a sub-field of Computer Science (CS) (Cesta, Orlandini, and Umbrico, 2018). The following section will describe AI as well as its related fields and methods.

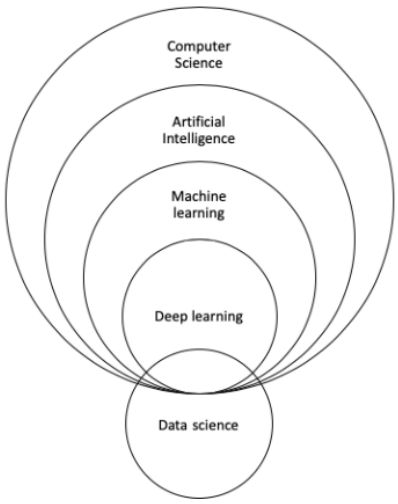


Figure 3.10: Sub-fields of AI

Computer Science (CS)

CS is the study of both computer hardware and software. Computer hardware relates to the physical parts of a computer and related devices, while software consists of the applications and programs that run the computer (Paul W. Murrill, 1973).

[12]More information about ALICE can be read at: https://alicetechnologies.com/

[13]Screenshot of ALICE, Project Bispevika

[14]Screenshot of ALICE, Project Bispevika

Artificial Intelligence (AI)
AI is a sub-field of CS, with a focus on creating intelligent machines which work just as well as human beings, or even better than humans, in certain specific tasks.

Just as is the case with ”digital”, people have different interpretations of AI. For some, AI is about artificial life-forms that can surpass human intelligence, and for others, almost any data-processing technology can be called AI. Even AI researchers have no exact definition of AI. One among many definitions is the following (Salehi and Burgueño, 2018):

The ability of a machine to mimic intelligent human behavior, thus seeking to use human-inspired algorithms for approximating conventionally challenging problems.

The father of AI is thought to be John McCarthy (1927-2011) [15]. The term AI was established when it was chosen as the topic of a summer seminar, known as the Dartmouth Conference, which was organized by McCarthy and held for the first time in 1956 at Dartmouth College in New Hampshire, United States of America. The term was created based on the following statement:

Any element of intelligence can be broken down into small steps so that each of the steps is as such so simple and mechanical that it can be written down as a computer program.

This statement cannot prove to be true. Nevertheless, the idea it proposes is fundamental when it comes to thinking about AI (Cesta, Orlandini, and Umbrico, 2018). AI-based systems can be designed to perform various tasks including speech recognition, with the aim of learning, perceiving, planning and solving real problems. However, a prerequisite for these systems is the feed of a significant amount of data from the real world (Ertel, 2017).

Machine learning (ML)
ML is a sub-field of AI which deals with the study, design, and development of algorithms that can learn from the data itself and make predictions using learned data. In other words, ML is the capability machines have to learn without being programmed what to do. ML makes AI methods adaptive (Ertel, 2017). The number of students taking introductory ML courses is growing at a fast rate. In 2017 initial ML course enrollment was 5x greater than it was in 2012 (Yoav, Perrault, Brynjolfsson, et al., 2018). This is no doubt due to the growing importance of ML as a sub-field of AI.

Deep learning (DL)
DL is a sub-field of ML which concentrates on learning the representations and features of data (Salehi and Burgueño, 2018). DL transforms a problem or a representation that is high dimensional into a lower dimensional representation. Once the problem of representation is determined the ML problem/representation can be solved. ”Deep” refers to the complexity of the mathematical models used (Ertel, 2017).

Data Science (DS)
DS is a multi-disciplinary field that uses scientific methods, processes, algorithms, and systems to extract knowledge and insights from structured and unstructured data.

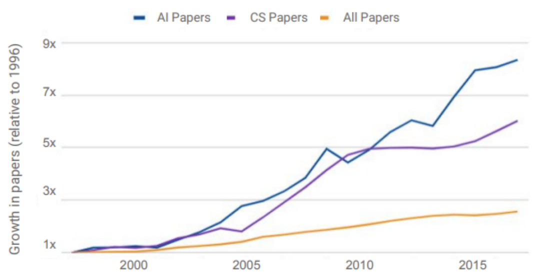
[15] http://jmc.stanford.edu/

According to Abbass (2019), AI-based technology should be able to do the following when taking advantage of the various methods mentioned above:

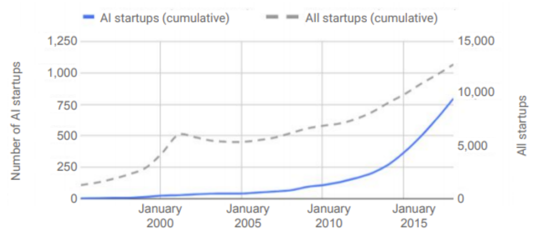
- Interpret data, represent and understand context and situation
- Assess opportunities and risks in contexts and situations
- Design, plan and generate courses of actions, select and execute one or more of them, and reason about an explain the choices they made
- Learn and adapt
- Share information between the different AI-methods

The development of AI in our society

AI is a "hot topic" these days, and media coverage and public discussion about AI is almost impossible to avoid. As Figure 3.11 (a) shows, papers about AI on Scopus [16] have increased sevenfold since 1996, and Computer Science (CS) papers have increased fivefold during the same time frame (Yoav, Perrault, Brynjolfsson, et al., 2018). AI is foreign and intangible for the majority of people, as it has long been a controversial topic, as there is uncertainty about how it will affect society. People are afraid that this intangible technology will take their jobs, or in the worst case scenario, even take control of Earth. However, surveys show that published AI articles became 2.5x more positive from 2016 to 2018 (Yoav, Perrault, Brynjolfsson, et al., 2018).



(a) Growth of annually published papers by topic (1996-2017). Data from Scopus with search term "Artificial Intelligence" (Yoav, Perrault, Brynjolfsson, et al., 2018)



(b) AI start-ups in contrast with all start-ups in U.S, January 1995-January 2018 (Yoav, Perrault, Brynjolfsson, et al., 2018)

Figure 3.11: Development in AI papers and AI start-ups

The investments in AI start-ups have increased, as shown in Figure 3.11 (b). The graph shows the number of venture-backed [17] U.S private start-ups that are active in a given year. The blue line shows AI start-ups only, while the grey line shows all venture-backed start-ups including AI start-ups. The graph plots the total number of start-ups in January of each year. Taken from Figure 3.11 (b), active AI start-ups have increased by 2.1x, while all active start-ups increased

[16] Large abstract and citation database of peer-reviewed literature: https://www.scopus.com/home.uri

[17] Venture-backed is connected to venture capital, which is a type of private equity. It is a form of financing provided by firms or funds to small early-stage firms that are deemed to have high growth potential, or which have demonstrated high growth (in terms of number of employees, annual revenue, or both).

1.3x in the period from January 2015 to January 2018. In addition to growth in start-ups, there has been a growth in conference attendance as well. ICLR's [18] 2018 conference attendance was 20x larger than it was in 2012 (Yoav, Perrault, Brynjolfsson, et al., 2018).

According to Lee (2018), the AI revolution will wash over us in a series of four waves: Internet AI, Business AI, Perception AI and Autonomous AI. The first two waves, internet AI and business AI, are already around us, reshaping our digital and economic world in a way that ordinary people can barely recognize. Perception AI is now digitizing our physical world, learning how to "see" the world around us and turning it into digital data which can be analyzed and solved by DL-algorithms. Autonomous AI will be the last wave to hit us but is already a hot topic among today's researchers. Autonomous AI is predicted to be the AI wave that will have the biggest impact on "normal people" (Lee, 2018).

What seems easy is actually hard, and what seems hard is actually easy

For most people, it is hard to understand AI-based technology, and which tasks are easy and which are hard. The following example illustrates the complexity of AI-based technology and the fact that what seems easy for humans is not necessarily easy for AI-based technology, and vice versa. The example is taken from the "Elements of AI" course [19].

> Look around and pick up an object in your hand, then think about what you did: You used your eyes to scan your surroundings. Further, you figured out some suitable objects for picking up, and then you chose one of them and planned a trajectory for your hand to reach the object you chose. Then you moved your hand by contracting various muscles in sequence and managed to squeeze the object with just the right amount of force to keep it between your fingers.
>
> It can be hard to appreciate how complicated all this is, but sometimes it becomes visible when something goes wrong: the object you pick is much heavier or lighter than you expected, or someone else opens a door just as you are reaching for the handle, and then you can find yourself seriously out of balance. Usually, these kinds of tasks feel effortless, but that feeling belies millions of years of evolution and several years of childhood practice. While easy for you, for a robot, grasping objects is extremely hard, and an active area of study.
>
> By contrast, the tasks of playing chess and solving mathematical exercises can seem to be very difficult for humans and require years of practice. However, these tasks are simple and fast when done by AI-based technology with a sufficient amount of available data.

Figure 3.12 [20] shows human tasks that AI-based technology has performed at a human or superhuman level. A description of each task is presented in Appendix 3. The tasks are highly specific, and the achievements, while impressive, say nothing about the ability of the system to generalize to other tasks (Yoav, Perrault, Brynjolfsson, et al., 2018). Although, it is not possible to concretely transfer the ability to other systems or industries, it can be seen from the timeline

[18] The International Conference on Learning Representations (ICLR) is the premier gathering of professionals dedicated to the advancement of the branch of artificial intelligence called representation learning, but generally referred to as deep learning. More information can be read at: https://iclr.cc/

[19] https://course.elementsofai.com/

[20] The information given in the figure is taken from Yoav, Perrault, Brynjolfsson, et al. (2018)

that the number of breakthroughs has increased in recent years. The construction industry is located at the starting line in terms of the AI-waves. However, based on the worldwide rapid development of AI-based technology, the implementation of AI in the construction industry could occur and be adopted faster than assumed. The following section presents the current and potential applications of AI-based technology in the construction industry.

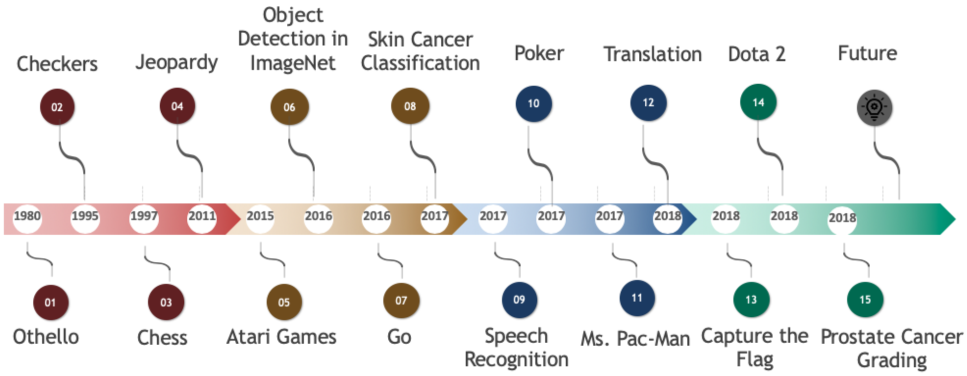


Figure 3.12: Human-level performance milestones.

3.2.3 AI in the construction industry

As is well-known, the adoption of AI-based technology is approximately zero in the construction industry (Blanco, Fuchs, Parsons, et al., 2018). However, potential exists: as Blanco, Fuchs, Parsons, et al. (2018) writes, "artificial intelligence [is] construction's next frontier". Based on other industries there are huge incentives for implementing AI-based technology for cost reduction, risk management and productivity improvements (Hagras, 2018).

Scheduling

Construction projects are complex, both in the way of building and the complexity of coordinating all the workers involved. Try to list every combination of how to build a simple house with for example 20 available workers. You would probably never have the capacity or patience to do so. The optimization of *schedules* can be seen as a contribution to improving the production efficiency on site. Take for example chess. The available node is 35. This means that to explore all possible scenarios up to 2 moves ahead; there are 35x35=1225 nodes, 3 moves requires visiting 42875 nodes; 4 moves 1500625; and 10 moves 2758547353515625. Probably not anyone's favorite pencil-and-paper homework exercise. Things become even more complicated in complex real-world scenarios such as the scheduling of a construction project. This means that whatever a human worker chooses to do will not always ultimately determine the outcome because there are factors that are beyond our control, and that are often unknown to us [21].

Scheduling with the use of AI-based technology is based on machine learning algorithms. Using historical figures in addition to human-inputs, machine learning algorithms can consider millions of alternatives for project delivery and continually enhance schedules. The ability to analyze enormous amounts of data is AI-based technology's greatest strength compared to humans. Based on historical figures and the input the human gives about, for example, how much

[21] The information given in this paragraph is taken from the Elements of AI course: https://course.elementsofai.com/

time they will spend building a wall and how much time they did spend building the wall, the algorithms store away information and remember it for next time. This is likely to improve the workflow and production efficiency on site (Schuh, Anderl, Gausemeier, et al., 2017).

Automation

According to Mahbub (2008), automation can be defined as the following:

A self-regulating process performed by using a programmable machine to carry out a series of tasks. Introducing the use of a machine to a production process is called mechanization. Automaton goes one step further. The process is not only supported by machines, but these machines can work in accordance with a program that regulates the behavior of the machines.

Robotics is a discipline overlapping AI and mechanical engineering. Robots are programmed devices consisting of mechanical actuators and sensory organs that are linked to a computer. The use of robotics is considered to automate tasks (Cesta, Orlandini, and Umbrico, 2018). Robots are designed to carry out various tasks in place of humans and must be more than simple computers. They must be able to sense and react to changes in their environment to be able to perform effectively (Mahbub, 2008). Robots require a combination of AI-methods of many kinds: reactive planning [22] to find the most convenient way to move from A to B, computer vision to identify obstacles, and decision making under uncertainty to cope with complex and dynamic environments [23].

Installations of robots have increased massively in the last few years. China has seen a 500% increase in annual robot installations since 2012, while in other regions, such as South Korea and Europe, annual robot installations have increased by 105% and 122% respectively (Yoav, Perrault, Brynjolfsson, et al., 2018). Warszawski (1984) states that the lack of active interest in the robotizing of construction work is largely caused by particular features of the construction industry:

- The unique nature of every project
- Production moves from one location to another
- Divided authority over the process (between the owner, designer and contractor)
- Rugged environment market

Traditional working methods have usually been preferred over new ideas borrowed from other industrial fields, so technological modifications of the existing processes have therefore never been seriously considered. Robots excel at repetitive tasks in a controlled environment. Construction sites are the opposite. The tasks are complex, often not repetitive, and the environment changes from day to day as the construction grows [24]. However, the construction industry is in a state of change, and some types of robots are now poised to break into the construction phase of the industry:

[22] Reactive planning differs from classical planning in tow aspect. Firstly, it can operate in a timely fashion and hence can cope with highly dynamic and unpredictable environments. Secondly, they compute just one next action in every instant, based on the current context.

[23] The information given is taken from: https://www.elementsofai.com/

[24] The information given is taken from: https://www.robotics.org/blog-article.cfm/Construction-Robots-Will-Change-the-Industry-Forever/93

- 3D-printing
- Robots for brick-laying, masonry and interior walls
- Demolition robots
- Remote-controlled or autonomous construction machinery

A *3D-printer* that can build large buildings on demand is not a normal building method. However, this technology is entering the market, and the first ever 3D-printed bridge [25] was recently built in the Netherlands. Robotics in *brick-laying* [26] should be a serious consideration in construction, as it improves the speed and the quality of the work compared to human execution. Robotic brick-laying is a rather simple process whereby construction workers simply feed bricks into a machine. Through the use of CAD software, the bricks are placed accurately and precisely. Some of the most advanced brick-laying machines today can complete an entire house within a few days [27]. Robots for *demolition* were the earliest appearance of robotics in construction. Having robots break down walls, crush concrete and gather all the debris makes the demolition process more efficient, and even more importantly, is far safer than using human labor. Autonomous vehicles are up and coming, and so are autonomous construction machines. Built Robotics [28] is one of the companies that today is launching self-driving construction equipment. The customers that have tried Built Robotics' machinery are embracing *autonomous construction equipment* because of two main factors: labor shortage and safety. Autonomous excavators are currently not ideal for work in areas with high traffic and many unpredictable human actions, but they are effective when it comes to excavating large and precise spaces, such as a smooth foundation for a building.

3.2.4 Summing up

The use of AI-based technology can be seen as a digital transformation, which is the integration of digital technologies in a way that make the organization fundamentally change how they operate. The literature shows that AI-based technology has the potential to infiltrate the construction industry, and the technology may help the construction industry to overcome the industry's most significant challenges, including costs, scheduling, and safety (Blanco, Fuchs, Parsons, et al., 2018). However, is none of the applications mentioned above currently a part of the "normal" way of building constructions. The construction industry is currently in the early testing phase of the digital transformation, and little to none projects have actually implemented AI-based technology (Blanco, Fuchs, Parsons, et al., 2018).

Any AI-algorithm is based on training rather than programming alone, which means that algorithms need a certain amount of data to perform at the level of humans, or even beyond.

Worldwide research considering AI-based technology has been going on for several decades, and a great deal of this technology has already been integrated in industries outside the construction industry. A central question concerning the implementation of AI-based technology will be that of *how* to foster a successful human-AI collaboration. The world is moving from the age of discovery to the age of implementation (Lee, 2018).

[25] https://www.dezeen.com/2018/10/22/worlds-first-3d-printed-steel-bridge-completed-mx3d-technology/
[26] https://www.construction-robotics.com/sam100/
[27] http://www.constructionworld.org/6-ways-robotics-transforming-construction-industry/
[28] https://www.builtrobotics.com/

3.3 Human-AI collaboration

Traditional culture classifies humans and technology as separate entities (Carpenter, Liu, Cao, et al., 2018). However, recent technological developments have resulted in advanced automation that can respond better than a human in specific situations (Abbass, 2019). Humans cannot compete with AI-based technology regarding the analysis of data, information, and knowledge; likewise AI-based technology cannot compete with a human's aptitude for pedagogy, creativity, visionary thinking and ethics (Carpenter, Liu, Cao, et al., 2018). In order to maximize creative behavior, humans and technology need to collaborate in a manner that will leverage the strengths of both (McCaffrey and Aceves-Fernandez, 2018). However, what will collaboration between AI-based technology and humans require of AI-systems, and what will it require of humans?

Until recently, current research on AI-based technology has focused on new algorithms rather than the usability, practical interpretability and efficacy for real users (Zhu, Liapis, Risi, et al., 2018). This section presents the prerequisites for a successful human-AI collaboration, as it is described in the literature. As mentioned earlier there is a lack of research considering the implementation of AI in the construction industry. The literature represented here is mainly taken from the IT industry, manufacturing industry, and the health care industry.

Figure 3.13 shows how every mission is not just about the integration of the user (human) and tool (machine) in order to perform a particular mission. The physical medium and societal environment also need to be considered, as does the role of management. Management is the crucial link between the human, machine, and mission as it provides proper training of personnel. Both the machine and the human collaborate within the physical medium and management, in order to solve the mission. The following section will focus on how the collaboration between the human and machine should function.

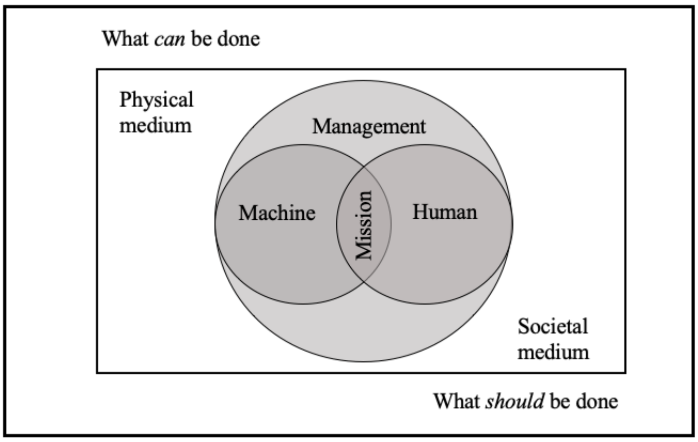


Figure 3.13: The five M's framework (Harris and J. Harris, 2004)

Machines are based on data. In many industries, there is a lack of data that is collected, including the construction industry (Blanco, Fuchs, Parsons, et al., 2018). If data exists, in many cases this data is only visible to a limited number of people who can access and understand the respective domain system (Schuh, Anderl, Gausemeier, et al., 2017). For non-AI engineers, who are typically the users of AI-based technology, questions arise such as: "Can users ensure that the AI-system has not learned a biased view of the world based on shortcomings of the training data or objective function?" (Hagras, 2018). "Can users gain confidence in the reliability of

AI-systems without an explanation of how they reached conclusions?" And would a doctor operate on a patient simply because the model said so?" Current research considering these questions says that the majority of users will need some explanation in order to decide whether they should trust or distrust the AI-systems (Hagras, 2018). How does the system arrive at a particular prediction and recommendation, and further how does it discern whether it is a good solution or not? Lack of trust in the AI-systems is one reason that the adoption of AI-based technology remains low in application areas where explainability is useful or indeed required (Chui, Manyika, and Miremadi, 2018).

Just as successful human-human cooperation requires defined tasks and responsibilities, human-AI cooperation will require the same. An interaction between the AI-based technology and the human is needed in order to increase trust, and further develop a functional human-AI collaboration. A key challenge related to this is *how* and *what* to share to get users to understand and trust without exposing them to the potentially massive amount of data used to train the network and used by the system when making decisions (Zhu, Liapis, Risi, et al., 2018). A data structure that both humans and AI-based technology can easily understand is needed (McCaffrey and Aceves-Fernandez, 2018). However, deciding what such an *explanation* should contain can be difficult (Fox, Long, and Magazzeni, 2017). The next section will address this.

3.3.1 Explainable AI

Although a fundamental understanding of the properties of different AI-methods is essential (Zhu, Liapis, Risi, et al., 2018; Kirsch, 2017), the goal of explainable AI is to investigate the actual usability in terms of how it supports users in their specific tasks. Explainable AI techniques should be developed with specific users and their needs in mind if AI is to fulfil users' expectations (Zhu, Liapis, Risi, et al., 2018).

Explanations serve to build understanding and possibly trust between the AI-system and the user (Zhu, Liapis, Risi, et al., 2018; Hagras, 2018). As stated in a report [29] from the AI Committee of the British Parliament:

The development of intelligible AI systems is a fundamental necessity if AI is to become an integral and trusted tool in our society...Whether this takes the form of technical transparency, explainability, or indeed both, will depend on the context and the stakes involved.

The concept of explainability sits at the intersection of several areas of ongoing research in AI (Hagras, 2018). Explainable AI methods can be seen as methods which can be easily understood and analyzed by humans. Methods that humanize the message, and address what people really care about in a way that is responsive to the mood and situation, and are not overly formal or legalistic (Engert, Kaetzler, Kordestani, et al., 2019). Methods that will empower the human to determine when to trust or distrust the AI-system (Hagras, 2018). The following section will focus on explainability through education, access, transparency, and time and practice.

Education

Just as trust is an essential factor for a successful collaboration between humans, as written in Section 3.1, trust is considered decisive with regard to human-AI collaboration as well. Trust blends a complex array of interactional factors including attitude, beliefs, control, emotion,

[29] The report can be read at: https://publications.parliament.uk/pa/ld201719/ldselect/ldai/100/10002.htm

risk and power (Abbass, 2019). As stated above, AI-based technology does not have attitudes, beliefs or emotions, and this combined with most humans' lack of understanding of AI, may make it difficult for humans to trust the output of AI. The human is in a vulnerable position. However, if this vulnerability is defined as function (capability, opportunity, intent), and one assumes that the AI-system's intent is aligned with the human's intent, humans can through *education* learn AI's capabilities and opportunities. In other words, it is possible to increase trust by educating humans about what AI-based technology can and cannot do, and where disruptions might occur (Abbass, 2019).

Access

Research shows that when a worker does not understand why a colleague is doing a task, a common question to ask is ”why?” (Arnold, Randall, Patterson, et al., 2010). Other research shows that when humans look at each other in the eyes there is less need for explanation (Kirsch, 2017). However, it is obvious that it is not possible to look a machine in the eye. Another way of communication and interaction is needed.

The AI-system needs to be *accessible*, so that the non-AI engineer can *interact fluidly* with the AI-system, without going through the AI engineer's interface, to edit data and inputs if needed (Chander, Wang, Srinivasan, et al., 2018). Chander, Wang, Srinivasan, et al. (2018) states that it will be crucial that the human decision-makers can interact with the AI-system fluidly as they would with an external human consultant who gives them the news that they may not like at first.

Fluid interaction will be especially necessary when the AI-system's recommendations do not match a human decision-maker's existing beliefs. Interactions that allow non-technical workers to edit the AI-system, as well as allowing the AI-system to guide the workers will be necessary. Such interactions will enable a collaborative exploration of the data, helping create a common ground where both the AI-system and the human's beliefs have been updated. Common ground and understanding will increase trust and is likely to contribute to a functional human-AI collaboration (Chander, Wang, Srinivasan, et al., 2018).

However, a real danger when trying to develop explainable systems is that of reducing explanations to statements of the obvious (Fox, Long, and Magazzeni, 2017). When a worker asks the question ”Why did you do that?” the answer is clearly not ”because it gets me closer to the goal.” A request for an explanation is an attempt to uncover a piece of knowledge that the questioner believes must make the system more accessible and that the questioner does not have (Fox, Long, and Magazzeni, 2017). Such a question is an excellent example of how complex the intention behind an apparently simple question can be. Let us look into some common questions that occur when working on site.

”Why did you do that?” or ”why didn't you do it this way?” are questions that are asked every day between colleagues on site. For humans, it is relatively easy to answer these questions through a conversation, but for an AI-system these questions are complicated, as there is rarely one right answer that can easily be read out of the AI-system's dataset. Concrete questions make it easier for the AI-system to search for data that can answer the question (Fox, Long, and Magazzeni, 2017). For example, one could ask the question ”why did you do action A? I would have done action B”. Another solution, that will usually be acceptable, is to demonstrate that the schedule produced was no worse than a schedule using the proposed alternative action. The differences between the schedule the human wants and the plan the AI-system has chosen should be compared and visualized. One schedule might be longer but cheaper than the other; depending on the relative values of time and money, either schedule might be considered better (Fox, Long, and Magazzeni, 2017).

However, people may require more information in order to trust the output and ask questions such as ”Why is what you propose more efficient/safe/cheap than something else?”. An answer to this question could be to point out the different bases for evaluation of the different plans (Fox, Long, and Magazzeni, 2017).

During execution, plan failure may occur, caused by a deviation between the expected behavior and the observed behavior. A typical question would be ”Why do I need to re-plan at this point?” or ”Why do I not have to re-plan at this point?” This question can be answered by visualizing what has diverged from expectations, and why it has caused plan failure, or why it has not caused plan failure (Fox, Long, and Magazzeni, 2017).

The literature agrees that interactions that result in a common ground of understanding will increase the human’s ability to find biased data, understand, and trust the AI-system (Fox, Long, and Magazzeni, 2017; Kirsch, 2017; Zhu, Liapis, Risi, et al., 2018). However, how should actual communication take place? Transparency of the model through visualization and neutral language are the most common forms of communication according to current research (Kirsch, 2017; Zhu, Liapis, Risi, et al., 2018) on explainable AI. The next section will look into this more deeply.

Transparency

Transparency is often a solution that results in a comfortable level of AI-system understanding for a human, helping humans to trust (Zhu, Liapis, Risi, et al., 2018). Human-human, machine-machine and human-machine communication should be configured so that data and information can be exchanged in real-time and so that all stakeholder groups are included in the communication process. As mentioned above, common communication will require that the data/information is delivered in a suitable form, so both humans and machines can read and understand it (Schuh, Anderl, Gausemeier, et al., 2017). In other words, the data/information needs to be transparent.

Local-interpretable-model-agnostic (LIME) [30] is a technique that visualizes the input data that the AI-system considers matters most to the final output. As Figure 3.14 [31] illustrates, the AI-system is first transformed into a dataset. Secondly, the most important factors are picked out, and illustrated in an explainable way, for example through graphs which show the importance of each factor. Based on the presented information from the AI-system, the individual can decide whether he or she should trust or distrust the output. If trusting, the person can make a decision based on the information given. Explanation and visualization methods such as LIME increase transparency and further trust (IBM, 2015). However, as with any other process, it needs to be considered whether this is the most efficient way of working compared to purely computational or purely human decision making (Kirsch, 2017).

[30] Further explanation can be read at: https://www.oreilly.com/learning/introduction-to-local-interpretable-model-agnostic-explanations-lime

[31] The figure is taken from the following webpage: https://www.oreilly.com/learning/introduction-to-local-interpretable-model-agnostic-explanations-lime

Fuzzy Logic System (FLS) [32] is another method for making the process more transparent. The system uses a set of linguistic if-then rules to explain the model, but are only understandable for non-AI engineers when simple problems (Biradar, 2016). However, the technique is not widely explored as an explainable AI technique yet (Hagras, 2018).

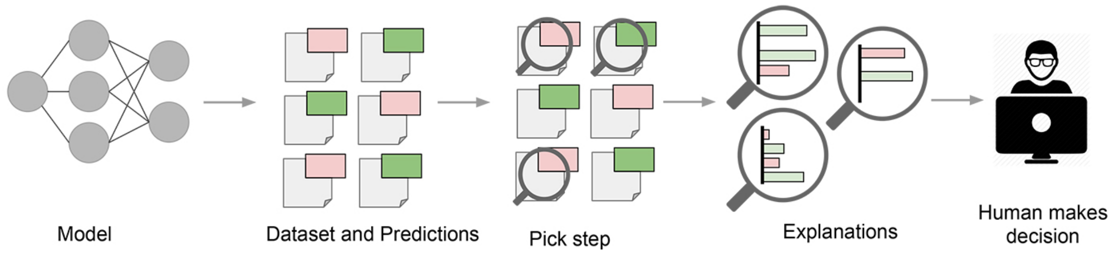


Figure 3.14: Illustration of LIME

In the domain of planning, the earlier focus has been on the explanation of plans, by using natural language. However, making sense of a plan is different from explaining *how* a plan was developed (Fox, Long, and Magazzeni, 2017). More recently, the focus has shifted from explaining the plans themselves to explaining *how* the AI-system produces the output. The explainability of the process linking the input and the output will increase trust but will require even greater transparency of the model used (Zhu, Liapis, Risi, et al., 2018).

Time and practice

Time and practice are two crucial factors related to trust. IBM (2015) states that if the AI-system operates reliably and predictably over a long time, humans will start to trust the AI-system to the same degree as they trust other humans. On the other hand, the more negative consequences the users see, the more likely they will distrust the AI-system, develop a negative attitude, and remove the AI-system from service (Abbass, 2019).

Research (Zhu, Liapis, Risi, et al., 2018; IBM, 2015; Fox, Long, and Magazzeni, 2017; Chander, Wang, Srinivasan, et al., 2018) agrees that where explainability is possible through transparency and interaction, it should be adopted, as it increases the trust and contributes to a functional human-AI collaboration. However, what about those models that are so complex that they cannot be explained?

3.3.2 Black box models

Black box models are AI-systems that receive input, produce an output, and offer no clue as to why this output was chosen. One example of black box models are models that are based on deep learning algorithms. Based on the above, such models will be hard for humans to trust. So why use black box models? Black box models give the best prediction accuracy in comparison to more transparent AI-models, such as decision trees (Hagras, 2018).

Researchers all around the world are currently searching for a solution to the problem of making black box models more explainable for the end-users, but for now, the significant amount of data and the complex models overwhelm the user, and the models fail to make the process understandable (Zhu, Liapis, Risi, et al., 2018). Currently, users either have to trust the black

[32] Further explanation of FLS can be read in the Biradar (2016)'s journal article

box models, and most likely get the most optimized output, or choose more explainable AI-methods, with less accurate output (Hagras, 2018).

3.3.3 Summing up

From humans and technology as separate entities to true human-AI collaboration. Humans are today using alignment with their existing beliefs as a way of accepting AI-systems into their team, much as they might for accepting a new human team member. For AI-systems to pass this test, the human needs to trust the AI-systems. In order to obtain trust, the AI-systems need to be explainable – by being accessible, interactive and transparent for non-technical stakeholders when it fails their beliefs test (Chander, Wang, Srinivasan, et al., 2018).

The need for interaction between the human and the AI-system will vary with the given situation. Some situations may require regular feedback from the AI-system; others require the visualization of results or the visualization of the whole process from input to output; while others may require explicit dialogue between the human and the AI-system that allows the AI-system to request help if necessary, and vice versa.

Chapter 4: Findings

The following chapter details findings from the empirical data collection that are relevant to the research questions. Figure 4.1 illustrates the structure of the findings.

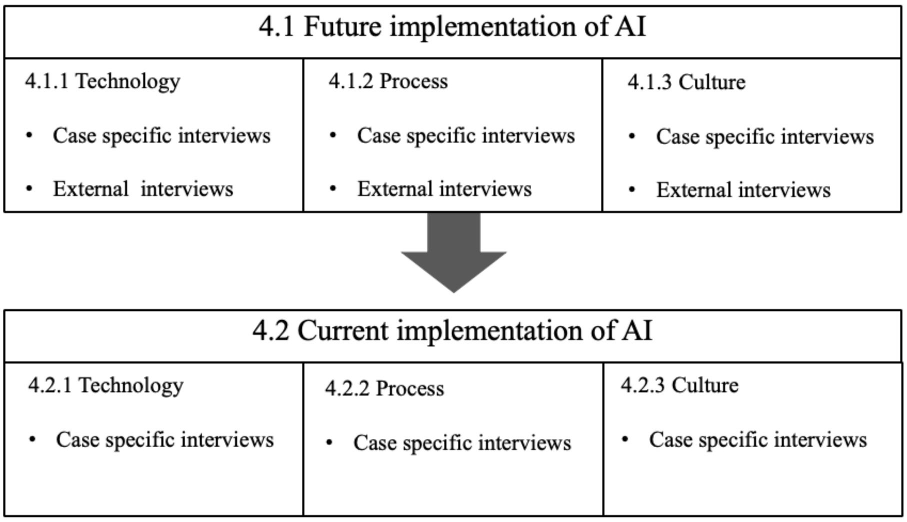


Figure 4.1: Structure of the empirical findings

The categories technology, process, and culture were developed in co-operation with supervisors during the development of the interview guide structure. Mind-mapping and discussion of questions relevant to the research questions were conducted. The mind-mapping in addition to inspiration by Arnold, Randall, Patterson, et al. (2010)'s and Roland and Westergård (2015)'s opinions regarding important implementation factors made the basis of the three categories.

It should be noted that the chosen assortment of findings is only intended as a practical approach to presentation and discussion, as many findings have relevance to more than one of the categories.

The presented findings will include quotations from the interviews. The quotations must be seen in relation to the interviewees' position, digital knowledge level, and age, stated in Table 2.4, Chapter 2, Methodology. Quotations will be marked as the following examples

- [subcontractor, L, 25-35] Means that the quotation is stated by a subcontractor with little digital knowledge (L) and age between 25-35 years.
- [project manager, S, 35-45] Means that the quotation is stated by a project manager with some digital knowledge (S) and age between 35-45 years.
- [site manager, E, 25-35] Means that the quotation is stated by a site manager with extensive digital knowledge (E) and age between 25-35 years.

4.1 Future implementation of AI

The following section presents findings relevant to RQ1:
What are the potential benefits of implementing AI in the construction industry?

The findings presented in this section are based on nine out of the eighteen case-specific interviews and all three external interviews. The nine case-specific interviewees from Project Bispevika have varying knowledge of AI; all have an interpretation of what AI is, but none can be considered expert users. The remaining nine case-specific interviewees are not included, due to their lack of knowledge concerning AI. The three external interviews were conducted with three different firms and three interviewees, as described in Table 2.6, Chapter 2, Methodology. All three interviewees have extensive knowledge of AI and can be seen as experts within the field.

4.1.1 Technology

Case specific interviews

The following section describes digital technology the case specific interviewees believe can be applied in the construction industry.

3D/4D models
The majority of the interviewees believe that *visualization of the construction in 3D/4D* will be widely used on all construction sites in the future.

Holograms
Holograms [1]. can make it easier to establish a common understanding of the actions on site.

Sensors
Sensors in combination with BIM can produce a digital map of the current situation on site. With the current situation on site through the sensors, in addition to the BIM would it be possible to compare the current situation and look into how the situation will look the next days, and by that plan where to store materials. The map should contain the possibility of reserving storage space. This technology may lead to less hours being spent on finding storage space and moving materials, and thus lead to increased predictability and productivity.

Robots
Two out of the nine interviewees [operation manager, E, 25-35 ; site manager, E, 25-35] mentioned the possibility of using *robots* for quality assurance purposes. Scaled Robotics [2] is a company that has developed a solution for the automation of *construction verification*. They use scanners to collect precise data from the site. The data is further sent to the online software, which processes the data in minutes and compares it with the BIM. Scaled Robotics has also developed a robot that can drive around the site while it continuously maps on the move. The map is compared to the BIM. The output of both the scanner and the driving robot is a 3D model of the building that highlights the elements which do not correspond to the BIM. The

[1]An advanced form of photography, where the image, so-called hologram, shows the motive three-dimensional. The hologram technology is used to create real and virtual images of objects. The method can also be used to store information optically. The health care industry is currently in the validation phase of using such technology. More information about holograms can be found at https://holocare.org/

[2]More information can be read at: https://www.scaledrobotics.com/

site manager then has the opportunity to act quickly and investigate the element further. The two interviewees believe that the implementation of such technology will reduce the costs in the future, as it reduces hundreds of hours spent on the manual checking of work quality, and thus will increase productivity. The robot can work through the night, and hours that were previously spent on manual quality checking by humans can be used for other value-creating work tasks.

One of the interviewees [subcontractor, S, 25-35] had great hope when it comes to *3D-printing*. While others believed that *self-driving construction machinery* will enter the construction industry in the near future.

However, several of the interviewees believed that it will take a long time before work tasks are fully automated, but had faith that work tasks can be partly automated in the near future, such as a robot painting a wall or installing fire protection in a room, before the human will have to physically transport the robot to the next apartment or floor.

Three of the interviewees [subcontractor, L, 35-45 ; subcontractor, S, 25-35 ; subcontractor, L, 45-55] spoke languages other than Norwegian as their native language. They wished for a robot that can continuously *translate between languages*, with output in the form of natural language or text. They said that language barriers are often a cause of misunderstandings and further delays in production.

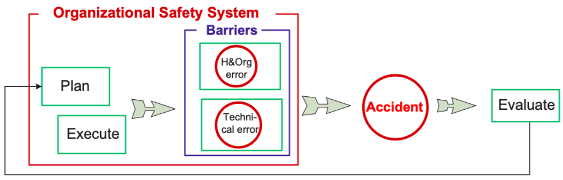
External interviews

The following section describes the AI-based technology the external interviewees believe can be applied in the construction industry, in addition to examples from the oil and gas industry, and healthcare industry.

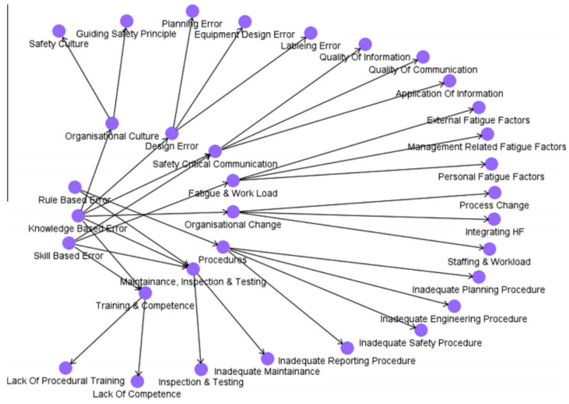
Machine learning
Machine learning is broadly used for *decision-making support* in the health care industry. The decision-making models are based on big sets of data that machine learning algorithms can analyze and by doing so predict developments and recommend actions for the doctors to take. According to one of the interviewees, the technology is mainly used for X-ray analysis and analysis of blood samples. The technology is widely used and developed within this industry due to the continuous generation of data across national borders. The significant amount of data makes the algorithms more accurate, and by that trustworthy.

Human related errors and random incidents will occur. One of the interviewees offered an example from the oil and gas industry: As illustrated in Figure 4.2 (a) errors that occur are mainly divided into technical errors and human and organizational errors. Human and organizational errors are further divided into active errors and latent errors. Active errors are typically associated with errors during execution while latent errors are often less apparent than active errors, as they are more separated in time and space from the accident. Based on the input given from the humans the algorithms can predict and take into account the human-related errors, when for example optimizing an execution schedule. Each human-related error will be adapted as a new case in the database. Figure 4.2 (a) [3] shows the process of handling errors, while Figure 4.2 (b) illustrates what a map of latent errors can look like. Each new error/accident is added to the map shown in Figure 4.2 (b).

[3]Figure 4.2 (a) and (b) was presented and explained during the interview, but they are also published in the article Skalle, Aamodt, and Laumann (2014) written by one of the interviewees.



(a) Three contributing factors involved in an accident: Human and Organizational (H and Org) Error, Technical Error and the resulting Organization Safety Level. Rectangles represent activities, circles represent occurrences (Skalle, Aamodt, and Laumann, 2014)



(b) The map of latent errors and their relationships.

Figure 4.2: The process of human related errors in the oil and gas industry

AI-systems that are *understandable* for the end user should be developed. However, two out of three interviewees answer that there is no point in designing too transparent models, as long as the users can use the system. Today technology exist that can *visualize* the process of some machine learning methods, such as case-based reasoning, from input to output. The third external interviewee means that the visualization of the process will be necessary for the human to understand and trust the output. The following quotation from one of the interviewees states their experiences with understandable AI-systems from an oil and gas project.

The workers at the platform had no knowledge concerning AI-based technology when the first AI-systems were implemented. However, the workers were competent within their field of work. The workers got visualized which factors the AI-system assumed as crucial. The visualization was sufficient for the workers to understand and trust the system. I believe that competent workers are key. Competent workers will be able to recognize if the system recommends something that will never be possible in real life and by that, the workers will identify bugs in the system.

The same interviewee explained that the workers can get visualized which factors from the historical cases that are matching the current case and how many % of correlations they have. Further, the workers were able to look into each case, its specific factors, and see the cause-impact relationship. One of the interviewees tells that two cases may look the same at first sight but end with completely different conclusions. One can imagine a set of circles within circles, where the human moves closer to the middle until a satisfactory knowledge level and trust are obtained.

Pattern recognition

Pattern recognition is the process of recognizing patterns by using a machine learning algorithm. This technology can, among other things, be used to *predict errors and danger* on site. The algorithms can be trained to predict errors, such as errors related to structural capacity, workflow, and situations related to safety.

The use of pattern recognition was introduced to the oil and gas industry through a machine learning method called *case based reasoning* [4]. Figure 4.3 [5] illustrates one system made up by case-based reasoning in the oil and gas industry. The model was made with the aim of predicting failures in oil and gas pipes, and if failures occur, enabling them to be solved more efficiently by revealing the root causes behind the failures.

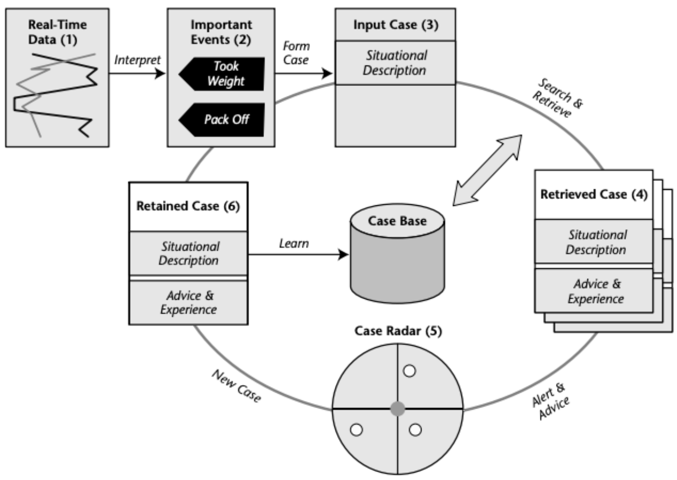


Figure 4.3: Case Based Reasoning cycle from an oil and gas project.

Real-time data from sensors in the pipes enters the model. In the retrieving step a new problem is described as a query case. The most similar case is found by using the system's similarity assessment method. The best case is selected, and the reuse step takes this case and either reuses it directly or adapts it to a solution that fits the query case. The revising step takes the solution and evaluates it, for example by applying it to the problem or getting it assessed by a domain expert. The case radar shows where the actual case is compared to other historical cases by visualization. The final step is retaining, where the algorithms learns from the problem-solving experience and updates the case base. This is the learning step, in which a new case may be added to the case base, or other changes may be made.

Pattern recognition in the construction industry can be used in *risk and safety management*. Sensors that use image recognition based on pattern recognition and machine learning algorithms can predict unsafe working conditions and possibly dangerous situations on site. The sensor must give a warning to the involved workers when it predicts a dangerous situation. Further, the workers must provide an input about whether the dangerous situation occurred or not. This is how AI-methods learn; next time they will be able to act more reliably. Image recognition can also be used to *monitor* the productivity and reliability of both staff and assets. Monitoring of staff could potentially lead to increased efficiency, but the law against personal privacy in Norway may be an obstacle.

The technological future

From their own experiences, the interviewees believe it is challenging to predict the future of AI-based technology. However, they believe that the technological development of AI-based technology that acts better than humans in specific domains, such as analyzing a significant

[4] A thorough description of the AI-method can be read in the following article written by one of the interviewees: https://folk.idi.ntnu.no/agnar/publications/aicom-94.pdf

[5] The figure was presented and explained to the author during the interview, but the figure can also be seen in the following article Gundersen, Sørmo, Aamodt, et al. (2012)

amount of data and executing simple and repetitive tasks, will continue. Considering the development in a long-term perspective, it will take more than 100 years before AI-based technology will have human intelligence on a broad level. A broad level means that machines will be able to act like humans in more or less every situation, including all unexpected situations and situations that contain empathy and ethics. As one of the interviewees said:

I have no belief that AI-based technology is going to out-smart humans. AI-based technology is not science fiction like newspapers and movies present it; it is pure technology.

4.1.2 Process

Case specific interviews

Table 4.1 summarizes the case specific interviewees' thoughts of the benefits the digital technology mentioned in Section 4.1.1 may bring.

Table 4.1: How the technological applications may impact the process of building

Impact	Contribution
Increased productivity	• Easier revision • Easier to plan execution • Easier to identify errors/difficulties • Common understanding through better communication • Better workflow • Never a bad day at work • Acts on statistics/databases • Several ”what ifs than humans” • Substitute human work
Increased safety	• Easier to foresee possible dangerous situations
Increased quality	• Better visual perception than humans

Training
In the literature, training is considered to be decisive for a successful implementation process. Based on this, the author specifically asked about which factors the interviewees experience as the most decisive when implementing new digital technology. Figure 4.4 presents the findings for this question.

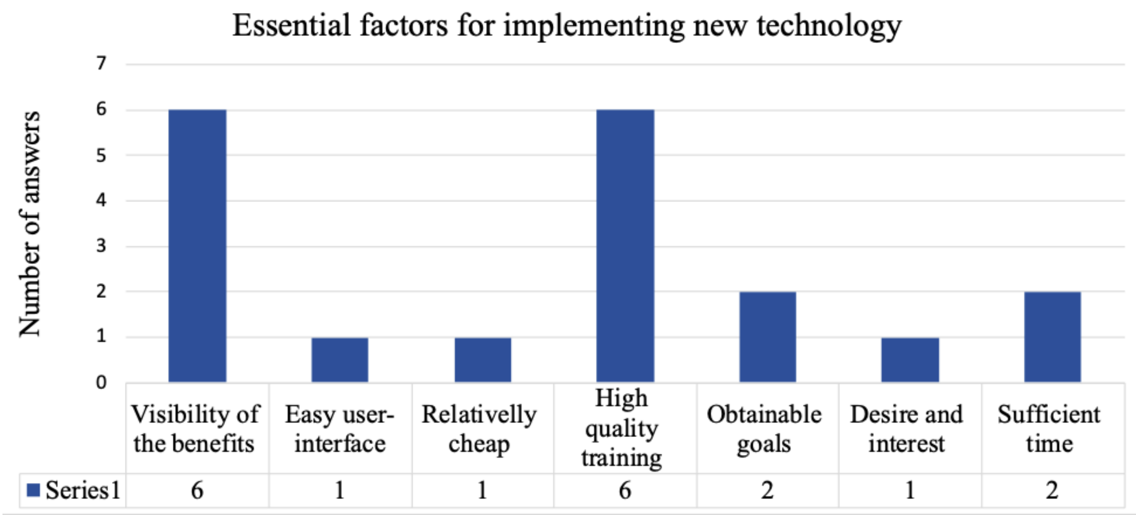


Figure 4.4: Decisive factors when implementing new digital technology.

External interviews

This section summarizes the external interviewees' thoughts considering the process of implementing the AI-based technology mentioned in Section 4.1.1.

Optimize and improve processes
The aim of using any technological tool, including AI-based technology, is to *optimize and improve processes*, such as making the process of identifying diseases easier for doctors, or helping humans to make faster and more precise decisions.

Thorough feasibility study
All three external interviewees pointed out the importance of conducting a *thorough feasibility study* in order to reveal if the technology will add the desired value. One of the interviewees stated the following:

AI is a "hot" topic these days. However, implementing AI-based technology is not necessarily the solution to every problem. Conducting a feasibility study is highly important as the implementation of such advanced technology will require a considerable amount of resources, in the form of money, time and knowledge.

Implementation drivers
All three interviewees emphasized the importance of having *implementation drivers* that have sufficient technical and pedagogical skills. However, one of the interviewees thought that finding persons that have knowledge about the IT domain, construction domain and have good pedagogical skills is challenging. One should instead enter into a closer collaboration between the different domains and exploit each other's strengths. The same interviewee believed that in the future the domains will be more dependent of each other, and the need for collaboration and trust between domains will increase.

4.1.3 Culture

Case specific interviews

This section summarizes the case specific interviewees' thoughts of how the future digital technology mentioned in Section 4.1.1 will impact the working culture.

A "robot's" impact on the work culture
Three of the interviewees [operation manager, E, 25-35 ; subcontractor, L, 45-55 ; subcontractor, S, 25-35] said that all the talk about automation and digitalization makes people afraid of *losing control over their working tasks*, or even worse, being substituted by a robot. They are afraid that the understanding of *why* workers act as they do will disappear, and that people will become less intelligent.

Several of the interviewees believed that robots could probably substitute many of the workers and their accompanying work tasks. However, they believe that the replacement of humans with robots will have a significant impact on the working culture on site. They point out that the human factors; *attitude, feelings, spirit, and soul* are essential for people's enjoyment of work. The following quotation exemplifies this [Planner, E, 25-35]:

Being around a human being is entirely different from being around a robot. A robot does not contain a soul with values. A robot is programmed; it is just empty. The only thing that gets out of a robot is what it is programmed to do, based on a particular input. A human being is not just a being made of skin and blood. It is a person with a soul, attitudes, beliefs, empathy, and emotions.

Human-AI trust
Human-AI trust has recently become a hot topic in the literature, and there is much ongoing research on the topic. Based on this, it was decided to ask more specifically about the interviewees' thoughts about trusting an AI-system, with the aim of unveiling factors that are crucial to obtain sufficient human-AI trust. As the thought of an AI-system can be intangible and not very concrete for a "normal worker", it was chosen to concretize the topic by asking if the interviewees would trust a *robot*. A robot may be easier to envision for people who do not know AI, but as mentioned in Section 3.2.2, robots require a combination of several AI-methods and are in reality more complicated than an AI-system that "only" is based on machine learning algorithms. Three specific cases, presented in Table 4.2, was made and presented to the interviewees. The following section presents the findings from each case.

Table 4.2: Case descriptions: Human-AI trust

Case	Case description
1	Imagine that you are working on site, and a colleague of yours is telling you to switch work tasks. What do you do?
2	Imagine that you are working on site, and a robot is telling you to switch work tasks. What do you do?
3	Imagine that you are walking on site with a robot. Suddenly the robot communicates that danger may occur and recommends an alternative way to go. You look up, down and to each side, but do not observe any danger. What do you do?

Case 1: Human-human trust

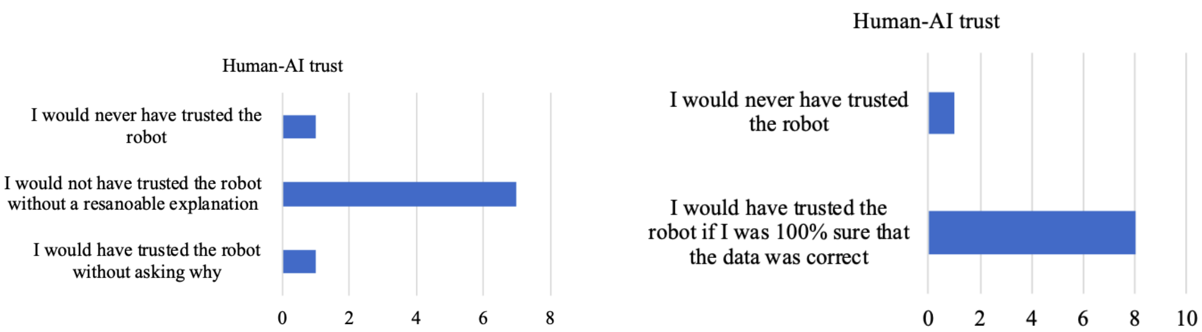
Figure 4.5: Findings Case 1: Human-human trust

As shown in Figure 4.5, all the interviewees answered that they would never simply trust a colleague unless the reason for changing tasks was evident. Several of the interviewees pointed out the importance of their relationship to the person asking. The two quotations below exemplify this [subcontractor, L, 35-45 ; site manager, S, 25-35].

People do not trust other people blindly before they have proven themselves to be trustworthy. Some people have intentions that are not necessarily the best for others.

I can only speak for myself, but I would want to know why. Maybe I have useful input, or see things differently than my colleague. However, I do believe that people with no ownership or feeling of responsibility of the work would have changed tasks without asking.

Case 2: Human-AI trust



(a) Human-AI trust

(b) Human-AI trust when correct data

Figure 4.6: Findings Case 2: Human-AI trust

As Figure 4.6 (a) shows, the majority of the interviewees answered that they would not trust the robot without receiving a reasonable *explanation*. The main reasons are that they cannot be 100% sure that the robot's advice is based on the right data/method/input, as illustrated in Figure 4.6 (b). By reasonable explanation, they mean an explanation that can make them understand *why* they are supposed to switch tasks. Several point out that understanding *why* is especially essential when considering who takes responsibility for, and has ownership of the task before, during and after execution. One of the interviewees said the following [planner, E, 25-35]:

Imagine a project that is delayed, which is not necessarily a result of bad planning. Then someone asks why we planned and executed as we did? Then we have a big problem. "The robot said we were supposed to do it, so we did it" is not a reasonable answer.

Several of the interviewees pointed out that visualization of the process behind the output would probably increase their understanding and trust of the robot. Some interviewees said that they would rely more on the robot if it could visualize *how* and *why* it suggested switching task. Two interviewees [subcontractor, L, 45-55 ; operation manager, E, 25-35] compared it with a chess machine that visualizes the smartest next moves that people are not able to calculate in such a short time. The interviewees would prefer visualization compared to natural language, as they believe it can be time-consuming and challenging for a robot to explain 100 steps ahead using natural language.

The interviewee who would trust the output of the robot even without an explanation stated the following [site manager, L, 55-65]:

The robot's decision will be based on input from humans. The person that would have given this input would probably be me, and I have no reason not to trust my own knowledge and work.

The interviewee [site manager, S, 25-35] who would never trust the robot, even if they had the opportunity to communicate said that it is impossible to be 100% sure that the robot is based on the right data. For this reason, there will be no point in communicating with it either.

Case 3: Human-AI trust safety aspect

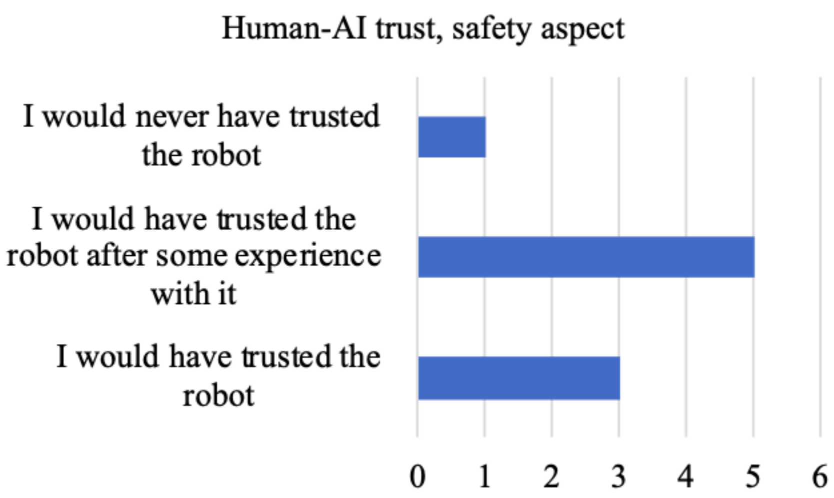


Figure 4.7: Findings Case 3: Human-AI trust, safety aspect

Figure 4.7 illustrates that the majority of interviewees would rely on the robot after becoming more known and used to the robot. They pointed out that it is challenging to know how reliable and trustworthy the robot is before interacting with it for some time; just as one would be more trusting of a human that acts reliably over a period of time.

Other points out that there has always been a great passage of people in the construction industry, people that come, and people that go. To continuously trust new people is part of the job, and a robot would be like a new person on site.

Those who would have trusted the robot said that there is no point in exposing oneself to possible danger. One interviewee [operation manager, E, 25-35] compared an on-site robot with a self-driving car :

Look at self-driving cars. They can predict obstructions, and possibly dangerous situations in the environment of the car, long before the human eye sees them. This technology would be equally valid for a construction site and based on that there is no reason to not trust the robot.

The interviewee [subcontractor, L, 45-55] who would never have trusted the robot said that the human eye is smarter than the robot and that humans will manage to make independent decisions regarding own safety.

External interviews

The external interviews had nothing to add, considering the technologies impact on the working culture.

4.2 Current implementation of AI

The following section presents findings relevant to RQ2:
What are the harvested benefits and barriers to the implementation of AI in the construction industry today?

The findings are based on all the eighteen case-specific interviewees, described in Table 2.4, Chapter 2, Methodology. To map the harvested benefits of AI in Project Bispevika, it was chosen to investigate the implementation of three digital tools: Touchplan, Synchro, and ALICE. The tools represent the three levels of digitization (digitization, digitalization, and digital transformation) as described in Section 3.2.1. Considering the lack of knowledge regarding AI-based technology, the main focus has been on which factors from the implementation of Touchplan and Synchro can be useful and transferable to the future implementation of ALICE.

4.2.1 Technology

AF Gruppen has its own department of innovation and digitization. The department was established January 2018 intending to support projects in the development and implementation of digital tools that support processes. Among other things, the department has announced the project *Digital Construction Site*, which aims to motivate and contribute to projects becoming more digital. One example from the project is the making of a BIM manual. The BIM manual aims to support employees' understanding of the BIM process and BIM-related tools used in AF Gruppen's projects, in addition to being a support when making the structure of the model.

The following section presents the findings concerning the *technology* around the current use of Touchplan, Synchro and ALICE in Team Bispevika.

TOUCHPLAN
The diveristy of the interviewees experience Touchplan as a user-friendly tool. The fact that Touchplan can be reached through a webpage on any computer makes the tool *accessible*. That the plans are digital makes it *easier to get an overview and edit* the whole plan and the dependencies of tasks.

Touchplan is based on the principles of the Last Planner System (LPS), where continuously learn from mistakes made is central. For every task that does not go according to the schedule, a cause should be identified. The interviewees experience this as too *time consuming* due to the *detailed level* of the tasks. Two of the interviewees [planner, E, 25-35 ; subcontractor, S, 25-35] said that identifying cause-impact factors contributed to discussions during meetings, due to the complexity of the mistakes. One mistake does not necessarily have one cause, but a mix of many causes. As a result of the challenge of determining the cause-effect factors *no good data is produced*. Data that is supposed to contribute to continuously learning. One of the planners in Bispevika stated that the current process of production monitoring in Touchplan is too time-consuming and requires *too much involvement* from the workers. The same planner stated that there is currently too much focus on the flow and gaining knowledge from mistakes, while the main aim is to build more efficiently at a higher quality.

SYNCHRO
Synchro makes it possible to look at the plan in 4D. The visualization makes it *easier to plan* and contributes to *shared understanding* and *communication* among the participants. One of

the interviewees [planner, E, 25-35] stated the following:

Synchro is the digital tool I see the greatest potential in, of the digital tools used in the project. Imagine that we are 20 people sitting in a meeting. We are discussing how to build a roof detail in one of the buildings on site. I have a picture in my head of how it is supposed to look, and so do the other 19 participants. Probably we are not seeing the same picture, or at least we cannot be sure. By visually seeing the detail in a 4D model, a common understanding is reached.

The fact that Synchro presents the construction digitally contributes to the continuous *revision of the construction model*. However, the *level of detail* in the models as well as the *illustrators' lack of practical experience* is considered to be barriers. As easy revision of the model is considered a benefit, it is a barrier that there are too *many versions of the model*. One example is that the construction consultant and the architect used two different systems of coordinates. The following quotation exemplifies the lack of details in the construction model [subcontractor, L, 45-55]:

We had a critical situation concerning the roof, where the reinforcement was supposed to be welded to a supporting beam. However, this was not included in the model. The model illustrated a clear gap between the reinforcement and the supporting beam. The information about the welding of the reinforcement was written in Norwegian, and you had to click on a special place in order to find the information. Building only based on a model, with no use of 2D drawings, will require early involvement of consultants and much more detailed models.

Both Touchplan and Synchro are tools that is supposed to strengthen the process of planning. Currently Synchro and Touchplan are *not synchronized*, and the site managers have to copy the plan made in Touchplan manually into Synchro. The interviewees disagreed on whether the process of manually copying the plan is value-creating or not. Some experienced it as double work, while others experienced it as valuable as the site managers would be updated on the schedule and would think through whether this was the right way of doing things.

The interviewees experienced Synchro as a tool with a *complex user-interface* compared to Touchplan; Synchro was therefore seen as less accessible and useful.

ALICE
ALICE is a software that uses human input and historical figures to aggregate data. The data given from the human is a BIM model, and data such as time frame, equipment, crew, etc. The algorithms analyze the input and output in the form of possible schedules are produced. The output enables the human to look into each schedule, visualize the schedule in 4D and in a Gantt diagram. The output aims to support the human in their decision-making. Team Bispevika is currently in the early implementation stage of ALICE, so technological success factors are too early to say something about. However, the tool enables visualization of the construction in 4D, which is highly appreciated among the workers that use Synchro. The current technological barrier is the lack of historical figures.

4.2.2 Process

The former chief of digitization an innovation stated that one project alone could not revolutionize the way an industry work. The entire company needs to contribute. An important decision was taken when the strategy for AF Gruppen, 2016-2020 was developed. The strategy stated that AF Gruppen should be an industrial investor. An investor that dares to be curious and search for new innovative and digital solutions that can strengthen their way of building. Construction

Venture [6] was established in 2018, with the aim of building a portfolio of companies that can change the way the industry work. Construct Venture has a focus on investing in companies that challenge the industry, facilitate collaboration an develop new solutions that can be used in AF's projects.

In Bispevika, digitization means improving the efficiency of their current processes empowered by digital processes. The intention is to strengthen the way they build by making processes more efficient with the help of digital tools and workflows. Efficiency is supposed to be improved by working smarter, not faster.

The following section presents the findings concerning the *process* around the current use of Touchplan, Synchro and ALICE in Team Bispevika.

TOUCHPLAN

Training strategy and implementation drivers

The interviewees disagreed on whether a *training strategy* exists or not. None of the interviewees had been through any particular training program and had learned Touchplan through "learning by doing" and receiving help from the *implementation drivers*. All interviewees said that the implementation drivers are crucial for getting Touchplan to work and that they do an excellent job. However, due to the confusion of a training strategy, the majority of the interviewees experienced *"learning by doing"* as sufficient training in Touchplan, as a result of its simple user-interface.

Routines

The interviewees also disagreed on whether there exists *routines* of using Touchplan. The interviewees from the project management team said that the project platform defines how the tools should be used, through which processes the tool shall support. However, only a few of the interviewees were aware of this or had "forgotten" the planning structure. As a result, there exist many individual comprehensions of *how* Touchplan is supposed to be used, and *why* the tool is being used.

Visibility of the benefits

Fourteen out of the eighteen interviewees could *see the benefits* of using Touchplan, and experienced that the tool improved their way of working. One of the interviewees [subcontractor, L, 45-55] said that he did not see the benefits of using Touchplan in the beginning, but after practice and several explanations from the implementation drivers did he understand its benefits, and now he is relatively satisfied with the tool.

On the contrary, one of the interviewees [site manager, S, 25-35] mentioned that Touchplan is too complex and that it is challenging for subcontractors that cannot even download an application on their phones to learn such a complex program. The same interviewee does also believe that there is no point in learning Touchplan, as the tool is expensive, so few projects will probably have the economy to use the tool in the future. However, it should be mentioned that this person has never tried Touchplan.

Another interviewee [subcontractor, L, 35-45] said that many of the workers recognized the benefits of using Touchplan at the beginning, but that there has been a lack of illuminating the benefits of Touchplan, and as a result people have lost motivation.

[6] Collaborative venture initiative between AF Gruppen and OBOS. More information about Construct Venture can be read at: https://afgruppen.no/selskaper/construct-venture/

Generational shift
One interviewee [site manager, S, 25-35] think it is absurd that 50+ people are supposed to learn the digital tools when the industry has not even landed on which tools to use. While several others think that if the tools are easy enough, will also the “older generation” be able to use it.

Two of the interviewees [site manager, S, 55-65 ; subcontractor, L, 45-55] with many years of experience mentioned that collaboration between inexperienced people and experienced people is crucial to success. The people with expertise from the site can teach the people with less experience about the building technology, while the persons with digital knowledge and less experience form site can learn the experienced workers’ digital knowledge. Another interviewee [planner, E, 25-35] stated the following :

Team Bispevika currently consists of around 60 people from AF Gruppen. Among those 60 persons, I have experienced few people offering the perfect balance between being innovative, earning money, and achieving an efficient flow in the production. People have different strengths, and these strengths must be combined in order to succeed.

Level of difference
Level of difference in the morning meetings are today considered as a barrier among the interviewees. One of the interviewees stated the following [subcontractor, S, 25-35]:

People lack knowledge of Touchplan when they start attending the meetings. Personally, I learn digital-technologies quite quickly. For me the meetings are not only getting boring but are time-consuming and expensive when half of the meeting time is spent on explaining what Touchplan is, and how to insert a task.

Lack of expectations
All three sub-contractors wished for more tangible expectations when it came to the use of digital tools in Bispevika. All three interviewees said that on other projects they were ordered to use a program called Dalux [7] and since they were ordered to use it they had to learn the program quickly.

Time-consuming
One interviewee [subcontractor, L, 35-45] said that before starting execution he/she had spent 30 hours scheduling. When the interviewee was finally ready to start the execution, the execution was exposed. The interviewee experienced that people were more concerned with moving around tasks in Touchplan than actually making progress on site.

On the contrary, others experience great value of Touchplan; both in the form of *progress on site* and *increased communication* between main-and subcontractors, which made it easier to discuss difficulties.

Improved digital knowledge
Despite several barriers, in general, skills concerning the use of digital-technology increased drastically over the last year. The following quotation exemplifies this [operation manager, L, 35-45]:

Before I started this project, I was not capable of opening a read-only mail, but now I move around in the 3D model, copy and paste things, and write relatively fast on my computer. It is fantastic!

[7] More information about Dalux can be read at: https://www.dalux.com/dalux-build/

SYNCHRO
Six of the interviewees went to an *external course* with the supplier of Synchro, and the majority of them found the course useful. *Visualization* of schedules in Synchro makes the process of planning more manageable, as it contributes toward a common understanding and communication. However, only a few of the interviewees use Synchro in their daily work life, due to *lack of time, resources, knowledge concerning 4D planning, and concrete and tangible goals.*

ALICE
As before mentioned, the implementation of ALICE is currently in an early stage. An implementation team has been created, and a feasibility study has been conducted. The implementation team consists of six persons with different background and qualities, working together, developing, and implementing the tool. The aim is to improve the efficiency of the workers' processes, by the use of the lean-methodology and AI.

The team is currently operating with two test cases: one for the interior work and one for the structure. These test cases are running parallel to the production on site. Based on the information given by the site managers, are two of the implementation team members continuously giving input to ALICE. Typically input is time used, equipment, crew, etc. As a result of the provided information is ALICE producing output in the form of possible schedules. Regularly are the team presenting a one-pager to the site managers. The one-pager contains a summary of the information provided by ALICE. Based on the presented one-pager, are the site managers asked the question whether the information given is useful or not?

In this way, are the workers gradually being prepared for the implementation of AI-based technology, in addition to the parallel development of the tool.

4.2.3 Culture

The former chief of innovation and digitization believes that the *attitudes* the management holds and how the management talks about innovation and digitization have a significant impact on the rest of the company's attitude. The former chief of innovation and digitization had experienced relatively good support around the digital switch in AF Gruppen, but was aware that many skeptics also exist. The interviewee pointed out the importance of being positive, but at the same time critical, as the wrong use of digital tools can result in the opposite of what was expected. The interviewee believes that the implementation of new processes and tools will be successful in the long term if people have the right attitude, motivation, and willingness to learn, not by forcing people to use them through contractual provisions.

In order to obtain positive attitudes and motivated workers, AF Gruppen is focusing on innovation and digitization in all contexts where AF workers gather. On internal webpages by drawing attention to innovative projects and persons, through pictures and videos, and the project *Digital Construction Site*. Team Bispevika is considered a good role model. They have received several visits, both from internal and external people. In addition, Team Bispevika is given a lot of attention by the owners (OSU) and the management in AF Gruppen.

The following sections presents findings related to the working culture in Team Bispevika.

Lean in Team Bispevika
The Bispevika-mindset is based on the lean approach. Bispevika defines lean as the following:

Lean is an ideology that provides a systematic approach to eliminating non-value-creating activities, streamlining value-creating activities and identifying new value-creating activities. The four lean pillars in Team Bispevika are: plan structure, digitization, contract and calculation, and performance culture.

Bispevika describes a performance culture as a culture where the team creates a relational capability. It has to be worthwhile to cooperate over time, both internally and with the customer and the partners. Team Bispevika emphasizes the importance of both common goals as well as individual goals, and the fact that all goals should be aggregated to the main goals of the project.

Open and flat working culture
All interviewees working for AF Gruppen agreed that Team Bispevika has an *open and flat working culture*. The following quotation strengthens this statement [operation manager, L, 35-45]:

I can talk to everyone on site, and I am not afraid of asking people for help. Although the director has the title 'director', we are in the end all colleagues with different areas of responsibility, but with a common goal.

Diversity of cultures on site and communication
Due to the employment immigration to Norway, there is a *diversity in cultures* on construction sites. Diversity of cultures often brings with it a multitude of spoken languages, and thus language barriers. Several of the interviewees mentioned the language barrier as one of the main reasons for bad *communication* and misunderstandings on site. One of the non-native interviewees [subcontractor, L,35-45] said that it can be demanding, due to the language barrier, to understand the intention behind work tasks. This lack of understanding may result in misunderstandings, which further result in a delay of progress, and a bad atmosphere on site.

Attitude
The *attitude* towards digitization varied among the interviewees. Some experienced digitization only as extra work, while others saw the possibilities and benefits that digitization can bring. The following three quotations present this diffusion of attitudes [site manager, S, 25-35 ; site manager, L, 55-65 ; site manager, E, 25-35]:

- *Why use time and money implementing and learning digital-technology when it is possible to produce work efficiently and on time without learning it?*
- *I experience that people have a positive attitude. I think that people understand that digitization has come to stay and that they are making an honest attempt to be positive and interested.*
- *As for every change it requires more work in the beginning, compared to the normal amount of work. When things take more time than first assumed people develop a negative attitude.*

Motivation and willingness
Several interviewees from AF Gruppen agreed that there was great *motivation and willingness* to learn digital technologies among the members of Team Bispevika. However, it is experienced more demanding to get people to learn Synchro than Touchplan, as Synchro requires more work and time compared to Touchplan. Other interviewees stated that it is not the workload and lack of time that are the main reasons for people not learning Synchro, but the lack of seeing what the tool will give them in a long-term perspective.

Sense of achievement
The interviewees stated that the *sense of achievement* concerning Touchplan and Synchro was relatively low among the interviewees. Several of the interviewees explained that there are new things to learn all the time, and as a result, there is no time to learn the tools properly and obtain achievement. The lack of achievement reflects the lack of ownership.

Trust among the workers in AF Gruppen, but a lack of trust in sub-contractors
Concerning *trust*, all the people in AF Gruppen said that they trust each other. However, they explained that there exists a lack of trust in the sub-contractors. This lack of trust is a result of the subcontractors not doing what they said they would.

In terms of trust and communication between the sub-contractors, one of the sub-contractors said that there exist trust and good communication. In contrast, other sub-contractors experienced a lack of trust and communication. The following two quotations exemplify [subcontractor, S, 25-35 ; subcontractor, L, 35-45]:

- *Good communication and trust between the sub-contractors are essential to success as the different work tasks are highly dependent on each other. I trust the others, and if I have any difficulties, I call them to ask.*
- *We have each other's numbers, but I never contact the other sub-contractors directly with a problem. Instead I call one of the workers in AF Gruppen.*

Chapter 5: Discussion

The following chapter uses established literature presented as the theoretical framework in Chapter 3 to discuss the findings from the empirical data collection presented in Chapter 4, Findings, in addition to presenting the author's opinions and thoughts. The same categories (Technology, Process, and Culture) as in Chapter 3, Findings, have been used to structure the chapter to preserve consistency in presentation.

5.1 Future implementation of AI

The following chapter discusses findings relevant to research question one:
What are the potential benefits of implementing AI in the construction industry?

5.1.1 Technology

As presented in Section 4.1, this study reveals several AI-methods that can be applied in the construction industry. *Machine learning's* ability to analyze big sets of data and learn from experiences can be used as decision-making support. *Pattern recognition* can, among other things, be used in the monitoring of the site and construction verification. Monitoring of the site may increase safety on site, while construction verification is likely to save hundreds of hours spent on construction verification by a human. Currently, several start-ups [1] considering the use of machine learning and pattern recognition are trying to break into the industry. This study also reveals that *robotics* can be used on construction sites, but are currently only used to carry out repetitive tasks in a controlled environment. In order to exploit the benefits mentioned above and in Section 4.1 several barriers must be broken down. The following section will address this.

Data collection

As Chui, Manyika, and Miremadi (2018) states, there is a prerequisite for every AI-system (including machine learning, pattern recognition, and robotics) to have a sufficient amount of data, high-quality data, and the right variables. The findings show that pattern recognition is widely used in the healthcare industry to detect early stages of diseases. Medical offices and hospitals are collaborating worldwide with the aim of continuously generating more data. As a result, AI-systems are becoming more accurate, precise, and thus more trustworthy every day. Can the construction industry transfer these experiences and learn from the healthcare industry?

One can argue that each construction project is unique, while all human bodies are composed of the same components. Based on the fact that each project is unique, it will be challenging to collect data that can be successfully transferred between different construction projects. To

[1] Some start-ups: https://alicetechnologies.com/, https://www.scaledrobotics.com/, https://3dr.com/products/site-scan-platform/

put it another way: if looking at each construction project holistically, it is evident that each project can be considered unique. They are located in different geographical places, and they look different, have different facades, different windows, etc. On the other hand, when breaking down each construction project into smaller parts, is each construction project really as unique and complex as it seems? As illustrated in Figure 5.1, it is possible to break down the whole construction into smaller parts. We go from looking at the whole construction, to looking at only the concrete structure, to looking at all the concrete slabs to looking at a single concrete slab. How many different ways are there to build a concrete slab? Probably not very many compared to the number of diseases that can occur in a human body; not to mention the range of causes of these diseases.

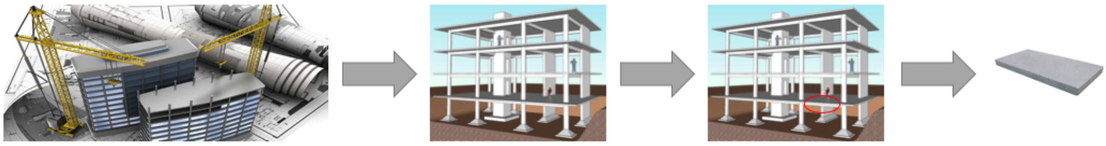


Figure 5.1: A construction: small parts built together

The more data the AI-system has available to it, the more precisely and trustworthy its conclusions will be (Chui, Manyika, and Miremadi, 2018). Logically, the generation of data will happen more quickly if several building projects generate data simultaneously, as with the medical offices and hospitals that are collaborating all over the world. Due to the construction industry's competitive way of working, close collaboration between firms has not been a norm in the industry. However, the lean philosophy, with its focus on collaboration and improving productivity by removing what is not productive, has now entered the construction industry (Koskela, 1992). Collaboration between firms to collect data can be seen as an act of removing what is not productive. A central question to discuss and solve in the future will be which of the firms will possess the collected data? Will a partnership based on commitments, as Senior and Swailes (2010) state as essential, be enough to ensure that all companies optimize to the benefit of all partners? Moreover, if the AI-system finds the perfect recipe for building a particular element, in terms of safety, productivity, and economy, how should the subcontractors be paid to do the job?

Reliable and true data

The amount of data produced is important; but even more significant is the quality of the data produced. As stated by Chui, Manyika, and Miremadi (2018) and the external interviewees it is not enough to have a sufficient amount of data from historical cases: the data needs to correspond to the real-life situation. It needs to be accurate, in order to be able to support humans in their work, as the AI-based algorithms learn from the given data and make predictions using learned data (Ertel, 2017).

This study shows that doctors in the healthcare industry are trained in the importance of giving the correct input data to the AI-system. The fact that the construction industry is project based and consists of a large number of specialized co-workers engaged in the same construction project for a limited time-frame (Skinnarland and Yndesdal, 2010) can make it challenging to communicate the importance of giving accurate input data. While in the healthcare industry it is the same doctors who produce data every day, in the construction industry, new people arrive at the site each week. These new people are also expected to produce reliable data. If one contractor breaks the cooperation and sub-optimizes the data, all the other collaborators will suffer (Kristensen, 2011), as the output is reflected by the input.

One of the interviewees [site manager, S, 55-65] stated that he/she would have trusted the given output because it is a result of human input, and the human giving that input would probably be him/her. However, one thing is to trust oneself: it is something else to rely on the historical data produced by someone else. It is likely to believe that the probability of human errors will increase with the number of people giving input to the system. The trust will, of course, depend on who ”someone else” is.

This study shows that trust among participants of AF Gruppen in Bispevika are considered high, while trust in the sub-contractors is deemed to be low. Team Bispevika has grown from 25 to 55 persons within six months. The growth indicates that many of the employees in AF Gruppen have worked together in a limited period of time. Based on this, it is likely to assume that trust in other AF employees is mainly based on calculus-based trust. It is noteworthy that AF employees have trust in other AF employees they do not know, but not in sub-contractors they do not know. Why such a difference? In the future the historical figures, which the output is based on, may be produced by a total stranger from another project created five years ago. How will that affect the trust in the data? Will employees be able to trust data produced by other companies when they are not even capable of trusting subcontractors at the current project?

Another interviewee stated that he/she would never have trusted robots due to the lack of knowing 100% that the robot is based on the right data. Anyhow, based on the complexity of the AI-systems, a human would never be capable of knowing 100% that the model is based on the correct data. However, a solution for finding biased data could be designing AI-systems that make it possible for humans to identify the potential biases. The next section will address this.

Designing understandable AI-systems

In order for the end user to be able to use the AI-system, in addition to identifying biases, it must to some extent be understandable. However, it is essential to distinguish between understanding the process behind the output and understanding the output. One aspect is to explain the choices made; another is to explain the logic behind these choices. Take, for example, ALICE, which can produce thousands of possible schedules. Will it be sufficient for the users to be given an explanation so they understand *why* the schedule is at it is, or will it be necessary for the workers to understand the process behind *how* the schedule was made?

This study points out that in the oil and gas industry a visualization of the process from the input to the output was needed for the workers to trust the output of the AI-system. However, the system did not directly visualize the proceeding of the data, but only the factors that were considered necessary for the human to know about. The oil and gas workers had no previous experience with AI-systems. Based on the current basic knowledge level and experience of AI in the construction industry (Kristensen, 2011), it is likely that the users will need to understand the process from the input to the output, as in the case of the oil and gas workers.

However, this study reveals that the external interviews (data engineers) believe that untrained users should only know *how* to use the tool. The statement is based on the belief that workers with high competence within their field of work will understand from the output whether a bias exists in the data set or not. If they do not find any unusual parameters in the output, they are likely to trust the output.

In contrast, the majority of the case-specific interviews state a need for understanding *why* the AI-system concludes with the given output before the system can be trusted. The case-specific interviewees believe they would have trusted the produced schedule if they were shown which factors differed between their version of the schedule and the one ALICE created, and *why* they should use ALICE's version instead of their own. Based on this, it is likely to believe that an explanation of the schedule is sufficient to obtain understanding and trust in the produced output. On the other hand, will it be more demanding to find biased data through an explanation *of* the schedule than an explanation of *how* the schedule was produced. Stated by the external interviewees, designing a system that enables the workers to look into each schedule, and see the cause-impact relationship will contribute to finding biased data. If the cause-impact relationship is not logically or practically feasible, a question can be asked whether the system may have been based on biased data. On the contrary, may the cause-impact relationship look illogical for the human, but still be the most optimized schedule.

Chander, Wang, Srinivasan, et al. (2018) states that in such situations where the human and AI-system disagree, or the human is not capable of understanding or trusting the system a human-AI interaction is needed. The next section will address this.

Human-AI interaction

Zhu, Liapis, Risi, et al. (2018), Hagras (2018), and Chander, Wang, Srinivasan, et al. (2018), state that interaction between the AI-system and the human is needed to obtain a sufficient level of trust and further develop a functional human-AI collaboration.

Knowing *how* and *what* information to share with the users can be challenging. Schuh, Anderl, Gausemeier, et al. (2017) state that a common barrier is that the data is only visible and understandable to a limited number of people who can access and understand the particular domain system. At the same time, Chander, Wang, Srinivasan, et al. (2018) illuminates the importance of AI-systems being accessible and understandable for non-AI engineers. The first step towards establishing communication and interaction between the human and the AI-system is to transform the digital data into a format that is understandable for humans.

Keeping the number of possible nodes in a chess game (mentioned in Section 3.2.3), it is evident that it will never be possible for a human brain to manage a totally transparent AI-system. Case-based reasoning, which is a machine learning method, is the process of solving new problems based on the solutions of similar past problems. For example, if planners give input about a project or a phase of a project to the AI-system, it will compare the input with historical figures from other projects. The system can then visualize how many % correlations the given input has with the different historical cases and which factors were essential in the historical cases. In other words, the human and AI interact through visualization. By looking into which factors were essential in the historical cases, workers will see connections they had never thought about before. By doing this, the system will not only advance its own continuous learning but will also contribute towards the knowledge of the workers. This is aligned with the lean-mindset, where continuous learning i essential (Ballard, 2000). By being given the opportunity to look into the essential factors of the historical cases, such as time-frame, economy, staff, safety, etc., the workers will be able to uncover errors in the data.

Explanation and interaction through visualization, as described above, can be a sufficient solution for obtaining trust in the AI-system. However, the fact that case-based reasoning enables humans to some extent, understand the AI-system and find biased data, is on the expense of the accuracy of the output. The alternative is the black-box models. In these models the accuracy is on the expense of the human understanding and possibility of finding biased data.

Natural language is another possible form of interaction with the AI-system. Anyhow, transfer human language into numbers that are understandable for the AI-system is considered more challenging than reshaping figures from the AI-system to a reasonable output to the human. When human speaks, one does not necessarily convey a precise meaning which directly can be transferable into numbers. The language is infiltrated by the given context, including humor, sarcasm, and irony. These are concepts that are challenging for a machine to understand.

Chander, Wang, Srinivasan, et al. (2018) illuminates the importance of fluid interaction when the AI-system's recommendation does not match the human's current belief. However, what happens if the human is unable to trust the system or disagrees with the system, despite interaction? Nothing very special will happen; the humans have to trust themselves as they did before the technology was available, which emphasizes that high domain knowledge will also be essential in the future.

5.1.2 Process

The majority of the interviewees think that the AI-methods mentioned in Section 4.1.1, Technology, can contribute to making the industry more productive and safe, and can increase the quality of the work done. This is in accordance with the literature's predictions about the construction's digital future (Salehi and Burgueño, 2018; Barbosa, Woetzel, Mischke, et al., 2017; Hagras, 2018; Blanco, Fuchs, Parsons, et al., 2018). However, it is easy to come up with words of praise concerning what benefits the technology will contribute to, but these words of praise are only what a person hopes AI will bring. It is important to come up with a strategy for *how* to gain these benefits. Is the technology just fascinating and ”cool”, or will the implementation of the technology gain more value than the current situation?

The AI-system's impact on work tasks and workflow

The majority of the case specific interviewees believe that the implementation of AI-based technology will impact their work tasks and the workflow, and that there will be less need for human labor. Three of the case-specific interviewees express concern about people getting less intelligent as a result of the implementation of more advanced digital technology. They feared that digital technology will take over the human need for thinking and understanding, and that knowledge of how to build will no longer be necessary. These statements differ from the beliefs of the external interviewees, who believe that high knowledge within each worker's domain will be essential for the AI-systems to function optimally. Imagine if doctors were entirely reliant on the analysis of an AI-system to determine whether surgery was necessary or not. Sooner or later all knowledge about recognizing diseases would fade away. This emphasizes the importance of the external interviews statement that knowledge within each worker's domain still is highly needed.

The following section will discuss how an AI-based planning tool, such as ALICE, could possibly impact work tasks and workflow, and if the tool will substitute human labor.

The process of planning

The *current process of planning* in the operating department in Bispevika is conducted in accordance to LPS (described in Section 3.1.4). The planning structure in Bispevika contains five levels: the main schedule, the phase schedule, the lookahead schedule, weekly schedules, and the morning meetings. The planning structure can be found in Appendix 4. The closer to execution, the more detailed are the schedules.

Simplified and shortly explained is the first step of making a schedule discussion of time-frame, available crew, materials, equipment, etc. as illustrated in Figure 5.2. Based on these factors are possible ways of executing discussed between relevant contractors. In the third step, participants agree on a schedule. During construction, a morning meeting is conducted where employees are updated about what was done the day before, what was not been done, and whether or not the project is progressing according to plan. If it is not, possible measures are discussed, and the schedule is updated, as illustrated in the last step of Figure 5.2. Unforeseen occurrences can always happen, either due to unexpected weather changes, lack of crew, materials, equipment or just bad scheduling. However, in line with the lean methodology, the aim is to learn from the mistakes made and prevent them from happening again (Kalsaas, 2017). Continuous learning and corrective action are today taken care of through PPC and root cause analysis. As written in Chapter 3, Theoretical framework, PPC compares the number of tasks completed with the number of tasks planned (Ballard, 2000). However, this does not indicate that the schedule was as efficient as it could be. In fact, the opposite may be the case.

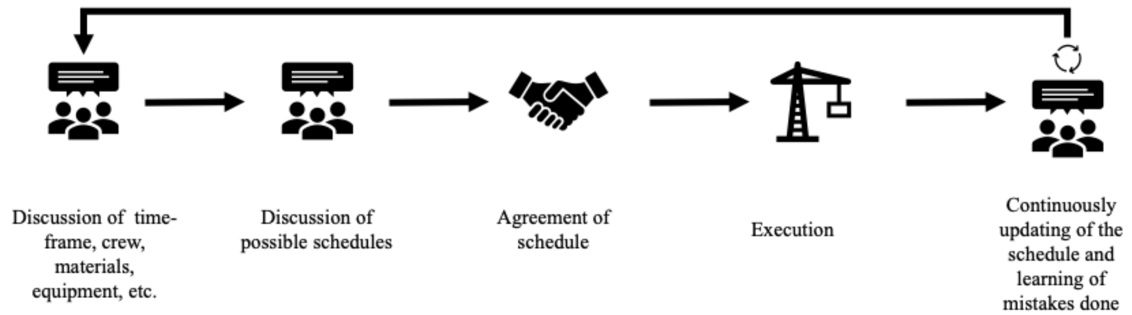


Figure 5.2: Illustration of the current process of planning in Team Bispevika

Let us now look into a *possible future planning process*, with the use of an AI-based planning tool. As shown in Figure 5.3, the first step will involve the workers discussing possible input, and is the same as the current situation shown in Figure 5.2. Further, the humans will agree on the input they insert in the AI-system, as they agree on the schedule in Figure 5.2. The AI-system will analyze the given data, compare it with historical figures (if they exist), and then recommend a huge amount of possible schedules. It is here that the decisive step in the process occurs, dividing current and future planning situations. Will the humans trust or distrust the schedules produced by the AI-system? If the humans trust the AI-system, the proposed schedule could be executed. During execution unforeseen incidents could occur on site, and the actual execution will most likely differ from the schedule provided by the AI-system. To ensure continuous learning the AI-system must be provided with input about the actual execution. By giving the AI-system the actual execution parameters the system will remember and learn from the data given. In other words, the AI-system will ensure continuous learning and improvement of the process of planning.

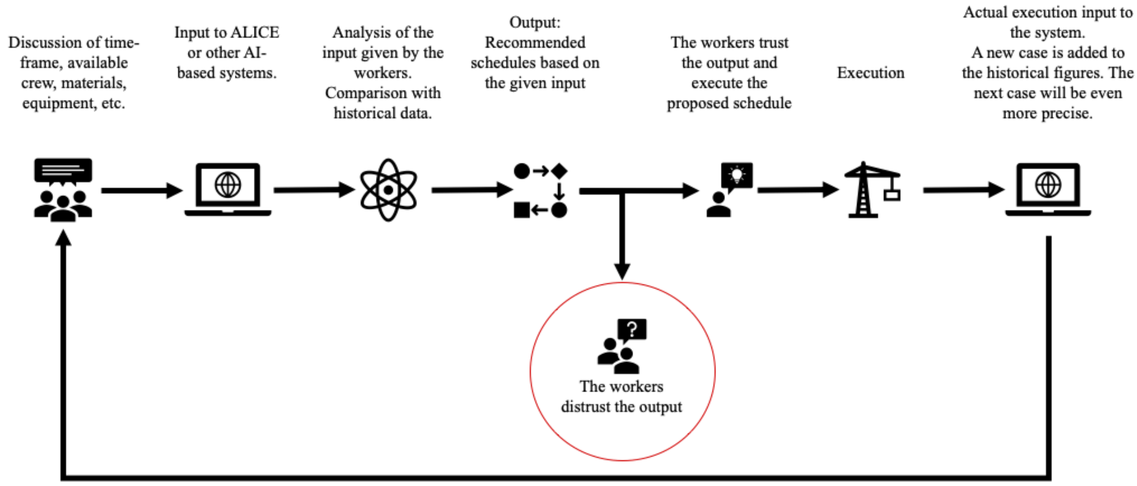


Figure 5.3: Illustration of the possible process of planning by the use of an AI-based planning tool

Comparing Figure 5.2 and Figure 5.3, will changes occur in the work tasks and workflow, and will ALICE or other AI-based planning tools substitute human workers?

The first thing that differentiates Figure 5.2 from Figure 5.3 is that the workers give the input to the AI-system instead of directly deciding the schedule. Anyhow, the workers still have to discuss among each other how much time they can potentially use, and map available workers, materials, equipment, etc. This underlines the importance of having high domain knowledge, as ALICE will be dependent of true data if it is supposed to produce reliable and trustworthy schedules. While the current situation bases its choices on the discussion between employees, in the future an extra step will occur.

The AI-system will analyze the input, and an output is produced. The output gives the workers many possible schedules to choose between. Further, the human must decide whether to trust the AI-system and choose one of the presented schedules; not trust the AI-system and choose what they think is the best way to execute; or combine their beliefs with one of the schedules presented by the AI-system. However, worth pointing out is that the human is in charge; the human has *control* over what is being executed. ALICE is not taking over the work of planning, the tool is just *supporting* the human to optimize their decisions. The question is whether or not the human trusts the schedules produced by the AI-system. To be able to decide whether the produced schedule is trustworthy or not, it is likely to believe that the workers must have knowledge and experience of what is practically possible to execute. When comparing Figure 5.2 and Figure 5.3, the only difference is that the AI-system provides the planners with even more schedules to choose between than they can produce by themselves.

However, a prerequisite for the AI-systems to empower the human, and by that gain value, is that the human is able to *trust* the produced schedules of the AI-system. Chui, Manyika, and Miremadi (2018) states that the fact that humans distrust the AI-systems is one reason that the adoption of AI-based technology remains low in application areas where explainability is needed. Human-AI trust will further be discussed in Section 5.1.3 Culture.

Training

A prerequisite for the process illustrated in Figure 5.3 is that the workers can manage the tool. The construction industry is one of the least digitized industries (Kristensen, 2011) and has approximately zero adaption of AI-based technology (Blanco, Fuchs, Parsons, et al., 2018). With this in mind, as well as the fact that fear tends to generate resistance to change (Atkinson, 2015), there should be a focus on training employees.

The interviewees believe that the factors "visibility of the benefits" and "high-quality training" will be the most decisive factors when implementing new digital technology. Visibility of the benefits can be seen in connection with making each employee's work-life easier, which Atkinson (2015) considers the best incentive for change. Making each employee's work-life easier may result in increased productivity and better workflow. That the interviewees consider "high-quality training" as essential is in accordance with the literature, which illuminates the importance of a well developed training strategy and competent implementation drivers (Arnold, Randall, Patterson, et al., 2010; Senior and Swailes, 2010; Atkinson, 2015).

Due to the implementation of a great amount of digital tools, the industry is moving from being a pure construction industry to becoming a construction-tech industry. The external interviewees believe that it will be challenging for one implementation driver to have sufficient knowledge within both construction and IT, in addition to having excellent pedagogical skills. A data scientist probably has no clue as to which factors are essential concerning a building, while a construction worker probably has no clue of which data is essential when developing an algorithmic system, or how to manage the system if bugs. Based on this, it looks as though the two domains will be highly dependent on each other in the future. As Roland and Westergård (2015) writes, weakness in one implementation driver should be balanced by another driver's strength. The collaboration can contribute to the exchange of useful knowledge and experiences between the different domains. As IT is an industry that works within almost every other industry, it should be fairly easy for IT-engineers to transfer their experiences from other industries to the construction industry. For example, an IT-engineer who has worked with the implementation of AI-systems in the oil and gas industry, may in their next project work with the implementation of AI-systems in the construction industry. What worked and what did not work in the oil and gas industry may be useful information to apply to the construction industry and vice versa.

However, given that the world is becoming more globalized, it cannot be taken for granted that the corresponding IT-support team will have offices in the same country as the ongoing project. Factors such as time differences and language barriers must be taken into account. It is evident that an IT-support team based on another continent will be less able to visit the project than an IT-support team based in the same city as the project. However, one must ask the question: is this a significant barrier? The systems will probably be available to manage from any computer, and communication via the internet and phones has never been as achievable as it is today. What can be seen as a challenge when several companies collaborate is the feeling of *responsibility* and *ownership* to how the AI-system works at the given projects.

The other factors mentioned by the interviewees as crucial regarding the implementation of new digital technology is an easy user interface, low costs, achievable goals, sufficient time and interest. It is notable that all these factors, except from interest, are also included in the formal subsystem (Figure 3.3 (a) and (b), Section 3.1). One reason that more or less none of the factors included in the informal subsystem were mentioned could be that the interviewees experienced these factors as obtained. However, another reason may be that the interviewees forgot or were not aware that the factors in the informal subsystem are essential for the successful implementation of a change.

Easy user interface, cheap tools, achievable goals, and sufficient time are all considered decisive factors for implementing change (Arnold, Randall, Patterson, et al., 2010; Roland and Westergård, 2015; Atkinson, 2015). However, the individuals who hold different positions and their beliefs, attitude, incentives and their ability to act and deliver are what will actually determine whether the change is implemented successfully or not.

5.1.3 Culture

It is notable that none of the external interviewees had anything to say about how the implementation of AI-based technology possibly will impact the work culture. The data-scientist's main task is to develop high-quality and understandable models for the end-user. On the other hand, in order to create understandable and user-friendly models, and sense ownership, knowledge of the working culture is likely to be important. The attitude of the users, their beliefs in the system, and not least their knowledge level are essential in terms of which approach the systems should have.

AI's impact on the working culture

Culture is defined as "the hidden 'scripts' that people use to guide their behaviors. [...] Over time, they become second nature and serve as shortcuts for guiding actions and making decisions" (Duarte and Snyder, 2006).

The study shows that several of the interviewees are afraid that the implementation of, for example, robots on site will harm the working culture. They point out the importance of having humans with attitudes, feelings, spirit, and souls. Given that robots lack attitudes, feelings, spirit, and souls, and stated that a robot has the behavior a human programs it to have, it is believable that robots will not impact the working culture. As illustrated in Figure 3.5, the project culture is formed by several sub-cultures, including the contractor's culture, each sub-contractor's culture, each consultant's culture, etc. If one assumes that technology such as robotics does not possess culture, it will not impact the project culture.

Several of the interviewees mentioned the language barrier as one of the main reasons for bad communication and misunderstandings on site. Misunderstandings often result in delays in progress, and foster bad atmosphere and attitudes among workers. When communication is not optimal, it is easy to *assume* rather than *know* what the other person meant or had as an intention; in reality, this could be something quite different.

Based on the above, a lack of common understanding can possibly contribute to unsatisfactory working culture. One of the desired applications mentioned by the interviewees is a system that can continuously translate between the different languages used on site. Since the language barrier is a cause of misunderstandings, which further impact the working culture negatively, the implementation of a robot that can translate would contribute to fewer misunderstandings, and by that impact the working culture positively. This type of technology will temporarily require high accuracy, and the use of such technology will also contain a risk of translating inexact.

Skinnarland and Yndesdal (2010) states that the short time-frame for which people work on a project can make it difficult to establish a common understanding of the working culture. The short time-frame will remain unchanged, but a translation system would perhaps make it easier to communicate and by this make it easier to establish shared values, norms and attitudes, which will impact the working culture positively.

Human-AI collaboration

As stated above, common understanding and *collaboration* are essential factors for an excellent working culture. Montiel-Overall (2005) defines collaboration as "[A] trusting, working relationship between two or more equal participants". Atkinson (2015) writes that a relationship without trust generates very little in terms of value. In contrary, does Mayer, Davis, and Schoorman (1995) state that it is possible for humans to cooperate without trusting each other, with the prerequisite that there is no risk. The question is whether this is valid for human-AI cooperation? Sigve Brekke, Chief Executive Officer (CEO) of Telenor Group stated:

If data is the new oil, trust is the new dollar[2].

The next sections will discuss human-AI trust.

The impact of attitudes, beliefs, and emotions on trust
As stated in the theoretical framework, trust blends a complex array of interactional factors, including attitude, beliefs, control, emotion, risk, and power (Abbass, 2019). Technology, including AI-based technology, is based on data and does not have attitudes, beliefs, or emotions. Taking the definition of Abbass (2019) into account, it will be challenging for a human to trust the output of an AI-system. In other words, it is supposed to be easier for a human to trust other humans than to trust technology.

However, findings from the study reveal the opposite. Zero (Figure 4.5: Findings case 1: human-human trust) of the interviewees asked would have immediately trusted an instruction from another human, while one (Figure 4.6: Findings case 2: human-AI trust) interviewee would have trusted an instruction from an AI-system.

One reason for not trusting a colleague without an explanation may be that the factors attitude, beliefs, and emotions are not considered relevant regarding trust. However, this is unlikely, as both Julsrud (2018), Mayer, Davis, and Schoorman (1995), Lewicki and Bunker (1996), and Abbass (2019) assume the factors as essential. By the same token, the fact that humans have attitudes beliefs, and emotions make them less trustworthy, as not every human has good intentions towards others. Intentions can be related to people's benevolence, which can be related to emotional-trust. Anyhow, the intention one person has for another person is likely to depend on their relation to the other person. As stated in the literature (McDermott, Khalfan, and Swan, 2007) the short time frame people are working together could make it difficult to establish close relations, which may result in people sub-optimizing at the expense of others. Another reason not to trust another colleague might be doubt in the colleague's *ability* to, for example, conduct a task. This can be related to both calculus-based trust and experienced-based trust. Due to the fact that people are working together in such a short time frame, makes calculus-based trust highly important. However, the doubt in a colleague's ability can also be related to experiences with the person, and thereby experienced-based trust. The interviewees'

[2]https://twitter.com/TelenorGroup/status/1005384034774605825

statement considering the lack of people's *ability* to finish according to the deadline can also be a mix of the two types of trust.

Even though a human can try to be rational will humans, to some extent, always be guided by emotions. As stated above, technology does not have attitudes, beliefs, and emotions, and thus, its decisions will always be based on statistics, which not contain underlying feelings or prejudices. To put it differently, as the statistics are based on human input, will the data, to some extent, include prejudices, as the data, mirror the input from the humans.

One interviewee [operation manager, E, 25-35] stated that he/she would have trusted the robot without a reasonable explanation. This indicates a high degree of calculus-based trust. Based on this statement one can ask the question: do humans put more trust in an AI-system's *ability* to conduct a specific task than the fellow human?

Control and risk
According to Abbass (2019), *control* is a factor that impacts trust. The study reveals that eight out of the nine interviewees would have trusted the robot if they were 100% sure that the AI-system was based on the correct data. However, according to Mayer, Davis, and Schoorman (1995) there is no need for *trust* if there is no *risk*. One of the reasons for using AI-based systems is AI's strength in analyzing data in a way that a human is not capable of (Ertel, 2017). With this in mind, it is considered impossible to obtain 100% control of the quality of the data. Without 100% control, there exist risk, and trust is needed.

Risk can also be related to the uncertainty regarding whether the AI-system will predicate an output that will function in real life or not. To put it differently, even more risk could be involved when humans plan a schedule, as their schedule will be based on individual expertise, not empirical evidence as with the AI-system.

However, control and further trust can also be obtained through *communication* and *explanation*. Typically knowledge− or experienced based trust. The findings state that all nine interviewees would have trusted the other human if they had the opportunity to interact/communicate and get an explanation of the human's request. Meanwhile, eight out of the nine interviewees would have trusted the AI-system if interaction/communication and explanation were possible. The findings mirror the fact that interaction between humans enables both rational and emotional trust, while interaction between human and AI-based technology is limited to rational trust.

The majority of the interviewees pointed out that they would probably trust AI-systems after some time and reliable experience with the system, on the same basis as how they start trusting other humans after reliable experiences. This statement illuminates the importance of experienced based trust, both between humans and between humans and AI-based technology.

Imagine someone practicing for their driving license for the first time. Most likely, the person will experience the opposite of having control. However, as a result of several driving lessons and theory courses, the individual will collect experiences, and their knowledge of driving will increase. The feeling of *control* when driving a car increases in line with increased expertise and knowledge. However, there will always be a *risk* of doing something wrong, but with enhanced experience and expertise, the *trust* in yourself as a driver will become greater. The point is, there will always be related risk whether the AI-system will operate reliable or not, but through training, it is likely that a person can learn the AI's capabilities, opportunities, and limitations, and thus gain a greater feeling of control, and further trust.

Anyhow, the fact that the construction industry is project-based, and many of the workers are on site for a limited period, can make it challenging to achieve enough time and experience to obtain experienced-based trust. On the other hand, the industry is known for its continuous replacement of workers. As the different contractors are dependent on each other's work on site, each employee has to rely on each other to some extent in the short period of working together. This illuminates the importance of calculus-based trust. Based on this it may be easier for construction workers to trust a robot, compared to industries that have little rotation of staffing and whose employees are used to dealing with the same people all the time.

Power

The last factor Abbass (2019) considers as essential for trusting someone or something is power. Power can be considered as the capacity or ability to direct or influence the behavior of others, or the course of events [3]. While it can be argued that the human gives the AI-system power in the form of control of data, it is the human who has produced this data. With this in mind, it will be the human who influences the behavior of the AI-system. This illuminates the importance of true and reliable data. To put it another way, the AI-system will influence the human in terms of recommendations based on data analysis, such as by offering decision-making support. On the positive side, the human will always have the opportunity to ignore the AI's recommendation when given decision-making support, or in the case of a robot, there will always be a possibility to shut down the whole system.

Based on the above mentioned, it is likely to believe that the interviewees are thinking of different aspect of trust when comparing human-human trust and human-AI trust. While it is possible to trust AI-based technology in a calculative, and a knowledge based way, it seems challenging to reach a higher level of trust by identification which seems to be reserved for fellow humans.

Responsibility

While the literature's main focus is on the importance of understanding the AI-system in order to be able to trust its output and further use it, this study reveals another essential factor for understanding and trusting the processes of the AI-system, namely *responsibility*. The study finds that few people will take responsibility and ownership for execution without knowing and having an understanding of what the execution is based on. This argument strengthens the importance of developing understandable AI-systems. Who takes responsibility for the AI-systems recommendations? Who takes responsibility for the quality of the data?

One of the interviewees [planner, E, 25-35] stated that it is not reasonable to put the responsibility of the output in the AI-system. However, this statement must be seen in the context of his/her position and the fact that he/she is a worker of AF Gruppen (main contractor). One can ask the question of whether this statement will be prevailing for every contractor? Will it be ”easier” for a subcontractor to trust the output as the responsibility will be on the main contractor? Will the lack of responsibility and ownership in the system impact the quality of the input produced? These are questions for future research.

[3]The definition of *power* is taken from: https://en.oxforddictionaries.com/definition/power

5.2 Current implementation of AI

The following chapter discusses findings relevant to research question two:
What are the harvested benefits of and the barriers facing the implementation of AI in the construction industry today?

5.2.1 Technology

The following section discusses the current technological situation regarding Touchplan, Synchro, and ALICE in Team Bispevika.

Transparency

Touchplan and Synchro represent transparent technology. *Transparent* technology is technology where the human controls how the input is transformed into an output. The schedules in Touchplan and Synchro are a result of human brain capacity. The human brain has a limited capacity to see different possibilities, and as a result, there is no guarantee that the given output is the most optimal.

Zhu, Liapis, Risi, et al. (2018) states that transparency is often a solution that results in a comfortable level of understanding for a human, giving human trust. This can be assumed to be correct in the case of Touchplan. Although Synchro is a transparent technology, several of the interviewees doubt the quality of the model displayed in Synchro. In other words, they doubt the people who created the model. The reason is not a lack of transparency, but bad experiences with the lack of information in the model. These negative experiences and the resulting negative attitude toward Synchro correspond to Abbass (2019)'s statement that the more negative consequences users see, the more likely they are to distrust and dislike the technology. As an alternative, some of the interviewees print out detailed rig maps in 2D. These 2D maps have no quality assurance that they are the right version. Why do workers place more trust in these than the 4D model? One reason could be that the 2D rig maps are more detailed. However, the fact that they are detailed does not ensure that the map is the right version and shows how and where different things is supposed to be built. A second reason may be that 2D maps are familiar to the workers; therefore they trust the 2D drawings more. As IBM (2015) states, time and experience are important factors affecting trust. A third reason may be that the workers think it is easier to both read and carry around a 2D paper map on site than an iPad.

Knowledge gap

The illustrators' lack of practical understanding and experience on site may be the reason for the lack of details in the 4D model (Synchro) as well as the presence of details that are not practically possible to construct. Due to digital developments in recent years, today's situation in the construction industry is characterized by a knowledge gap. The knowledge gap consists of two parts. The people with practical experience from the site who lack digital knowledge, and new arrivals who lack practical experience but have greater digital knowledge. For this reason, collaboration between the illustrators and the workers on site is essential. The model must, therefore, be accessible for the workers so that the errors in the model can be revealed before execution. This is considered implemented in Bispevika, as several of the interviewees actively use the model to look at the construction in 3D.

Time-consuming

Another reason for lack of details in the 4D model (Synchro) can be the lack of *time* to edit the model, as changes continuously occur.

In order to maintain continuous learning root cause analysis is conducted on the tasks in Touchplan that did not go as planned. Due to construction sites' complexity, unforeseen actions, or bad planning, there are many tasks that do not go according to plan. The interviewees experienced that Touchplan requests a too-detailed level of root cause analysis, as it is time-consuming to assign a cause to every task that is not executed according to the plan.

On the positive side, the amount of detail available in Touchplan facilitates opportunities to assign a person/contractor responsible of a task. According to the literature, responsibility increases commitment to a task. By assigning responsibility of a task to one person, one might think that the person will be able to name the root cause of any issues that occur related to that task. This is the ideal situation, but unfortunately it is not reality. The cause of not finishing the task can have several reasons, be dependent on several workers and contractors, and people may disagree on the actual cause. As a result of how slow the process is, the root cause analysis is often skipped or done imperfectly. As a result, no useful data is produced.

The fact that Touchplan requires too much time and involvement of workers can be seen as a hindrance to maintaining motivation and commitment to the program. To put it another way: the fact that people experience it as too time-consuming can be seen in connection with the lack of maintaining the visibility of the benefits of doing the root cause analysis. Visibility of the benefits and *how* the tool can contribute to each worker is according to the literature (Atkinson, 2015) and stated by this study, the best incentive for implementing a change. Visible benefits must outweigh the time consumed.

User-friendly

The majority of the interviewees experienced Touchplan as user-friendly, as the program is accessible from all digital platforms, has an easy user interface and is transparent. The experiences with Touchplan show that accessibility, a simple user interface, and transparency are essential factors for obtaining usability. This is confirmed by the fact that Synchro is also a transparent technology, but the interviewees consider the program to be less accessible due to its more complex user interface. Chander, Wang, Srinivasan, et al. (2018) illuminates the importance of being able to edit parameters in the program without having to be an IT-engineer to do so. This is possible in both Touchplan and Synchro.

One of the interviewees [site manager, S, 25-35] stated that Touchplan is too difficult and complex. Anyhow, this statement should be seen in connection with the fact that the interviewee has never used Touchplan. However, does this statement illuminate the fact that people have apparent prejudice, opinions, and attitudes before they even have tried the tool. This statement throw light on the importance of showing the *benefits* and *why* Touchplan is being used at the project. Rumors and attitudes considering digital tools, such as Touchplan and Synchro, disperse fast between different workers and contractor on the construction site. People are getting influenced by colleagues' attitudes and not at least the leaders' attitudes. Each worker should cultivate critical-positive attitude until he/she has made up own experiences and opinions.

Both Touchplan and Synchro visualize the schedule for the workers; Touchplan in the form of a 2D schedule, and Synchro in the form of a 4D visualization of the schedule. Interviewees and theory (IBM, 2015) state that visualization contributes to a common understanding, which improves the communication between people in a team. Visualization is highly useful as the diversity in languages on site can make it challenging to communicate with natural language.

ALICE is based on machine learning algorithms and as such is not totally transparent like Touchplan and Synchro. With the fact that ALICE is in the early testing phase is the tool working perfectly. However, in order to function optimally in the future is a sufficient amount of data needed.

5.2.2 Process

The following sections will discuss the four phases of Meyers, Durlak, and Wandersman (2012)'s implementation model, shown in Figure 3.1.

Phase 1: Evaluation of possible change

Phase 1 consists of evaluating whether the change will benefit the organization or not. An evaluation of the implementation of Touchplan, Synchro, and ALICE was conducted in Bispevika. According to Senior and Swailes (2010), the assessment should be done by key persons who are supposed to follow the change through the whole implementation. In addition to the management, one out of two implementation drivers was present and was a central voice in the evaluation of the change.

Phase 2: Structure of the implementation

Phase 2 is the phase where the structure of the implementation is produced. What is needed to succeed with the implementation work? The phase includes both the establishment of the implementation team and the production of an implementation strategy.

Implementation drivers
Roland and Westergård (2015) state that implementation drivers are assumed to be necessary for successful implementation and further contribute to sustainable change. The theory splits the implementation drivers into three categories: the competence drivers, the leadership drivers, and the organization drivers (Roland and Westergård, 2015).

There are two *competence implementation drivers* with regards to the implementation of digital tools in Bispevika today. The competence drivers aim to develop, improve, and maintain the belief in the implementation process – thus establishing loyalty to the implementation. The two competence implementation drivers at Bispevika are an essential part of the other employees' motivation. Based on this study it seems as if the competence implementation drivers fulfil Roland and Westergård (2015)'s criteria, as there was unanimous agreement among the interviewees that the implementation drivers are doing a great job.

Despite the overall good impression of the competence implementation drivers, one interviewee [subcontractor, S, 25-35] experienced the lack of knowledge regarding practical building in one of the implementation drivers as challenging. Of course, in an ideal world all implementation drivers would have high competence within the technical aspects of building, high knowledge concerning IT, and pedagogical skills for teaching new things. Instead of focusing on what the implementation drivers are not good at, as for example practical building technology, the focus should be on their knowledge of the digital tools and their ability to teach and improve what they are good at. A painter does not have much knowledge about the electrician and vice versa.

The statement above can be seen in connection with the relatively traditional and hierarchical career development in the construction industry. Newly graduated engineers often start out as an operation manager within one or several fields of knowledge, such as Health safety and environment (HSE), painting or facades. The next step is the site manager, before the worker often chooses between being a project manager or a project leader. Bearing in mind the changes brought by digitization, is it time to think beyond this traditional hierarchical career development? Perhaps digitization and innovation should be a natural career specialization? It seems like Bispevika has realized the restructuring of the team that follows the digitization, as several untraditional positions are found at the project. One example is the competence implementation drivers.

The *leadership implementation drivers* should contribute with technical support and adaption (Roland and Westergård, 2015). The leadership of Team Bispevika consists of people that dare to invest in new and innovative solutions that can strengthen their way of building. As one of the interviewees said: “We have been told that we are Norway’s most digital construction site; it is our job to live up to that.” However, there is no point in being the most digital construction site in Norway if digitalization does not improve building methods. It is easy to focus on the image of being digital, rather than the actual aim of digitizing. This study indicates, and the author experiences the management in Team Bispevika as being highly aware of this. They have a strong focus on determining which processes the different digital tools are supposed to support. However, it is questionable how well this is communicated to the whole team, as there are several different ideas of why the various tools are in use. It may also be that the leaders have expressed the purpose, but that people simply have forgotten it.

The *organization implementation driver* should contribute as a support system. They should create and maintain the structure during the change, and offer resources which facilitate learning (Roland and Westergård, 2015). The organization driver in AF Gruppen is the department of innovation and digitization. The department supports projects with knowledge and in some cases, financial support. However, financial support for individual projects is somewhat controversial. AF Gruppen believes that the motivation to be more digital should come from the interest and eagerness in the team; their so-called inner motivation. The inner belief that technology will strengthen their way of working in terms of quality, safety, and economy. According to Atkinson (2015), inner motivation is the best incentive for change.

Ensuring the visibility of the benefits of using digital tools should help people see the benefits in a long-term perspective and get people motivated to implement digital tools that can strengthen their work. Project Bispevika is today a role model and inspiration for many other projects.

However, the author questions whether it is a little too gullible of the management to believe that people have inner motivation to learn digital tools. This may be true for some people, but is it true for the majority of the workers? If a team deliver to schedule and earn money, which motivation should they have for investing money and time in new technology? A construction project is limited in time and is based on making the largest profit. Given that the implementation of a change will require extra resources, it is tempting for projects to skip the implementation of digital tools, as these tools are not guaranteed to increase value in the given project. Due to the fact that it can be demanding to get projects to think in a long-term perspective, economic support from the innovation and digitization department could be a solution. Anyhow, the question whether projects should be supported financially or not, is closely related to how quickly the firm wants the digitization to happen. The findings reveal that the sub-contractors wish there were higher expectations or even contractual requirements to take in use digital tools. This contradicts AF's wish about inner motivation to learn digital tools among the workers. If the use of digital tools is made part of people's contracts, workers will be forced to learn the tools quickly. By learning them quickly, they may obtain a sense of achievement and ownership of the tools more quickly.

Implementation strategy
The study reveals that there is confusion within Team Bispevika as to whether an implementation strategy exists or not. The majority of the interviewees say there is no implementation strategy. In contrast, the management team says that the "planning structure" can be seen as a strategy, as it defines *how* and *when* the different digital tools are supposed to be used. Atkinson (2015) states that an implementation strategy should consist of how the goals are to be reached, coordination, who is responsible, specify the desired results and outcomes, and a timeline for achieving the goals. Looking at the "planning structure" in Appendix 4, it contains points of progress that can be considered as goals for how to reach planning of high quality, who is responsible for the different plans, the desired results and outcomes, and a timeline for achieving the planned goals.

However, the "planning structure" can be seen as an strategy on *how* the tools are supposed to support the process of planning, but it thus not contain a strategy for *how* people should be able to manage the digital tools, such as Touchplan and ALICE. A prerequisite of the "planning structure" is that people manage Touchplan and Synchro. Roland and Westergård (2015) state that in order to succeed with the implementation of a change a training strategy should be developed. A training strategy consists of a training needs analysis, training design, and training evaluation, as illustrated in Figure 3.4, Chapter 3, Theoretical framework. All three factors are equally essential to implementing the change and achieving a sustainable training strategy (Arnold, Randall, Patterson, et al., 2010).

It seems like the competence implementation drivers have clear thoughts about who needs to learn the different skills (training analysis), but that there is a lack of a clear and tangible structure (training design) in addition to continuously evaluating the workers involved (training evaluation). As illustrated in Figure 5.4, two of the three arrows are missing. The training cycle is not complete, and thus, according to the literature, is likely to fail.

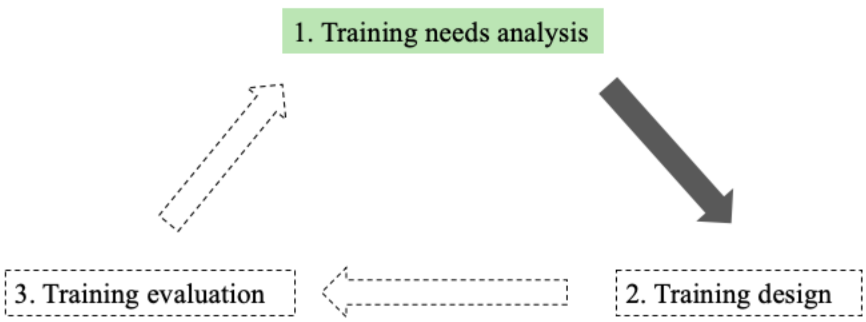


Figure 5.4: Illustration of the current training situation in Team Bispevika

Phase 3: The implementation process

Roland and Westergård (2015) state that Phase 3 consists of the actual implementation process, where the structure made in Phase 2 should be put into practice.

Training

The *training* in Touchplan today consists of "learning by doing" and help from the implementation drivers is given when needed. Despite the lack of a training design and a training evaluation, the study reveals that "learning by doing" seems to provide sufficient training in Touchplan, due to its simple user interface. So why should Bispevika put more resources into training if the workers experience "learning by doing" as sufficient?

Although the interviewees say that "learning by doing" has been sufficient, the majority of the interviewees also state that they experience the implementation of Touchplan as an extra burden. This can be related to the lack of a proper training design, as a training design should contain what the implementation will require from the workers, in addition to short-term goals that are visible, unambitious, and related to the change effort (Arnold, Randall, Patterson, et al., 2010; Senior and Swailes, 2010). The short-term goals are supposed to ensure the motivation of the employees towards longer-term goals. On the contrary, does recent research (Kahneman, 2011) state that the use of too-broad goals in complex processes can result in the opposite of what is expected. Three of the interviewees point out that the goal is to be "Norway's most digital construction site". This is an excellent example of a too-general goal that is both unmanageable and unmeasurable. Team Bispevika emphasizes in their document "Lean in Team Bispevika" the importance of common goals as well as individual goals, and the fact that all goals should be aggregated to the main goals of the project. This statement corresponds to the literature, but based on this study can the statement not be considered conducted. It seems like the project have main goals, but that there is a lack of dividing the main goals into more tangible and individual goals related to each individual's work tasks.

The experience of Touchplan as an extra burden can also be seen in connection with the fact that many of the employees are new at the project and in AF Gruppen. With this in mind, it may not be Touchplan that is the particular burden, but the totality of everything. The entirety of workload can also be the reason that those who are not new at the project experience Touchplan as an extra burden.

Another reason that people experience the implementation of Touchplan as an extra burden could be the lack of clear benefits resulting from using Touchplan. This is verified by the two of the interviewees [subcontractor, L, 35-45 ; subcontractor, S, 25-35] and is in accordance to the literature (Atkinson, 2015). Other interviewees states that they see the benefits of using

Touchplan, but that they do not use it actively because they have to be out on site, getting things to happen in real life and not only in plans. It is evident that the persons saying this are not aware of what the aim of using Touchplan is, as the whole aim of using Touchplan is to make the workflow out on site better. Such misunderstandings can be seen in connection with the lack of a training strategy and lack of information given. In the light of the lack of a defined training design, the author gets the impression that the implementation drivers talk about the benefits during meetings and through daily communication with the different workers. Based on this could another reason to this statement be a result of peoples attitudes and fear of change?

It may be right that “learning by doing” is sufficient in terms of being able to *use* Touchplan, but as a result of “learning by doing” being the main approach there exist several different ideas about *why* Touchplan is supposed to be used. Being able to manage the technical aspects of Touchplan is essential; but being able to use Touchplan does not generate value in itself. It is *why* and *how* the workers use Touchplan that can give value in the form of improving their work tasks.

Although Touchplan has a relatively easy user interface, the threshold for using the tool is higher than that of fastening paper-tasks on a wall (which is the analog way of the LPS), especially among the ”older” generation. Some of the interviewees experience that the difference in technical knowledge in the meetings is costly as the meetings are time-consuming. The meetings are time-consuming since the implementation drivers have to explain what Touchplan is and how to insert tasks in the tool every time a new sub-contractor arrives at the site. This could also be connected to the lack of a training design. With new workers continuously arriving on the site and newcomers learning Touchplan through meetings, it is evident that there will be a high level of difference between the knowledge of newly arrived contractors and those who have worked with Touchplan for some months. It is especially challenging when the meetings are conducted in Norwegian, and some of the workers barely talk English. Trying to learn the program at the same time as the worker is supposed to understand the context of what is being said in the meeting is too much for them to handle in one go.

It is reasonable to believe that many such situations could be avoided if there was a defined approach to handling new workers on site. Their language skills and technical skills could be assessed, and based on that, short-term goals and long-term goals can be set for *how* to reach the desired level. To decrease the level of difference in the meetings, a short session and explanation of *why* and *how* to use Touchplan could be conducted before newcomers enter the meetings. However, this will require a lot of resources as new workers continuously arrive and leave the site. One should ask the question: how much value will be obtained compared to the resources invested?

Generational shift

The “older generation” is often described as less positive towards digitization and it is usually assumed that they have poor digital skills. However, the findings show that the “older interviewees” were just as positively disposed towards digitization as the “young interviewees”. Concerning lack of digital knowledge, Table 2.4 indicates that “older people” tend to have fewer digital skills. However, it is easy to forget that the only generation that has grown up with smartphones is the generation that today is entering the industry. The focus is often on the fact that the “older generation” lacks digital knowledge, while the fact that the “younger generation” often lacks practical experience and knowledge is often forgotten.

Some of the interviewees mentioned that it is absurd to make people over 50 learn new digital tools when the industry has not decided which digital tools to use. However, what if the industry never agrees on which digital tools to use? Moreover, is the aim to decide on one tool? The world, including the the digital world, is in continuous development.

Today, many people regularly replace their phones when a new model enters the market. They buy the newest one because it has a better camera, weighs less, and is faster than the older model. One can think of the use of digital tools on a construction site in the same way. Digital tools are continuously being exchanged as new models are launched that can help the workers, for example, to plan even better than the previous tool did. Instead of focusing on the tool itself, the focus should be on *how* the tool can help workers do an even better job.

The fact that Team Bispevika today uses both Touchplan and Synchro, and is now in the early testing stage of implementing ALICE, illuminates the continuous development of digital tools. Due to the continuous development of digital tools, the author believes that it is crucial to build training strategies around people and not around the tool.

One can ask the question whether it is most value creating letting the "older generation" do what they are best at and skip the training in digital tools, or if it is value-creating to train them in the use of digital tools. As some interviewees believe that the older generation will have difficulties learning new things, others believe that everyone can learn, including the older generation, as long as the tools are easy to use. Touchplan is an excellent example of this as it is a relatively user-friendly tool. As mentioned before, even though Touchplan is user-friendly, it is typically more challenging for the "older generation" to put a task into Touchplan (the digital wall) compared to placing a paper-task on the wall. This highlights the importance of having implementation drivers that are patient and never gives up. Currently, are the implementation drivers doing a great job of this in Bispevika, as one implementation driver attends all morning meetings where Touchplan is used. Their great job is reflected by the fact that the "older generation" is equally positive to the digitization as the "younger generation," which is not considered the current norm in the construction industry.

Senior and Swailes (2010) states that a *training evaluation* should determine whether the training has worked or not. The implementation drivers in Team Bispevika have definite opinions of what they think has worked and what has not worked, but these ideas are not written down or systematically mapped. Senior and Swailes (2010) state that one essential part of the evaluation is to evaluate whether the training goals are achieved or not. In the case of Team Bispevika this is impossible as the training goals were never defined. The lack of a training evaluation is a domino effect of the lack of a training strategy. It is today sub-contractors that have left the site and are finished with their work. Their experiences with Touchplan would be highly valuable for maintaining continuous learning. Even though the implementation drivers have memories of their positive and negative experiences, it be easier to refer to, for example, a survey.

Phase 4: Improvement
Phase 4 is the improvement phase, where what worked, what did not work, and how the implementation process can be improved should be evaluated (Roland and Westergård, 2015). Several of the interviewees said that it is too early to evaluate the implementation process of Touchplan and Synchro, as the tools cannot be considered implemented. This statement contradicts the lean-mindset, where *continuous improvement* is central. The fact that new people are leaving and entering the construction site during the project is an excellent opportunity to continuously improve. How the groundworkers experienced the use of Touchplan and Synchro is important in order to be able to improve processes when, for example, the electrician enters the site.

Today Bispevika puts trust in individual expertise over empirics, as the experiences of and ideas for improvement are taken care of in each individual employee's head. What happens with these experiences when people leave the project? New people enter with no experiences and start from scratch, making their own experiences. What about the exchange of experiences between different projects, or even across firms? Having a routine of, for example, a survey when the different contractors enter and leave the site would generate data on how the different contractors experienced the use of, for example, Touchplan. In this way, continuous improvement would be based on empirics rather than each employee's personal idea and experience.

5.2.3 Culture

The interviewees from AF Gruppen stated that the project is characterized by an open and flat working culture with high trust among the workers in AF Gruppen. Montiel-Overall (2005) stated that trust is an essential factor in good collaboration. However, although the working culture among the AF workers can be considered good, the findings reveal distrust of the sub-contractors. This verify Skinnarland and Yndesdal (2010) statement that there still is a feeling of "us" and "them" instead of "we" on construction sites. The findings show that the level of trust between the main contractor (AF Gruppen) and the sub-contractors is low due to promises being broken. This supports McDermott, Khalfan, and Swan (2007)'s research and can be related the lack of experienced-based trust.

So why do people not keep their promises? The interviewees from the sub-contractors and the main contractors agree that the main contractor assigns too much work to the sub-contractors to keep up the progress. So why do the sub-contractors promise that they will finish work they know they will most likely not be able to finish? One reason could be that many of the sub-contractors are people from other countries than Norway. Countries with different working cultures. For example, their native working culture could be characterized by not speaking about existing challenges. The only thing that matters is that tasks are finished before the deadline. However, the deadline is coming on Norwegian construction sites as well, and as a result, is the main contractor pushing through work.

The findings show that there are different experiences as to whether there is trust among the different sub-contractors or not. This is natural, as trust depends on the relationships people have to each other. However, the fact that all contractors are supposed to earn money may result in people thinking and acting for their own benefit and individual objectives rather than the common goal (Zhu, Liapis, Risi, et al., 2018).

Workers who sub-optimize in order to benefit themselves can be seen in connection with the limited time the various contractors spend working together. It is challenging to build a relationship to each other and by that experienced- and identification-based trust in such a short time-frame. However, is calculus-based trust possible to obtain without knowing each other. An interesting topic is how to obtain an high level of calculus-based trust across contractors? Based on this study does it seems like calculus-based trust, is reserved to colleagues of each contractor.

The short time-frame also makes it difficult to create ownership of and commitment to the whole project, which is key to success, according to Skinnarland and Yndesdal (2010). However, one can ask the question whether commitment to and ownership of the whole project are necessary? Does a project gain more value when all sub-contractors have ownership of the whole process compared to only having ownership of their contract? The author believes that having ownership of the whole project is not necessarily the key, but rather *respect* for all the other contractors' work is essential. *Respect* for the work others have done before new workers enter the site, *respect* for the work people are doing while they are on site, and *respect* for the people coming after them. A culture that is characterized by a feeling that every small piece of the construction is meaningful for the whole project to succeed.

Skinnarland and Yndesdal (2010) states that weekly and daily meetings contribute toward helping people get to know each other and improve their understanding of themselves in a broader context. Both weekly and daily meetings are conducted in Bispevika, but there are still many who experience that different contractors do not show enough respect toward each other's work. One reason could be that it is only the site leaders for each sub-contractor in addition to the main contractor that participate in the morning meetings. As Figure 3.5, Chapter 3, Theoretical Framework, shows, each person's culture, and each of the subcontractors' cultures impact the project culture. Several sub-contractors use people from staffing agencies, which makes it difficult to obtain a common culture. As a result, the project culture is even more influenced by each person's individual culture.

Chapter 6: Conclusion

The following chapter answers the two research questions and the purpose of this master thesis report as described in, Chapter 1, Introduction. As a closure recommendations for further research are given.

6.1 Conclusion of research questions and purpose

This thesis constitutes a piece of pioneering work, as it investigates the implementation of AI in the construction industry, and how humans and AI-based technology should collaborate. The research has been conducted as a literature study, a case study of Team Bispevika containing document study and eighteen interviews, in addition to three external interviews with expert firms within the domain of AI. The chosen interviewees represent a diversity of people in terms of their positions, knowledge, age, and attitudes towards AI. Given the diversity of interviewees, it is possible to assume that the findings of this study can be generalized to other projects in Norway as well as projects abroad.

6.1.1 Future implementation of AI

The following section will answer the first research question:
What are the potential benefits of implementing AI in the construction industry?

It can be concluded that AI has come to stay and that several benefits of implementing AI exist. Figure 6.1 presents the possible benefits within the categories Technology, Process, and Culture and how these benefits together can remold the construction industry by making the construction process more productive and safe, and by increasing the quality of constructions.

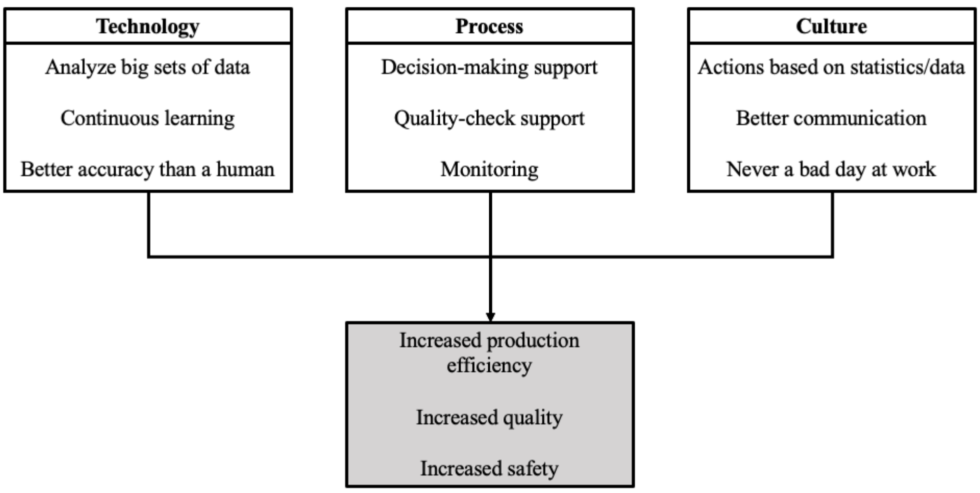


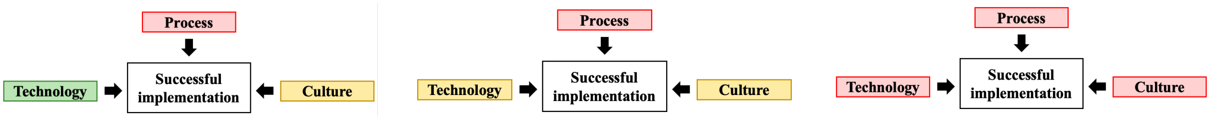
Figure 6.1: Possible benefits of implementing AI in the construction industry

6.1.2 Current implementation of AI

The following section will answer the second research question:
What are the harvested benefits of and barriers to the implementation of AI in the construction industry today?

Technology, Process, and Culture are interdependent factors and affect each other. It can be concluded that all three factors are equally important to succeed with an implementation. Figure 6.2 (a), (b) and (c) illustrates the concluded current implementation situation of Touchplan (digitization), Synchro (digitalization), and ALICE (digital transformation) in Team Bispevika. Green illustrates the required level for a successful implementation, and yellow illustrates that some factors are achieved but not everyone, while red illustrates that the required level for a successful implementation is far from reached.

As illustrated in Figures 6.2 (a), (b), and (c), none of the three digital tools investigated can be considered implemented. Table 6.1 summarizes the concluded harvested benefits of and barriers to the implementation of Touchplan, Synchro, and ALICE in Team Bispevika today.



(a) Current implementation of Touchplan (Digitization)

(b) Current implementation of Synchro (Digitalization)

(c) Current implementation of ALICE (Digital transformation)

Figure 6.2: Current implementation of Touchplan, Synchro and ALICE in Team Bispevika

Touchplan represent the first step of digitization: digitization. The process where analog information is presented digitally. Touchplan is a transparent, accessible tool and thereby user-friendly. Given these points, *Technology* is considered sufficiently developed to succeed with the implementation, and as a result, Technology is shaded green. Due to the low user interface have ”learning by doing” with help from implementation drivers been sufficient to obtain knowledge about *how* to *use* Touchplan. Anyhow, ”learning by doing” is not considered a sustainable method for implementing change, as both *how* and *why* the tools are being used is considered necessary. With this in mind *Process* is shaded red, mainly due to the lack of a clear training strategy. Despite the lack of a clear training strategy, the implementation drivers have managed to stimulate engagement and positive attitudes among the majority of the employees. This has further resulted in the willingness and motivation to learn and use the tool. However, the employees miss a sense of achievement and ownership, and as a result, *Culture* is shaded yellow.

Synchro represents the second step of digitization: digitalization. Digitalization is the process where machines can perform human-controlled processes. Like Touchplan, Synchro is based on transparent technology, but due to its complex user-interface the tool is not developed enough to ensure success with its implementation, and as a result, *Technology* is shaded yellow. Visualization of the construction in 4D can be seen as a success factor as it increases the common understanding among workers, which makes the process of planning easier. Although Synchro contributes to common understanding among workers, *Process* is shaded red as there is no defined training strategy. The complex user interface and the lack of a training strategy are reflected by the fact that few of the interviewees actually used Synchro. Generally speaking, have people in Team Bispevika a positive attitude considering the digitalization. Despite this, the time needed to learn Synchro is predominant compared to the visible benefits of using Synchro.

As a result, there is a lack of motivation to learn Synchro among workers, a lack of achievement and a lack of ownership. Given these points, *Culture* is shaded yellow.

ALICE is based on AI-technology and represents the third step of digitization: digital transformation. Digital transformation is the integration of digital technologies in a way that makes the organization fundamentally change how they operate. ALICE is currently in the testing phase. The AI-technology itself is present, but the absence of a sufficient amount of data makes *Technology* red as a sufficient amount of data with high quality is a prerequisite for ALICE to function optimally. *Process* is shaded red, mainly due to the lack of a strategy for collecting data. *Culture* is shaded red as the work of achieving a human-AI collaboration and human-AI trust cannot be considered complete. However, this conclusion should be seen in the perspective that ALICE is in the early testing stage. An implementation team is established, strategies are under development, and the work of preparing the workers for the digital transformation has started. Although ALICE is far from implemented, it can be concluded that the implementation of ALICE is on the right track.

Table 6.1: Harvested benefits of and barriers to the implementation of Touchplan, Synchro, and ALICE in Team Bispevika

		Technology	**Process**	**Culture**
Touchplan (Digitization)	Benefits	Transparent Accessible User-friendly	Implementation team • Competence • Leadership • Organization	Open and flat working culture Willingness and motivation to learn
	Barriers	Too detailed	Lack of training strategy • Training design • Training evaluation Time consuming Variation in digital skills The growth of the organization	Building trust between contractors Respect for other contractors' work Lack of a sense of achievement Lack of ownership
Synchro (Digitalization)	Benefits	Transparent Enables visualization of construction in 4D	Contributes to a common understanding	Open and flat working culture
	Barriers	Complex user-interface	Lack of training strategy • Training design • Training evaluation Time consuming Variation in digital skills The growth of the organization	Building trust between contractors Lack of respect for others' work Lack of a sense of achievement Lack of ownership
ALICE (Digital transformation)	Benefits	The technology is present	Implementation team	Relatively positive attitude considering the digital transformation
	Barriers	Lack of a significant amount of high-quality data	Lack of strategy for collecting data	Human-AI collaboration Human-AI trust

6.1.3 Closure of the gap between the future and current implementation of AI

The following section will answer the purpose of this master thesis report:
How can the construction industry close the gap between the potential benefits and harvested benefits of AI?

It can be concluded that a gap exists between the future and the current situation of implementing AI in the construction industry. The gap has been identified by looking into the possible benefits of implementing AI and today's harvested benefits of and barriers to implementing AI in the construction industry.

Figure 6.3 illustrates a successful implementation process where Technology, Process, and Culture are all shaded green. Research done in this thesis shows that all three factors are equally important to succeed with an implementation of a change, including the implementation of AI-based technology. It can further be concluded that several of the experiences gained in the lower levels of digitization (Touchplan and Synchro) are valuable and transferable when approaching the implementation of the digital transformation (ALICE). Table 6.2 presents the concluded factors that must be fulfilled in order to close the gap between the future and current implementation of AI in the construction industry. As shown, is Table 6.2 divided into the factors that are transferable from the lower levels of digitization (Touchplan and Synchro) and the new factors that will be essential to the implementation of the digital transformation (ALICE).

Due to AI's technological complexity, AI-based technology differs from lower degrees of digitization as it has other prerequisites concerning trust and collaboration with humans. Human-AI trust is concluded to be the most decisive factor in obtaining a successful human-AI collaboration, which is considered necessary for exploiting the benefits AI-based technology offers. Human-AI trust must be obtained in a calculative, and knowledge-based way, as it seems difficult to reach a higher level of trust through identification, which seems to be reserved for fellow humans. Essential factors for obtaining human-AI trust are concluded to be the following:

- Transparent AI-systems
- Human-AI interaction through visualization or natural language
- Education in the AI-system's capabilities and limitations
- Time and experience

In order to obtain trust, the output must be understandable for the human. This can be ensured through *transparent AI-systems*. *Human-AI interaction* is needed to obtain progress in situations where the human and the AI-system disagree on the given output. Non-AI engineers need to be able to interact with the AI-system, without going through the AI engineer's interface. *Education* in the AI-system's capabilities and limitations will increase the human's ability to decide when it is reasonable to trust the AI-system and in which situations it is not reasonable to trust the AI-system. Moreover, just as trust between humans is built up over time and with experience, *time* and *experience* will also be key factors in building human-AI trust. As AI-based technology becomes a part of the workflow sufficient experience will be gained and confidence in the systems will be obtained. The factors mentioned above will increase the causality, make the system more understandable, make it possible for humans to identify biases, increase trust, and contribute to a functional human-AI collaboration.

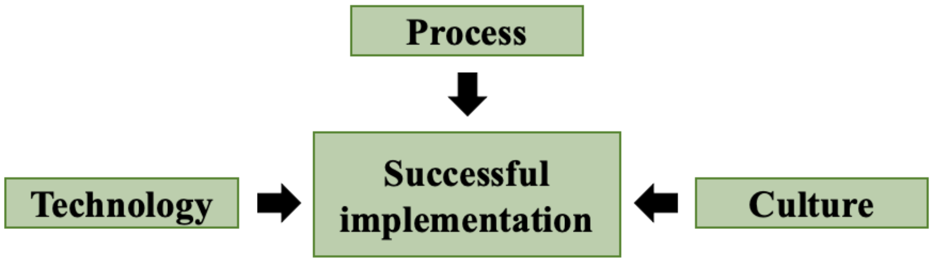


Figure 6.3: Successful implementation

Table 6.2: Factors concluded to be decisive for closing the gap between the current and future implementation of AI in the construction industry

	Technology	Process	Culture
Transferable experiences from lower levels of digitization	• Develop user-friendly AI-systems	• Develop a training strategy which includes analysis, design, and evaluation • Develop concrete goals for each employee, including long-term goals and short-terms goals • Illuminate for the whole team, the benefits of using AI-based technology • Make the use of digital tools contractual • Combine individual expertise with empirical data	• Create a culture characterized by a collaborative attitude, commitment, respect, and curiosity • Create a culture where the norm is continuous change and improvement • Build trust between contractors by establishing a common project culture • Combine young and old workers
Essential factors arriving with the digital transformation	• Sufficient amount of data • Collect high quality data • The AI-system must provide an explainable output	• Develop a strategy for collecting data • Coordination and collaboration with IT experts	• **Obtain a sufficient level of human-AI trust**

Digital technology, including AI-based technology, should be seen less as a thing and more as a way of doing things. New digital technology is continuously launched. Structuring the digital tools to be technology neutral will allow organizations to keep pace with the rapid advances being made, rather than rethinking their approach every time. However, a prerequisite for keeping pace will be employees with the desire and curiosity to learn new digital technology and the ability to learn things quickly. In order to capitalize on the entire capacity of AI-system, organizations should institute fresh working relationships between humans as well as between humans and AI-systems, and modernize the idea of work.

6.2 Further Research

This study has revealed several topics of interest, which are recommended for further research.

This master thesis report is based on a case study of Team Bispevika, a construction project in Oslo, Norway, in addition to three external interviews with expert firms within the domain of AI. To establish a basis for comparison, it could be interesting to collect more data from other project organizations. Additional data concerning the first two levels of digitization (digitization and digitalization) can be collected from other construction projects in Norway. Regarding the collection of data about AI-based technology (digital transformation), it is recommended to look deeper into other industries, such as the oil and gas industry, healthcare industry, and financial industry, in addition to contacting construction projects located abroad that have used ALICE or similar AI-based tools. This recommendation is based on the lack of implementation of AI-based technology in the construction phase in Norway. A broader collection of data will increase the validity and reliability of the findings.

The implementation of ALICE is currently in the early testing stage. For further research, it will be interesting to follow the implementation of ALICE in Team Bispevika and see how the implementation takes place in practice. As sufficient data and data of high quality are prerequisites for AI-based technologies to function, it could be valuable to look into a potential strategy for collecting data. Relevant themes related to a potential strategy for collecting data are the possibility of collaborating across construction firms, or with an external IT company to distribute the data. Another interesting subject is who is responsible for the data provided, and who is going to own the data?

Another interesting area to investigate would be to map how much transparency and human-AI interaction is needed in the AI-system to obtain a sufficient level of human-AI trust. In view of this, a survey with highly specific questions could be a propitious method for collecting data.

The research done does also reveals that the future will bring closer collaboration across countries. Related to this, it could be interesting to investigate ownership and trust between participants who have never met each other in person, or only a few times.

This study was limited to looking at the implementation of AI-based technology in the construction industry. However, as society in general is getting more digitized, it could be interesting to look into the implementation of AI-based technology in the design phase of construction as well as the operation and maintenance phases.

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PART 2: CONFERENCE PAPER

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THE INTRODUCTION OF AI IN THE CONSTRUCTION INDUSTRY AND ITS IMPACT ON HUMAN BEHAVIOR

Marte H. Schia[1], Bo C. Trollsås[2], Håkon Fyhn[3] and Ola Lædre[4]

ABSTRACT

The digital shift has arrived in the construction industry, with the aim of increasing the efficiency. However, how should the industry implement digital tools? And how should a human-technology relationship work? The purpose of this paper is to illuminate how the construction industry can close the gap between the potential benefits and the harvested benefits of implementation of AI. This paper presents research based on a comprehensive literature review, a case study of a construction project in Norway, and three external interviews. The case study consists of a document study and seventeen semi-structured interviews.

The experiences established through this research indicate that it is possible to gain experience from the implementation of basic digital tools when implementing advanced technology, such as artificial intelligence (AI). When come at AI, the human-AI trust will be the most decisive factor for a successful implementation. This paper constitutes a piece of pioneer work, as it investigates the implementation of AI, and how humans and technology should work together.

This research is limited down to one case study as well as three digital tools. To extend the research it is recommended to discuss the adaption of AI on premise of the users, collect more empirical data and look into experiences done by other industries.

KEYWORDS

Collaboration, Commitment, Trust, Digitization, Artificial Intelligence

INTRODUCTION

The construction industry is currently experiencing transformation from traditional, hierarchically organized construction sites to digital and more autonomous ones. A digital shift is taking place, and the development of the digital is advancing so fast that the industry struggles to keep up (Harty et al. 2015). This paper constitutes to a piece of pioneer work, as it investigates the implementation of AI. Implementation of AI is a relatively unexplored topic, especially within the construction industry. AI can

[1] M.Sc. student, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, +47 950 76 760, martehsc@stud.ntnu.no

[2] Planner & Business Development VDC, AF Gruppen, Oslo, Norway, +47 922 64 865, bochristian.trollsas@afgruppen.no

[3] Senior Researcher, Department of Social Research, Norwegian University of Science and Technology (NTNU), Trondheim Norway, +47 917 43 561, hakon.fyhn@ntnu.no

[4] Associate professor, Department of Civil and Transport Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway +47 911 89 938, ola.ladre@ntnu.no

automate several operations and increase the efficiency of the building process (Salehi and Burgueño 2018). This is aligned with the lean-mindset, where minimizing waste and maximizing value is central (Ballard and Howell 2003).

Based on the above mentioned, the purpose of this paper is to illuminate how the construction industry can close the gap between the potential benefits and the harvested benefits of implementation of AI. In order to find a way of closing the gap, the following two research questions has been developed.

- What are the potential benefits of implementing AI in the construction industry?
- How does the construction industry harvest the benefits of AI implementation today?

This research is limited to a case study of a building project located in Oslo, Norway, in addition to three external interviews. The case study is restricted to look at three digital tools. Based on the lack of published research regarding the implementation of AI, a document study and interviews has been chosen as case specific methods. It has also been necessary for the authors to take advantage of the research regarding implementation of lean, last planner system (LPS), lower levels of digitization and other industries. In the following, the article consists of a method chapter, a theoretical framework, findings and discussion and at the end a conclusion and further research.

METHOD

This study is based on a qualitative research method with the use of triangulation. Triangulation increases the research's validity (Yin 2009). Initially, a literature study has been performed in order to map current research on the topic. The empirical data collection consists of a single case study and three external interviews. Case study was chosen to obtain data from an ongoing project. External interviews were chosen with the aim of taking advantage of the experiences done by other industries. The following section describes the line of action of the methods used.

LITERATURE STUDY

The literature study was carried out using several acknowledged databases, journals, conference articles, articles, books and snowballing, in addition to recommendations from supervisors. A systematic searching strategy was developed, with keywords such as "Lean", "Last Planner System", "Implementation", "Digitization", "Culture", "Change", "Human Behavior", "Artificial Intelligence" in combination with various search functions and limitations such as "construction industry". The reliability-objectivity-accuracy-aptitude principle was used to evaluate the sources (NTNU 2019). Findings from the literature study are presented in the theoretical framework as a current state of research related to the topic of the study.

EMPIRICAL DATA

Case Study

Due to the lack of published research regarding implementation of AI, was case study chosen as a suitable method. The chosen case is Bispevika, a building project in Oslo, Norway. The project consists of approximately 7 years of construction and NOK 4-5 billion (AF Gruppen 2019). Bispevika was chosen based on its non-traditional way of working regarding innovative processes and tools, and the fact that a project of that scale seems a perfect testing ground for implementations due to the possibility of learning and the possibility of having the same people improving it along the way. The

Bispevika-mindset is based on a lean approach. To get a grip on the implementation of AI, it is chosen to look closer into the implementation of the three digital tools described in Table 1.

Table 1: Explanation of the chosen digital tools at Bispevika

Tool	Description	Level of digitization	Implementation phase
Touchplan	A web-based construction collaborative tool, which can be seen as a digital version of the tools in the LPS (Sticky notes and physical boards) (Touchplan 2018)	Digitization	Late implementation
Synchro	A 4D digital construction platform. Gives the workers the opportunity to visualize, discuss and collaborate in order to find all possible constraints before executing (Synchro 2019)	Digitalization	Midway implementation
ALICE	An AI planning Software which uses the input from the users to, create and optimize schedules based on the recipes created (ALICE 2017)	Digital Transformation	Early testing

Document study and interviews was chosen as suitable methods to collect data. Two of the authors were also participating on a workshop with, and about ALICE, with the intent of acquire more knowledge about the tool.

Document Study

Mainly, three different project documents were used to support the data from the interviews and increase the authors knowledge regarding the project and ALICE. The document “Lean in Team Bispevika” is considered a guideline of understanding the culture and the way of working at the project. The documents “ALICE overview” and “Construction Information Model” can be considered as necessarily to acquire information about the complexity of ALICE.

Interviews

Seventeen semi-structured in-depth interviews, in addition to one pilot interview was carried out with interviewees from the main contractor and subcontractors. More specifically, 1 interviewee represented the company management, 3 represented the project management, 10 represented the operating department and 3 represented different subcontractors. The interviewees were people with different experiences, knowledge and mindsets regarding digitization.

The intention of the interviews has been to unveil the interviewees' opinions regarding the digital shift and its impact on the human behavior. A semi-structured technique was chosen to allow the interviewer to angle the questions and topics toward the relevance based on answers given by the interviewee (Yin 2009). Interviews was carried out with a prepared interview guide. The guide was developed in collaboration with supervisors/co-writers through a brainstorming of questions related to the research questions. Furthermore, all questions were grouped into categories, and the categories was named: Technology, Process and Culture. All interviews were recorded and completely transcribed. The analysis was conducted with inspiration from a step-wise-deductive inductive method, with the use of coding (Tjora 2017).

External interviews

With the aim of unveiling useful experiences considering implementation of AI in other industries, three external interviews were conducted. The three interviewees represented three different companies, further described in Table 2. All three interviews were conducted and analysed in the same way as the case specific interviews.

Table 2: Description of external companies

Company	Description company	Description interviewee
Norwegian open AI lab	Research center that brings together various research efforts within AI. Current key areas for the research are health, energy, ocean space, digital economy and smart environments (NTNU 2019)	Professor in Computer Science and AI. Long experience within the development and implementation of AI systems within the oil and gas industry and fishing industry
Inmeta	One of the leading consulting companies within machine learning in Norway (Inmeta 2019)	Data scientist with specialization within machine learning. Experience with development and implementation of AI systems in the healthcare industry
Spacemaker	Norwegian start-up company that has developed an AI based technology that calculate and optimize a construction site (Spacemaker 2019)	Chief Operating Officer with experience within implementation of AI in the design phase of construction projects

THEORETICAL FRAMEWORK

The construction industry is claimed to be undigitized and with a low productivity development compared to other industries (Barbosa et al. 2017). However, research indicates that the right implementation of digitization will increase efficiency of the building process (Barbosa et al. 2017). More advanced technology such as AI is now entering the industry. With more or less no research considering the implementation of AI, it will be necessary to take advantage of research regarding the implementation process itself and combine it with the technical knowledge of AI.

IMPLEMENTATION AND THE IMPACT ON HUMAN BEHAVIOUR

Implementation consists of the process of putting into practice an idea, program, or a set of activities and structures new to people attempting or expecting to change (Fullan 2007). Implementation can be considered as a change process, with inputs and a wish about a specific output. Research shows that incomplete implementations are often a result of incomplete preliminary work, where organizations are focusing on "what" instead of "how" (Noonan 2017; Senior and Swailes 2010).

Organizations are about people, and people forms cultures. Senior and Swailes (2010) defines culture as the following: "What is typical for the organization, the habits, the prevailing attitudes, the grown-up pattern of accepted and expected behavior". An implementation can also be considered as culture work. Culture is deep-seated, and is, therefore, likely to be resistant to change (Senior and Swailes 2010).

Motivation to change is decisive when implementing something new, but how do people get motivated? The goal-setting theory is strongly supported by research (Arnold et al. 2010). Setting performance goals that are specific and challenging (but not impossible), and to which the person feels committed, is likely to improve their work performance, their self-efficacy and their willingness to commit to new challenges (Arnold et al. 2010). However, recent research indicates that clear performance goals is not always beneficial. When working with simple processes, performance goals are considered beneficial, but when the processes are complex the same measures could actually inhibit productivity (Kahneman 2011).

Implementing change can be a long-term process, and commitment to the process can be weakened. The achievement of short-term wins is therefore essential, both as a motivating factor and as a mechanism for tracking the process towards the longer-term goals (Senior and Swailes 2010; Arnold et al. 2010). Another central factor considering motivation is the "implementation drivers". The people which drives the development further. The implementation is likely to fail if only the implementation drivers are motivated, as collaboration is key to innovation. Collaborative attitude, relationships based on trust and responsibility towards each other will facilitate motivation (Senior and Swailes 2010).

Every change will require training (Roland and Westergård 2015; Arnold et al. 2010). A training strategy should be developed and consist of: Training needs analysis, training design and training evaluation. All three are equally vital (Arnold et al. 2010).

As above mentioned, an organization is about people and people that forms cultures. So, what will happen when an organization is formed of people and AI? Will the factors motivation, commitment, collaboration, and trust as the literature are mentioning as decisive for a successful implementation be affected? In order to answer this, it is necessary to look deeper into the possibilities and limitations of the AI.

AI IN CONSTRUCTION

Digitization, digitalization, and digital transformation are often referred to as the same. However, the words represent different levels of the digital. Digitization involves creating a digital version of analog information, such as checklists on your mobile device instead of paper. Digitalization refers to the second level, where machines can perform human-controlled processes, such as continuously updating your Building Information Model (BIM). Digital Transformation is the integration of digital technologies in a way that the organization is fundamentally changing how they operate (Clerck 2016).

AI is defined as the ability of a machine to mimic intelligent human behavior, thus seeking to use human-inspired algorithms for approximating conventionally challenging problems (Salehi and Burgueño 2018). The implementation of AI can be seen as a digital transformation. Bolton (2018) exhibit the leading advantages of AI for organizations to be the following: Improve end-users experience using the data it provides, automate tasks to allow humans to focus on work that will add value and reduce human errors and deliver services more quickly. This can be seen in relation with the lean principles where maximizing value, minimizing waste and increase the efficiency of the working process is central (Ballard and Howell 1998).

As well-known is the adaption of AI relatively low in the construction industry (Blanco et al. 2018). However, today there are some start-ups that offers applications relevant to scheduling and image recognition. Using historical figures in addition to human-inputs, algorithms can consider millions of alternatives for project delivery and continually enhance the schedules. Image recognition can identify unsafe workers and aggregate this data to inform future training and education priorities. However, any AI-algorithm is based on training rather than programmed, which means that algorithms needs a certain amount of data to perform at the level of humans. Obtaining large data sets is today considered as a limitation for many building companies (Chui et al. 2018).

AI may help the construction industry to overcome the industry's greatest challenges, including costs, scheduling and safety (Blanco et al. 2018). However, is the construction industry in the starting phase of the digital transformation, and few projects have actually implemented AI. A central question considering the implementation will be how to get a successful human-AI collaboration?

HUMAN-AI COLLABORATION

The digital shift introduces new ways of working, where humans and technology have to cooperate. Traditional culture classifies humans and technology as separate entities (Carpenter et al. 2018). However, the last years technological development have resulted in advanced automation that can respond better than a human in specific situations (Abbass 2019). Humans can't compete with AI regarding analysis of data, information and knowledge, likewise AI cannot compete with a human's ability of pedagogy, creativity, visions and ethics (Carpenter et al. 2018).

As a successful human-human cooperation requires defined tasks and responsibility, a human-AI cooperation will require the same. Although, the tasks and responsibility are distributed between the human and AI, it can be difficult for the human to trust the AI output. How AI arrives at a particular prediction and recommendation, and further discern whether it is a good solution or not? This is one reason that adoption of some AI tools remains low in application areas where explainability is useful or indeed required (Chui et al. 2018).

Trust blend a complex array of interactions factors including attitude, beliefs, control, emotion, risk and power (Abbass 2019). Stated that AI do not have attitude, beliefs or emotion in addition to the human lack of understanding, may cause it hard for a human to trust the output. The human is in a vulnerable situation. However, if vulnerability is defined as f (capability, opportunity, intent), and one assume that the AI's intent is aligned with the human's intent, humans can through training learn AI's capabilities and opportunities. In other words, it is possible to increase the transparency, and further the trust, by educating humans about what AI can and cannot do, and where disruption might occur (Abbass 2019).

However, what happens if the human and AI disagree? Fluid interaction which allow the human to edit AI, and the AI to guide the human will be necessarily. The aim is to enable a collaborative exploration of the data that leads to common ground where both the AI and the human beliefs have been updated (Chander et al. 2018). An interaction that makes it possible for the AI to answer questions such as "Why do I need to re-plan at this point" will increase the human's ability to find biased data, understand and trust the AI (Fox et al. 2017) .

Another important factor regarding trust is time. If the machine operate reliably and predictable over a long time, humans will start to trust AI to the same degree they trust other humans (International Business Machines 2015). However, while it is possible to trust AI in a calculative, and a knowledge based way, it is difficult to reach a higher level of trust by identification (Lewicki and Bunker 1996) which seems to be reserved for fellow humans.

FINDINGS AND DISCUSSION

This section presents findings and discussion from the collected empirical data. With the aim of mapping where the construction industry is likely to be in the future considering AI and where the industry currently is regarding AI.

THE POTENTIAL BENEFITS OF ARTIFICIAL INTELLIGENCE

The digital shift is taking place, but it can be difficult to predict how the digitization will impact the construction industry. The findings are based on three external interviews, with high AI knowledge, in addition to nine case specific interviewees, with relatively low AI knowledge. The remaining eight case specific interviewees are not included, due to their lack of knowledge considering AI. The interviewees were asked an open question considering AI's future in the construction industry to map people's thoughts about construction's digital future. The question resulted in both examples of applications and possible impacts. During the analysis of the collected data, the applications emerged into three AI categories inspired by Lee (2018) and Blanco (2018), namely: Machine learning, Pattern recognition and Automation.

Machine learning consists of algorithms that can analyse data and develop new solutions based on historical figures in a way a human never would be capable of. **Pattern recognition** is the process of recognizing patterns by using a machine learning algorithm. **Automation** is the process where AI will be able to carry out tasks done initially by humans, or tasks that go beyond human's ability. Table 3 is structured after these three categories, further is the potential benefits of taking them in use discussed.

Table 3: Future application of AI presented by Team Bispevika

Categories of AI	Application	Impact
Machine learning	Scheduling	Analysis of a large amount of data based on historical figures and human input. Makes it possible to evaluate millions of scheduling options that take humans exponentially longer to accomplish
Pattern recognition	Health, Safety and Environment	Predict/early detection of dangerous situations by using machine learning algorithms in combination with pattern recognition
Pattern recognition	Storing space	A digital map that continuously shows the site and where it is possible to store materials or machines. Will increase the predictability and efficiency on site
Pattern recognition	Detection of unregistered people	Using pattern recognition to detect people and find those who are not registered at the construction site. Will increase the safety and possibility of larceny and criminal damage
Automation	Robots executing dangerous work	For example, work in the height, such as fire protection of steel beams. Will improve the safety of humans
Automation	Self-driving construction machinery	The use of robots and self-driving construction machinery will change work flow
Automation	Quality assure work	Robots that drives around the construction site scanning the site situation and compare it with the BIM. This technology may save hundreds of hours spent of quality assuring work, both considering the main- and subcontractors

All applications mentioned in Table 3 will impact the workflow and work tasks. In order to function optimally, the applications will require human-AI trust and human-AI collaboration. The industry is today putting trust in individual expertise over empirics. This is interesting as the human remember feelings more than the actual event as a whole (Kahneman 2011). AI will act on common sense with no underlying intentions. One interviewee says the following: "Some people have bad intentions, that an AI would never have. I would have been equally sceptical to a human being as an AI, owing to people's intentions". This makes it easier to trust AI. AI will also have the ability to explore several "What ifs" while humans cannot. This is positive considering the optimization of processes but on the other hand, the reason why there is a need for transparency, as described in the theoretical framework. AI will never have a bad day at work. A result will be increased predictability in workflow and quality.

However, good solutions will require the right amount of data, sufficient data, and the right variables. All nine case specific interviewees are mentioning that knowing that AI is based on the right data set or BIM will be a prerequisite for trusting the AI. Eleven out of twelve interviewees point out that visualization of why and how the output is made will increase their understanding of the causality and further increase the trust. One interviewee says the following: "I would have managed to rely on the AI if it visualized why and how the output was made. Exemplification makes people understand and learn." The need for explanation corresponds with the research described in the theoretical framework. As stated in the theoretical framework will interaction with AI be necessarily to get a functional collaboration. However, the majority of the interviewees sees it hard to imagine how communication with AI should work, especially if the AI and human disagree. Others can't imagine how they are supposed to disagree, if the input to the AI are based on human thoughts.

Considering the future, can it be beneficial to investigate the logistics and transportation industry and take advantage of their experiences considering machine learning and route optimization. The healthcare sector can contribute to experiences regarding pattern recognition. Experiences considering robotics can be taken from the manufacturing industry.

HARVESTED BENEFITS OF ARTIFICIAL INTELLIGENCE

This section is based on the seventeen case specific interviewees. To map the harvested benefits of artificial intelligence in Team Bispevika, it was chosen to investigate the implementation of three digital tools: Touchplan, Synchro and ALICE. The tools represent the three levels of digitization (digitization, digitalization and digital transformation), described in the theoretical framework. Table 4 and the following discussion will be structured after these three tools. The categories and sub-categories were developed in co-operation with supervisors as a foundation of the interview guide. A brainstorming and discussion of questions relevant for the research questions were conducted. Further, the different questions were emerged into Technology, Process and Culture and their following sub-categories as shown in Table 4. The three categories Technology, Process and Culture was inspired by Arnold (2010), and Roland and Westergård (2015) opinions regarding important implementation factors. An implementation can be seen as successful when all rows in Table 4 is marked.

Table 4: Today's situation regarding implementation of digital tools at Team Bispevika

Categories	Sub-categories	Touchplan (Digitization)	Synchro (Digitalization)	ALICE (Digital Transformation)
Technology	Knowledge	X	X	
	Training	X		
	Use	X		
	Person Independence	X		
Process	Knowledge	X	X	
	Training			
	Routines			
	Person independence			
Culture	Visibility of the utility	X		
	Willingness to use	X		
	Sense of achievement			
	Ownership			

Touchplan is a web-based construction collaborative tool, which is a digital version of the tools in the LPS (Sticky notes and physical boards). There is currently no training strategy regarding LPS or the use of Touchplan. Most interviewees think that the technical training is enough, although there is no defined training strategy. The interviewees consider themselves as competent users that can operate independent of expert users. This can be seen in the context of Toucplan's easy user interface. It is important for a successful implementation to illuminate the benefits it has for each employee's daily work tasks. Team Bispevika manage this in a good way, which is reflected by the high willingness and motivation to use Touchplan. One interviewee tells the following: "Six month ago, the only thing I was able to do on a computer was opening an e-mail. Today I am using Touchplan to plan and coordinate my work tasks. It's fantastic."

However, it is notable, that the interviewees tell that they are feeling person independent, but at the same time feel no sense of achievement, ownership nor commitment. This underlines how dependent they are on implementation drivers, in combination with the lack of a well-defined strategy and concrete goals. It seems like the implementation drivers have clear thoughts about who needs to learn the different things (training analysis), but that there is a lack of getting it into a clear and tangible structure (training design) in addition to continuously evaluation with the workers involved (training evaluation). As stated in the theoretical framework will all three factors (analysis, design and evaluation) be decisive.

Synchro is a 4D digital construction platform, which gives the workers the opportunity to visualize, discuss and collaborate in order to find all possible constraints before executing. As with Touchplan, there is currently no defined training strategy regarding 4D planning nor training in Synchro. There are today few people that can operate the program, and the interviewees are mentioning lack of time and extra work as main reasons. The lack of time may be a result of prioritizing in connection with the fact that few interviewees see the upsides of learning Synchro. This seems to affect the willingness and motivation to learn, and further the sense of achievement, ownership and commitment. However, those who are using it are pointing out the benefits of using the 4D model to get a common understanding of work tasks. The model is especially helpful in terms of the diversity of languages on a construction site.

Touchplan and Synchro represent transparent technology. Transparent technology is technology where the human control how the input is transformed to an output. As a result of the human controlled process, which makes the process transparent, is the output reliable and easy to trust. However, there is no guarantee that the given output is the most optimized, for example in terms of progression, staffing and cost, as the human brain have limited capacity of seeing different possibilities.

ALICE is based on AI which analyze, optimize and provide an output, such as a schedule. The tool is currently in the testing phase, which is illuminated by the empty rows in Table 4. AI is today a "hot" topic and widely used term. As the understanding of AI is not general knowledge in the industry, it will be difficult for a worker to understand how ALICE arrives at the presented output, and further trust the output. Today's lack of historical figures makes ALICE dependent of human-input. Humans partially controls the output, which makes it easier to trust the output. However, with enough historical figures the human input will no longer be necessary. Trust between humans are a decisive factor for a good collaboration and will likewise be important for a good human-AI collaboration. All interviewees agree that the implementation of AI will require other knowledge and training than the lower degrees of digitization.

CONCLUSION AND FURTHER RESEARCH

This paper has the purpose of illuminating how the construction industry can close the gap between the potential benefits and the harvested benefits of the implementation of AI. The gap has been identified by looking into the construction's possible benefits of implementing AI and today's harvested benefits of AI.

The research has been conducted as a literature study, a case study of Team Bispevika and three external interviewees. It is possible to assume that the results can be generalized to other projects, as the chosen interviewees are persons with different positions, knowledge and attitudes considering the digital shift. Research done in this paper shows that technology, process, and culture are equally important to succeed with an implementation. Figure 3 and 4 illustrates the current implementation situation of Touchplan (digitization) and ALICE (digital transformation). Dark grey illustrates the required level for a successful implementation, and light grey illustrates that some factors are achieved but not everyone, while white illustrates that the required level for a successful implementation is far from reached.

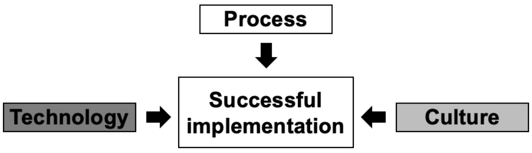

Figure 3: Implementation of Touchplan

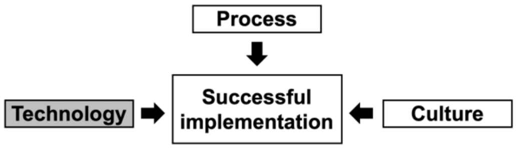

Figure 4: Implementation of ALICE

As shown in Figure 3, **Touchplan** and LPS are not considered implemented. However, Touchplan can be considered as a user-friendly tool, where **Technology** is sufficiently developed in order to succeed with the implementation. The expert users have managed to make engagement and positive attitude among the employees. This has further resulted in the willingness and motivation to learn and use the tool. The employees miss the sense of achievement and ownership, and as a result, is **Culture** marked light grey. The **Process** is marked white as there is no clear training strategy. As illustrated in Figure 4, **ALICE** is not fully implemented, and is currently in the testing phase. The AI-technology itself is present, but the absence of historical figures and transparency makes the **Technology** light grey. **Process** and **Culture** is marked white as there is no defined strategy of implementing ALICE nor a flexible, motivated and knowledgeable working culture. It can be concluded that AI has come to stay, and that there exist several benefits by implementing AI. However, several barriers must be broken in order to take advantage of the proposed benefits. Table 5 presents the factors concluded to be decisive for a successful implementation of AI.

Table 5: Factors considered essential for closing the gap between the current and future use of AI in the construction industry

Experiences	Experiences and thoughts that can contribute to close the gap between the current and future use of AI
Touchplan and Synchro	• A well-defined training strategy • The training should focus on the process it is supposed to support • Concrete goals for each employee, including long-term goals and short-terms goals • Implementation drivers with positive attitude • Cultivate a culture characterized by a positive attitude, commitment, and curiosity • Involvement is important, but equally important is expectations • A Team should consist of people with experience from both production and use of digital tools • The use of 3D models improves the common understanding and communication • Getting a positive reputation will make the implementation process easier
Other factors considered important. Based on literature, empirical data and the authors thoughts	• It should be taken advantage of AI in those cases where the technology can improve the process • Interaction with the AI will be necessarily in order to collaborate and trust the AI • A user interface that normal people can understand • Visualization of the process from input to output will increase causality and further the trust • Increased technological knowledge considering AI will contribute to trust • Good experience considering the use of AI, will increase the trust • Implementation drivers with good understanding of human and AI • Available support is needed in a longer period compared to the lower degrees of digitization • Data with sufficient quality

The combination of human-AI trust and continuously optimizing a process makes it possible to increase the efficiency. Trust between humans and AI can more easily prevail when first established due to a lower possibility of conflict. AI can therefore be a supplement to improve a lean workflow.

AI technology differs from lower degrees of digitization as it has other prerequisites considering trust and collaboration with humans. It is recommended that further research discuss the adaption of AI on the premise of the users, collects more empirical data and investigates experiences done by other industries.

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PART 3: APPENDIX

Appendix 1: Search engines

The search engines used during the literature study are described in the table below. The search engines webpages are given in footnotes.

[1] $https://bibsys-almaprimo.hosted.exlibrisgroup.com/primo-explore/search?vid=NTNU_UB$
[2] https://www.scopus.com/search/form.uri?display=basic
[3] https://www.elsevier.com/solutions/engineering-village/content/compendex
[4] https://www.sciencedirect.com/
[5] https://scholar.google.com/intl/en-US/scholar/about.html
[6] https://www.google.no/

Description of search engines

Search engine	Description	Peer reviewed
Oria [1]	NTNU's digital library. Collection of published literature, including master theses	No
Scopus [2]	Produced by Elsevier and is according to the publisher the largest abstract and citation database of peer-reviewed literature. Consists of literature within natural science, technology, medicine etc. The search engine shows the number of citations and the h-index of the authors, which is useful information when evaluating the source	Yes
Ei Compendex [3]	The second search engine owned by Elsevier. Is according to Elsevier the world's most complete literature database within the science of engineering. 14% of the published literature consists of literature about civil engineering. The database is convenient when narrowing the search directly to literature regarding engineering. On the other hand, there is a possibility of missing relevant literature. The database does not show the number of citations or h-indexes	Yes
Science Direct [4]	According to Science Direct, this search engine is the world's leading source for scientific, technical, and medical research, with published journals, books and articles	Yes
Google Scholar [5]	Google's scientific database. Provides a simple way of searching for scholarly literature. The database aims to rank documents based on the author, full field text, publisher, citations and h-indexes. However, the literature should be read with critical eyes as there is no prerequisite that the literature is peer-reviewed. The database is useful for finding known literature, such as books	No
Google [6]	Uncritical and not scientific and should not be used as the primary engine for finding research-based literature. The search engine can be useful when the aim is to collect basic knowledge about a subject, or when searching for different companies that can have useful reports, such as McKinsey & Company	No

Appendix 2: Interview guide

Intervjuguide

Implementering av kunstig intelligens i byggebransjen, med fokus på menneske-AI samarbeid.

Dato	
Navn på informant	
Stilling	
Avdeling	
E-post	
Samtykker informant i at intervjuet blir tatt opp	Ja: Nei:

Intervjuet vil bestå av følgende fire hoveddeler:
- Fase 1: Intervjuer forteller litt om seg selv og hvorfor man er her
- Fase 2: Informant forteller om seg selv og sin erfaring i byggebransjen
- Fase 3: Kjernen av intervjuer hvor spørsmål vedrørende tema skal besvares
- Fase 4: Oppsummering

Det er valgt en semi-strukturert intervjumetode, som vil si at intervjuer stiller spørsmål, men dialog og tilpasning av spørsmål vil være mulig. Intervjuer ønsker dine personlige meninger og synspunkter om temaet.

Fase 1: Bakgrunn for intervjuet

Mitt navn er Marte Helle Schia og jeg studerer nå siste året Bygg- og miljøteknikk ved NTNU i Trondheim. Jeg har de tre foregående somrene hatt sommerjobb i AF Gruppen. Jeg skrev i høst prosjektoppgave i samarbeid med AF Gruppen og Team Bispevika, og jeg fortsetter nå på det arbeidet i min masteroppgave. Oppgaven er utarbeidet i samarbeid med Bo Christian Trollsås, Planner VDC ved prosjekt Bispevika.

Byggebransjen befinner seg nå i det digitale skiftet og skal gå fra å være en tradisjonell bransje til å bli mer digital og innovativ. Min masteroppgave tar for seg implementeringen av verktøy basert på kunstig intelligens i byggefasen. Hensikten med oppgaven er å kartlegge hvordan man kan lukke gapet mellom dagens implementering av kunstig intelligens og fremtidig bruk av kunstig intelligens. På bakgrunn av at kunstig intelligens er et relativt ukjent teknologisk område innenfor byggebransjen er det avgjørende å hente erfaringer fra implementeringen av mindre avanserte verktøy. Litteraturstudier, dokumentstudier, og intervjuer skal belyse tema, og følgende forskningsspørsmål er definert:

1. Hva er de potensielle fordelene ved å implementere AI i byggebransjen?
2. Hvilke fordeler og barrierer opplever man ved implementering av AI i byggebransjen i dag?

Som informant bidrar du med informasjon som kan være avgjørende for å finne en bedre implementeringsprosess når det gjelder dagens digitale verktøy, men også fremtidens.

Fase 2: Informant forteller om seg selv

Tema	Notater
1. Utdanning 2. Erfaring i bransjen 3. Erfaring med AI/digitale verktøy	

Fase 3: Spørsmål

Forskningsspørsmål 1: Hva er de potensielle fordelene ved å implementere AI i byggebransjen?

<table>
<tr><td rowspan="5">Teknologi

- Hvilke digitale verktøy kunne du tenke deg å benytte deg av i fremtiden?
- Hva tror du er fordelen ved å ta i bruk de verktøyene du nevner?
- Tror du verktøyene du nevner vil føre med seg noen ulemper?
- Hvilke teknologisk kjennskap tror du vil kreves av deg for å bruke verktøyene?
- Hvilken opplæring vil det kreve?
o Hva skal til for at du lærer deg/tar i bruk det verktøyet?</td><td></td><td>Touchplan</td><td>Synchro</td><td>ALICE</td></tr>
<tr><td>Kjennskap</td><td></td><td></td><td></td></tr>
<tr><td>Opplæring</td><td></td><td></td><td></td></tr>
<tr><td>Bruk</td><td></td><td></td><td></td></tr>
<tr><td>Tilgjengelighet</td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Prosess

- Se for deg at du istedenfor å samarbeide med en kollega/menneske skal samarbeide med en maskin. Hvordan ser du for deg at det hadde vært?
- Hva tror du er de viktigste faktorene for opplæring i digitale verktøy i fremtiden?
- Hadde du hatt et behov for å se hva maskinen baserte valgene sine på? (gjennomsiktighet, visualisering)
- Ville du som menneske stått for den endelige beslutningen eller hadde du stolt på at maskinen tok det riktige valget?
- Er det andre metoder du tenker kan være nyttig når det gjelder kommunikasjon og samarbeid mellom mennesket og maskin/teknologi?</td><td>Prosjektstruktur</td><td></td><td></td><td></td></tr>
<tr><td>Ledelse</td><td></td><td></td><td></td></tr>
<tr><td>Strategi</td><td></td><td></td><td></td></tr>
<tr><td>Opplæring</td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Kultur

- Hvordan burde man synliggjøre nytten i fremtiden?
- Hvordan skal man skape motivasjon til å lære seg de digitale verktøyene?
- Hvordan skal man oppnå mestring og eierskap?
- Hvordan tror du arbeidskulturen bli påvirket av digitaliseringen?
- Ville du klart å stole på en robot/maskin?</td><td>Synliggjøring av nytten</td><td></td><td></td><td></td></tr>
<tr><td>Villighet til bruk</td><td></td><td></td><td></td></tr>
<tr><td>Mestring</td><td></td><td></td><td></td></tr>
<tr><td>Eierskap</td><td></td><td></td><td></td></tr>
<tr><td>Ønske/motivasjon for utvikling</td><td></td><td></td><td></td></tr>
</table>

Spørsmål relatert til fremtidig tillitt til AI-baserte verktøy. Her eksemplifisert med en robot.		
Case 1	**Case 2**	**Case 3**
Se for deg at du er ute på byggeplassen og jobber, hvor du samarbeider med en robot. Roboten har oversikt over alt når det gjelder bygget og byggets fremdrift. Plutselig sier roboten at du skal stoppe med det arbeidet du driver med, og gå videre til en annen arbeidsoppgave. Hva ville du gjort? Ville du klart å stole på at det roboten sier er riktig?	Se for deg at du er ute på byggeplassen og jobber, hvor du samarbeider med en kollega. Plutselig sier kollegaen din at du skal stoppe med det arbeidet du driver med, og gå videre til en annen arbeidsoppgave. Hva ville du da gjort?	Du er ute og går på byggeplassen sammen med en robot som kjører ved siden av deg. Plutselig signaliserer roboten at du ikke kan gå der du har tenkt. Den vil at du skal ta en annen vei. Du titter rundt deg, og i dine øyne ser det helt trygt ut å gå videre. Hva gjør du?

Forskningsspørsmål 2: Hvilke fordeler og barrierer opplever du ved implementeringen av AI i byggebransjen i dag?

Teknologi		**Touchplan**	**Synchro**	**ALICE**
- Hvilke digitale verktøy bruker du i dag? - Hvilken kunnskap har du om verktøyet? - I hvilken grad benytter du det? - Fordeler med verktøyet? - Ulemper med verktøyet? - Hvilken teknologisk kunnskap kreves av deg for å bruke verktøyet? - Bruker du verktøyet uten hjelp fra andre? - Styrker verktøyet dine arbeidsoppgaver? - Er det noen digitale verktøy du skulle ønske du kunne bruke?	Kjennskap			
	Opplæring			
	Bruk			
	Tilgjengelighet			
Prosess - Har dere noen rutiner når gjelder bruk av de digitale verktøyene? - Hvilken opplæring har du fått? 1. Hvis opplæring: Føler du opplæringen er tilstrekkelig? 2. Hvis ikke: Skulle du ønske noe var annerledes? - Føler du ledelsen/sjefen din legger til rette for at du skal kunne lære deg verktøyene? - Langsiktige mål? Kortsiktige mål?	Prosjektstruktur			
	Ledelse			
	Strategi			
	Opplæring			
Kultur - Hvordan synliggjøres nytten av verktøyene? Ser du nytten av å bruke verktøyet? - Har du motivasjon for å bruke verktøyene? - Føler du mestring når du bruker verktøyene? - Føler du eierskap til verktøyene? - Hvilke holdninger har folk med henblikk på å lære seg nye digitale verktøy? 1. Er folk endringsvillige? - Hvordan fungerer samarbeidet mellom folk? 2. Har folk tillit til hverandre? / Stoler man på hverandre - Stoler du på verktøyet?	Synliggjøring av nytten			
	Villighet til bruk			
	Mestring			
	Eierskap			
	Ønske/motivasjon for utvikling			

Fase 4: Oppsummering

Har informant noe mer å legge til?		
Informant samtykker til at intervjuer kan ta kontakt hvis det skulle dukke opp usikkerheter eller nye spørsmål	Ja____	Nei_____
Ønsker informant å motta et oppsummerende dokument etter endt intervju?	Ja_____	Nei_____

Appendix 3: Human level performance milestones

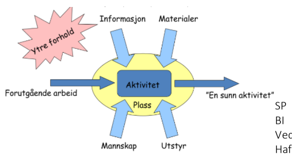
Description human-level milestones AI (Yoav, Perrault, Brynjolfsson, et al., 2018).

Tasl	Description
1	In the 1980s Kai-Fu Lee and Sanjoy Manhajan developed BILL, a Bayesian learning-based system for playing the board game Othello. In 1989 the game beat the highest ranked U.S player, Brain Rose
2	In 1952, Arthur Samuels built a series of programs that players the game of checkers and improved via self-play. In 1995 the checker—playing program, beat the world champion
3	IBM's DeepBlue system beat chess champion Gary Kasparov. Today, chess programs running on smart phones can play the grand-master level
4	IBM Watson computer system competed on the popular quiz show Jeopardy, and won against former winners Bra Rutter and Ken Jennings
5	A team of Google DeepMind used a reinforcement learning system to learn how to play 49 Atari games. The system was able to achieve human-level performance in a majority of the games
6	The error rate of automatic labeling of ImageNet declined from 28% in 2010 to less than 3%. Human performance is around 5%
7	The AlphaGo system developed by the Google DeepMind team beat Lee Sedol, one of the world's greatest Go players. An extended version was developed, that beat the original AlphaGo system 100-0
8	An system trained on a data set of 129,450 clinical images of 2,032 different diseases and compared its diagnostic performance against 21 board-certified dermatologists. The AI system was capable of classifying skin cancer at comfortable level
9	Microsoft and IBM both achieved performance within close range of 2human-parity2 speech recognition in the limited Switchboard domain
10	A program called DeepStack won enough poker games to prove the statistical significance of its skill over the professionals
11	A deep learning team acquired by Microsoft, created an AI system that learned how to reach the game's maximum point value 999,900
12	A Microsoft machine translation system achieved human-level quality and accuracy hen translating stories from Chinese to English
13	A DeepMind agent reached human-level performance in Quake III Arena Capture the flag. The agents showed human-like behaviors such as navigating, following, and defending
14	Open AI's team of five neural networks, defeats amateur human teams at Dota 2. Open AI dive was trained by playing 180 years worth of games against itself every day
15	Google developed a deep learning system that can achieve an overall accuracy of 70% when grading prostate cancer in prostatectomy specimens. Human accuracy was 61%

Appendix 4: Planning Structure, Project Bispevika, Department of operation

Planstruktur drift v2.0

Nivå: Strategisk → Operasjonelt | Infoflyt: Ovenfra og ned / Nedenfra og opp

	Plannivå (tidshorisont)	Planeier/ Ansvarlig	Møte-struktur	Involverte	Fremdrift	Koordinering eksternt	Rigg og logistikk	HMS, Kvalitet, BREEAM	Risikostyring
1	**Hoved-fremdriftsplan**	PL	Hver 4. uke	BH PGL AL KS-leder	• Etablere prosjektets hovedfaser og delfaser • Identifisere milepæler og datofeste disse i samråd med faseeiere • Rapportere framdrift pr fase • Vurdere konsekvens og ekstraordinære tiltak som følge av innrapporterte avvik i underliggende plannivåer	Kunde/BH	Etablere/vedlikeholde grunnlag for overordnet riggplan • Kontor, spis og skift • EL-skap og vann • Lagerplasser og utstyrskontainere • Tårn- og mobilkraner Identifisere rigg- og logistikkutfordringer som må jobbes videre med i faseplanene	Utarbeide/vedlikeholde prosjektplan, og sørge for at alle AL og DL er opplært i og jobber etter denne	Oppstart Topp 10-lister Kvartalsgjennomgang
2	**Faseplan** (for hver fase)	AL pr. Gjeldende fase	Ca 3 mnd før oppstart av fasen, med ukentlige møter (se prosjekt-styringsplan for individuell tilpasning)	Fra AF: Samtlige AL HMS KS PRL BREEAM Fra SP: PL/AL BAS	1. Etablere godt gjennomtenkte arbeidssoner 2. Identifisere alle fags aktiviteter innenfor disse arbeidssonene i touchplan 3. Angi ressurser på aktivitetene i touchplan (tid og bemanning) 4. Sette sammen sonene til en samlet faseplan og optimalisere planen i touchplan 5. Speile planen fra touchplan i Synchro 6. Aktivt bruke Synchro til å analyser din fase Planen skal inneholde: • Delmilepæler (f.eks. Oppstart/slutt pr. sone) • Være bevisst på hva er på kritisk linje *Rapportere evt avvik som påvirker **hovedframdriftsplanen***	Kunde/BH SP BI Vedal Hafslund	• Finne løsninger på identifiserte punkter fra hovedframdriftsplanen • Innhente forventet leveransefrekvens for hver SP Starte møteserie for å detaljere riggplan for fasen: • Faringsveier • Lossesoner og adkomstveier • Avfallskontainere • Stillaser • Heiser • HMS-kontainer • Lagerplass	• Kalle inn til jevnlige konstruksjonsgjennomganger med relevante aktører og rådgivere • Gjennomgå risikoanalysen og legge inn frist for SJA i faseplanen (touchplan) • Kontrollere at SP-dokumentasjon er mottatt (KISS, HMS-plan, Kontrollplan) og avsette tid til gjennomgang av dette • Konferer med BREEAM-ansvarlig om elementer for fasen • Ferdigstille AFs Verifikasjonsplan for fasen	Identifisér risiko «topp 5» for fasen hentet fra prosjektets topp-10 liste, og legg inn milepælene for disse inn i touchplan.
3	**Utkikksplan** (3-9 uker fram)	AL/DL pr. Gjeldende fase	Hver andre uke	Fra AF: DL HMS Fra SP: PL/AL BAS Cramo	 2. Identifisere eventuelle uteglemte/mer detaljerte aktiviteter 3. Vurdere ekstraordinære tiltak opp mot milepæler/hindringer/leveranser for perioden *Rapportere evt avvik som påvirker **faseplanen***	SP BI Vedal Hafslund	• Vurdere om nye aktiviteter trigger særskilte endringer i riggplanen • Tilpasse faringsveier, lossesoner og lagerplasser. • Vurdere sesongjusterte tiltak • Avstemme riggplan mot BI, Vedal, Skanska og Bundebygg sine framdriftsplaner	• Justere dato for SJA i touchplan hvis endringer • Evt BREEAM utfordringer løses • Sørge for oppdatert ProductXchange-bibliotek hvis nye produkter skal inn på anlegget • Kontrollere at KS-avvik, FDV etc. kommer inn på rett sted i KS-systemet.	Planlegg aksjoner på risikomilepæler fra faseplanen som gjør seg gjeldende i perioden (i touchplan)
4	**Ukeplan** (1-2 uker fram)	BAS SP	Ukentlig	Fra AF: AL/DL HMS Fra SP: BAS	1. Dra inn aktiviteter fra utkikksplan og justere i tid (toucplan) 2. Supplere med evt. nye aktiviteter. 3. Forplikte dette ovenfor andre samarbeidspartnere for å skape forutsigbar ukeplan i touchplan 4. Speile rapporteringen i synchro ukentlig *Rapportere evt avvik som påvirker **utkikksplanen***	SP BI	• Bestille lossesoner i touchplan og OSU-bookingsystem • Bestille krantid i touchplan • Bestille/avbestille leieutstyr • Verifisere riggplanen • Vurdere spesielle hensyn mtp vær • Vedlikehold av utstyr og riggområde • Legge inn lørdags-jobbing i touchplan	• Avtale tid og utføre planlagte SJA • Sørge for at det er fokus på sikkerhet, og planlegge for sikker drift • Planlegge kvalitet i utførelsen, klargjøre sjekklister og kontrollpunkter	Ta aksjon på risikoelementer fra utkikksplanen som gjør seg gjeldende i perioden.
5	**Morgenmøte** (gårsdagen/ dagen)	BAS SP	Daglig	Fra AF: AL/DL HMS Fra SP: BAS	1. Statusutsjekk gårsdagen og angi rotårsak hvis avvik på planen 2. Koordinere avvik I planen med berørte samarbeidspartnere *Rapportere evt avvik som påvirker **ukeplanen***		• Avklare dagens transportsituasjon • Utføre endringer i riggoppsettet	• Utføre punkter fra vernerundereferat • Fylle ut sjekklister Still spørsmålene: • Hvilke risikoer er det med aktivitetene dere skal utføre i dag? • Er barrierene på plass?	Statusutsjekk på aksjoner i touchplan

Marte Helle Schia

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NTNU
Norwegian University of
Science and Technology

AF GRUPPEN