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How to Prepare the Construction Industry for 3D Printing of Concrete

A qualitative research among five contractor companies in Norway

Master's thesis in Project Management
Supervisor: Nils Olsson
June 2019

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

NTNU
Kunnskap for en bedre verden

HINDCON

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ABSTRACT

The future construction industry can involve 3D printing technology. The purpose of this research has been to examine how to prepare the construction industry for 3D printing of concrete. The research covers an overview of the technologies used in the construction industry today, especially in contractor companies. The overall topic has been confined from a variety of existing technologies in the construction industry to the specific technology 3D printing of concrete. The study focusses on large-scale printers for construction. As an example, the hybrid 3D concrete printer being developed by HINDCON is presented. HINDCON is an ongoing project funded by the European Commission with a duration from 2016 to 2019. Due to limited access to public information about the HINDCON project, the emphasis of this research is on general 3D printing for large-scale use. A qualitative approach has been used to obtain complex and nuanced data about the current situation in the construction industry. This has been done with a small-N-study, by interviewing 11 respondents from five contractor companies in Norway. All respondents were anonymous in the research. A categoric analysis of the collected data has been done. The literature explains the current situation in the construction industry, including for instance industrialization and technology development in the construction industry. The technology behind 3D printing is accordingly explained, in addition to previous experiences and particular challenges related to 3D printing of concrete. A previous study about 3D printing is presented, and challenges related to 3D printing technology are described. The findings reveal that all respondents experienced their workplace as accommodating for new technology. They also felt they could influence which technologies are being used on construction sites. None had ever experienced 3D printing on a construction site, but 73% had done some research on their own about the topic. 64% thought 3D printing will streamline and shorten the construction process. 46% believed that a 3D printer, like the one from HINDCON, has a future on the construction site, but at the same time it will be a helpful tool and aid for the prefabricated concrete producers. One possible alternative to approach 3D printing is presented in this research. This research can be valuable for those preparing for use of 3D printing technology, or more generally those who want to embrace new technology and innovation, also in other industries than construction.

SAMMENDRAG

Fremtidens byggebransje kan inneholde 3D-printingteknologi. Formålet med denne studien har vært å undersøke hvordan man kan forberede byggebransjen på 3D-printing av betong. Forskningen dekker en oversikt over teknologiene som brukes i byggebransjen i dag, særlig i entreprenørfirmaer. Det overordnede temaet har blitt begrenset fra en rekke eksisterende teknologier i byggebransjen, til den spesifikke teknologien 3D-printing av betong. Studien fokuserer på printere i stor skala som er ment for byggebransjen. Et eksempel som blir presentert er den hybride 3D-betongprinteren som utvikles av HINDCON. HINDCON er et pågående prosjekt finansiert av Europakommisjonen med en varighet fra 2016 til 2019. På grunn av begrenset tilgang til offentlig informasjon om HINDCON-prosjektet, ligger fokuset i denne undersøkelsen på generell 3D-printing for storskala bruk. En kvalitativ tilnærming har blitt brukt for å oppnå komplekse og nyanserte data om den nåværende situasjonen i byggebransjen. Dette har blitt gjort med en liten-N-studie, ved å intervjue 11 respondenter fra fem entreprenørfirmaer i Norge. Alle respondentene var anonyme i undersøkelsen. En kategorisk analyse av de innsamlede dataene ble gjort. Litteraturen forklarer den nåværende situasjonen i byggebransjen. Dette inkluderer blant annet industrialisering og teknologiutvikling i byggebransjen. Teknologien bak 3D-printing er forklart, i tillegg til tidligere erfaringer og spesielle utfordringer knyttet til 3D-printing av betong. En tidligere studie om 3D-printing presenteres, og utfordringer knyttet til 3D-printingteknologi er beskrevet. Resultatene viser at alle respondentene i denne undersøkelsen opplevde sin arbeidsplass som imøtekommende for ny teknologi. De følte også at de kunne påvirke hvilke teknologier som brukes på byggeplasser. Ingen hadde noen gang opplevd 3D-printing på en byggeplass, men 73% hadde gjort en selvstudie på temaet. 64% trodde 3D-printing vil kunne effektivisere og forkorte byggeprosessen. 46% trodde at en 3D-printer, som den fra HINDCON, har en fremtid på byggeplass, men også vil være et nyttig verktøy og hjelpemiddel for prefabrikkeringsprodusentene av betongelementer. Et mulig alternativ for å tilnærme seg 3D-printing er presentert i denne undersøkelsen. Denne undersøkelsen kan være verdifull for de som forbereder seg på bruk av 3D-printingteknologi eller mer generelt de som ønsker å omfavne ny teknologi og innovasjon, også i andre næringer enn byggebransjen.

PREFACE

The purpose of this study is to get an overview of how the construction industry sees the upcoming and still evolving 3D printing technology. This information can be used to prepare the construction industry for 3D printing of concrete. HINDCON is a currently ongoing project founded by the European Commission where the aim is to develop a hybrid 3D printing machine using concrete as a material for large-scale use. By interviewing people in the industry, the aim here is to understand how 3D printing of concrete can be utilized in the construction industry. Different ways of 3D printing exist, and the choice will affect the workflow and environment on the construction site. HINDCON was in charge of the travel expenses from the interviews in this research.

This master's thesis (30 STP credits) has been made at the Norwegian University of Science and Technology in Trondheim, Norway, for the spring semester in 2019. The duration of the study was set to 20 weeks, and the academic responsibility was at the Department of Mechanical and Industrial Engineering. This report continues the work done in the Specialization Project (15 STP credits) on the same topic, for the course TPK4920 – Project and Quality Management. Some parts of the theory chapter can be found overlapping in both reports.

I would like to thank my supervisor from the department, Professor Nils Olsson. First for accepting me for cooperation and then for excellent support throughout the whole process. He introduced me to the HINDCON project and assisted me with relevant articles. In addition, I would like to thank everyone who participated in interviews and their companies for sharing information and thoughts.

Mathilde Skeide
Trondheim, 11th June 2019

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Abbreviations and Acronyms

2D	Two dimensional
3D	Three dimensional
3DP	Three-dimensional printing
ABM	Advanced building material
AI	Artificial intelligence
AM	Additive manufacturing
AR	Augmented reality
BIM	Building information modelling
CAD	Computer aided design
CEO	Chief executive officer
CLT	Cross laminated timber
CNC	Computer numerical control
FCP	Freeform construction process
GDP	Gross domestic product
HINDCON	Hybrid industrial construction
HLM	Hybrid layerd manufacturing
HSE	Health, safety and environment
IoT	Internet of Things
LC	Lean construction
LM	Layered manufacturing
QA	Quality assurance
R&D	Research and development
RFID	Radio frequency identification
RP	Rapid prototyping
SJA	Safe job analysis
SM	Subtractive manufacturing
SMEs	Small and medium enterprise
VDC	Virtual design construction
VR	Virtual reality
WP	Work package

1 Introduction

The future construction industry can involve 3D printing technology. This report looks at how the industry can prepare for such a technology. To explore this, 11 interviews were conducted among employees in five contractor companies in Norway. This chapter of the report explains the background for the topic choice, the project purpose with a presentation of the research questions, limitations, and scope for the research, and an overview of the report structure.

1.1 Background

This research concentrate on technology in the construction industry, 3D printing in general and challenges related to 3D printing of concrete. The phenomenon *3D printing of concrete* is relatively new to the construction industry. It is one of many technologies advancing these days. It has the potential to significantly change today's construction processes, both on-site and off-site. It is impossible to predict what lies ahead. Consequently, it is also difficult to plan the future. The development of technology, environment, politics and other trends in the society makes strategic planning hard (World Economic Forum & The Boston Consulting Group, 2018). Three scenarios are described to be likely to represent the future of the construction industry. The different scenarios of the future world are based on past experiences and global trends today. These extreme scenarios are not predictions of the future, but possible outcomes of what exists today. They can be relevant for everyone's preparations and planning if potentially radical changes happen in the future (Buehler, Buffet, & Castagnino, 2018; World Economic Forum & The Boston Consulting Group, 2018). The three scenarios found in the literature are listed below (World Economic Forum & The Boston Consulting Group, 2018):

1. Building a virtual world: *"virtual reality touches all aspects of life, and intelligent systems and robots run the construction industry"*
2. Factories run the world: *"a corporate-dominated society uses prefabrication and modularization to create cost-efficient structures"*

3. A green reboot: *"a world concerned with addressing scarce natural resources and climate change rebuilds using eco-friendly construction methods and sustainable materials"*

In all the three scenarios mentioned above, 3D printing technology is relevant for implementation. The use of 3D printing in large-scale is still limited but can possibly change in the future. Scenario 1 could involve 3D printer robots at construction sites. The building information modelling (BIM) technology, which is widely used today, can be connected with a 3D printing robot for a more automatic, intelligent, and streamlined process. 3D printing can in scenario 2 conceivably be a part of a factory or be a complement for the construction site. Scenario 3 embrace 3D printing technology because the additive manufacturing process creates less waste than traditional construction methods, which supports a greener world.

3D printing technology is one of many technologies making progress these days. 3D printing is not a new technology, but the type HINDCON is developing is unique. It is a hybrid 3D printing machine with robot technologies, using concrete as a material for large-scale printing. HINDCON is a currently ongoing project funded by the European Commission. The HINDCON printer is yet not applied anywhere because it is still under development. But the construction industry has several examples that prove a willingness to exploit the potential and interest in using hybrid 3D printing technology (Arica et al., 2017). The focus areas covered in this master's thesis evolved from the HINDCON project description, which addresses several work packages (WPs) to be complied (HINDCON, 2016a).

1.2 Project Purpose

The purpose of the study is to describe how to prepare the construction industry for 3D printing of concrete. 11 interviews were conducted among five contractor companies in Norway to get an overview of how the construction industry sees the upcoming and still evolving 3D printing technology. By interviewing people in the industry, the aim is to understand how 3D printing of concrete can be utilized in the construction industry. Different ways of 3D printing exist, and the choice will affect the workflow and environment on the construction site.

HINDCON's work package nine (WP9), which became the basis for this master's thesis, covers replicability, technology transfer, and training. Challenges related to 3D printing became revealed through the pre-study of this research. In this research, it is investigated how to deal with these challenges, along with other consequences that follow from 3D printing technology. To understand how innovations and new technology are handled in the construction industry, earlier experiences are studied. This gives an indication of what to be aware of when 3D printing is attempted (HINDCON, 2016a). Because of the restrictions regarding documentation and information about the HINDCON project, this research focused more on the general use of 3D printing. The topic was narrowed down to focus on known challenges related to 3D printing. This included, for instance, investigation of safety, operation, the competence of operators, location of production robot (location on-site versus off-site location). These challenges were among the more addressed in the interview guide and hereunder analysed and discussed. This research gives an alternative approach to 3D printing, which could be seen from a wider perspective than only for the construction industry. All this form the base for the problem statement and the research questions.

1.2.1 Research Questions

The research questions are both exploring and testing, which implies to elaborate on what we know little about and to see the extent of the phenomenon of 3D printing (Jacobsen, 2005). The main focus is on describing the situation with 3D printing in the construction industry in 2019. This research takes a cross-section at this point in time to explain the current situation. The kind of research questions used in this project requires a research method that highlights nuanced and in-depth data, but at the same time is open for unexpected circumstances and then open for contextual conditions (Jacobsen, 2005).

The problem statement defined for this study is:

- *How to prepare the construction industry for 3D printing of concrete?*

Three research questions are defined to specify the problem statement addressed in this research. The questions are:

RQ1: *How active are construction companies to embrace new technologies in the industry?*

RQ2: *How feasible is 3D printing in the construction industry? And what about the 3D concrete printer from HINDCON in particular?*

RQ3: *How to handle challenges arising from 3D printing of concrete?*

Answers to these questions gives an overview of the current situation of technology use in the construction industry, the feasibility of 3D printing in construction and relevant challenges arising from it. The answers will be valuable for those preparing for use of 3D printing technology or more generally those who want to embrace new technology and innovation.

1.2.2 Scope & Limitations

The phenomenon *3D printing of concrete* is narrowed in from wider topics. The overall topic of technology is defined down to automation, robots, 3D printing robots and in the end, 3D printers using concrete as a material. Figure 1-1 illustrates the limitation of the phenomenon. The research topic is focused on 3D printing of concrete, but not completely restricted from the wider topics. The topic is narrowed in because it must answer the research questions specifically. The wider topics are to some degree elaborated in the research and in the interviews to set the circumstances for understanding 3D printing.

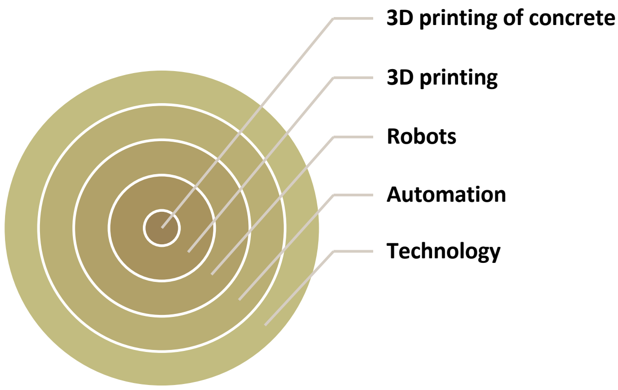

Figure 1-1: Approaching the phenomenon 3D printing of concrete, and related topics

Several appellations to a 3D printer are used in this study. Examples of formulations used are *3D printer* or only *printer*. Sometimes also a more general term was used, for instance *robot* or *machine*, which in this study both cover the term 3D printer. When the HINDCON 3D printer is referred to, it is mentioned explicit. It is important to mention that 3D printing exists with various materials and scope, but this report focus on the material concrete and for large-scale industrial and construction printing purposes. This is expressed as *3D concrete printing* or *3D printing of concrete.* In this research a 3D printer is imagined as the one presented by HINDCON[1].

3D printers are in this study not focusing on printers for home use, which commonly prints small objects in plastic. The technology and many of the features are the same, but in this study the focus is on large-scale printers for construction usage. The respondents might have had different perceptions of 3D printers before the interviews. To solve this, the HINDCON project video was shown during the interviews.

[1] HINDCON presentation video: https://www.youtube.com/watch?v=Y9AskMrvS5k&feature=youtu.be [26.03.19]

As a master student, the number of interviews possible to cover was limited by the time and resources available. Interviewing between 8 and 12 persons was seen as reasonable by the supervisor. All respondents should be working in the construction industry. They should have knowledge or experience from construction work on-site, but there were no specific job positions preferred. The research got 11 respondents from five different construction companies. The companies were Betonmast AS, HENT AS, JM Norge AS, Veidekke ASA and Ø.M. Fjeld AS. In the following only the company name itself will be used. The research's focus is not on the particular companies, but rather on the respondents' thoughts.

Limited availability to public information about the HINDCON project caused this study to be general about 3D printing. The HINDCON project video was the only source of information for the respondents regarding the particular printer. This gave all the respondents the same basis for discussion about the challenges presented regarding 3D printing. As a result of this limitation, the second part of research question number two became difficult to answer.

1.3 Outline

The sequence of this master's thesis is as described in Figure 1-2. After this introduction follows the theory used to back the empirical findings. The theory chapter gives an overview of today's construction industry. It explains about the industrialization that happens in the industry, thereafter about the technology development in general. It continues to narrow down to the concept of 3D printing and the use of concrete as material for this. As an example of a 3D printer is the HINDCON project presented. A summary of the theory chapter sums up the main points.

The next chapter is about the method, explaining in detail about the research design and how the data collection happened. A short explanation of the literature used in the study is also presented.

The chapter about the empirical findings covers the responses from the 11 interviews done in the research. The responses are divided into four categories to stepwise approach the core about challenges related to 3D printing. The findings from the interviews that are representative in numbers are summarized in one subsection.

The discussion chapter is next. Here the responses from the interviews are evaluated and compared across the topics and questions in the interview guide. The findings are discussed in relation to the research questions.

The last chapter is the conclusion chapter with answers to the research questions and comments to the value of the work, limitations and recommendations for further work.

Lastly are the references used in the study. Appendices are found in the end and includes, for instance, the interview guides in both Norwegian and English.

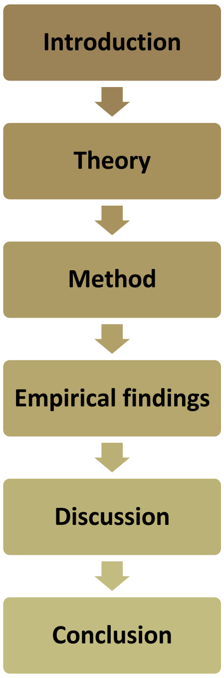

Figure 1-2: Structure of the master's thesis

2 Theory

The theory chapter covers the background information necessary to understand the discussion chapter in the report. The first part looks into where the construction industry is today regarding development and impact factors. Next is the industrialization in the industry explained. It follows up with a subsection focusing on global changes and development, alteration of the construction industry and an example of a pioneer company. The following part introduces the concept of 3D printing. The HINDCON project is used as an example of a 3D printer in this research. It continues with a description of the manufacturing technologies used for 3D printing. In the next part, experiences with 3D printing are presented. The main phenomenon in this report – 3D printing of concrete – is addressed with advantages and disadvantages related to it. Lastly is a summary chapter of the theory.

2.1 Status of the Construction Industry

The built environment influences the life quality to a vast mass of the world's population. The construction industry provides accommodation, plants, and infrastructure in nearly every corner of the world. It sets the frames for how almost everyone lives, works and plays. Figure 2-1 shows some of the largest contributors to the global construction volume. Due to the fact that the construction industry accounts for a large scope and scale, it stands for 6% of global gross domestic product (GDP) and the number is increasing (World Economic Forum & The Boston Consulting Group, 2016, 2018). The world experiences lack of valuable minerals, metals and organic materials. The construction industry is on top regarding the consumption of raw materials. The materials used and the construction itself require high quality, and in some parts also improved quality. Concerning the world's total carbon emissions, constructed objects in the industry make up 25-40%, while 30% of the greenhouse gas emissions are related to buildings (World Economic Forum & The Boston Consulting Group, 2016). At the same time, the urban areas around the world are getting more and more crowded. It is estimated that 200,000 people move there every day (World Economic Forum & The Boston Consulting Group, 2016). The need for housing along with general infrastructure is, therefore, increasing rapidly. To be able to follow up on this challenge, the construction industry needs to adapt.

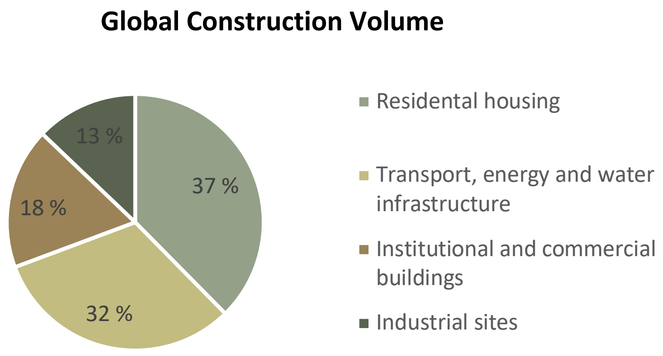

Figure 2-1: Illustration of contributors to the global construction volume

Retrieved from: (World Economic Forum & The Boston Consulting Group, 2016)

Innovation is defined as *"a new idea or method, or the use of new ideas and methods"* (Cambridge University Press, 2019). It can be classified in four types depending on how different or creative it is, as shown in Table 2-1. 3D printing technology is considered as a radical innovation for large construction projects (Shafqat, 2017). The core concept of the 3D printer is overturned together with a change in the core concept and components.

Table 2-1: Different types of innovation

Retrieved from: (Arica et al., 2017; Henderson & Clark, 1990)

Innovation type	**Product is reinforced**	**Product is overturned**	**No change in core concept and components**	**Core concepts and components are changed**
Incremental innovation	X		X	
Radical innovation		X		X
Architectural innovation	X			X
Modular innovation		X	X	

To a certain extent, innovation has occurred on company level in the construction industry. But the innovations in processes and products over the last few decades have not been adopted or adapted properly in the construction industry, compared to most other industries. For the last 50 years, the global productivity has remained flat (World Economic Forum & The Boston Consulting Group, 2016). For instance, the construction industry is often compared to the automobile industry. The automotive industry has already undergone radical and disruptive changes, while digital transformation is in progress (World Economic Forum & The Boston Consulting Group, 2016). As John M. Beck, Executive Chairman in Aecon Group Canada expressed in a report (World Economic Forum & The Boston Consulting Group, 2016):

> *"In the automobile industry, for example, robotics, computerized design and a host of other technical and work process innovations have helped to create a global industry that is now more productive and cost-effective, and increasingly environmentally friendly and sustainable."*

This can be one explanation of why the construction industry is perceived by many as conservative (World Economic Forum & The Boston Consulting Group, 2016). This industry is based on competitive procurement models, but the conservative approach to product design and delivery has led to silos in project management. It is frequently observed that construction projects experience challenges, such as (Thomsen, Darrington, Dunne, & Lichtig, 2009):

- High costs
- Long build time
- Lack of innovation
- End product with low quality
- Low productivity
- Inefficiency
- Work injuries
- Rework
- Disputes

A survey for a master's thesis about innovation and 3D printing was conducted in 2017 among 36 construction companies in Europe, with a special focus on the industry in Norway and Spain (Shafqat, 2017). The respondents in the survey could tick off as many alternatives as wanted in each question. It was discovered that areas of experienced innovation in the construction industry the recent years were distributed as presented in Table 2-2, regarding the five given alternatives.

Table 2-2: Survey results of areas with experienced innovation

Retrieved and reformatted from: (Shafqat, 2017)

Alternative	**Respondents**	**Percentage**
IT (including BIM and communication)	26	72.2%
Construction materials	21	58.3%
Production processes	17	47.2%
Design	17	47.2%
Other	0	0%

The same survey also asked the participants what the barriers to innovation in the construction industry are in their opinion (Shafqat, 2017). The results are presented in Figure 1-1. Three barriers stand out from the others. That is conservatism in the construction industry, the risk associated with adopting new technology, and multiple stakeholders lack in cooperation to implement innovation.

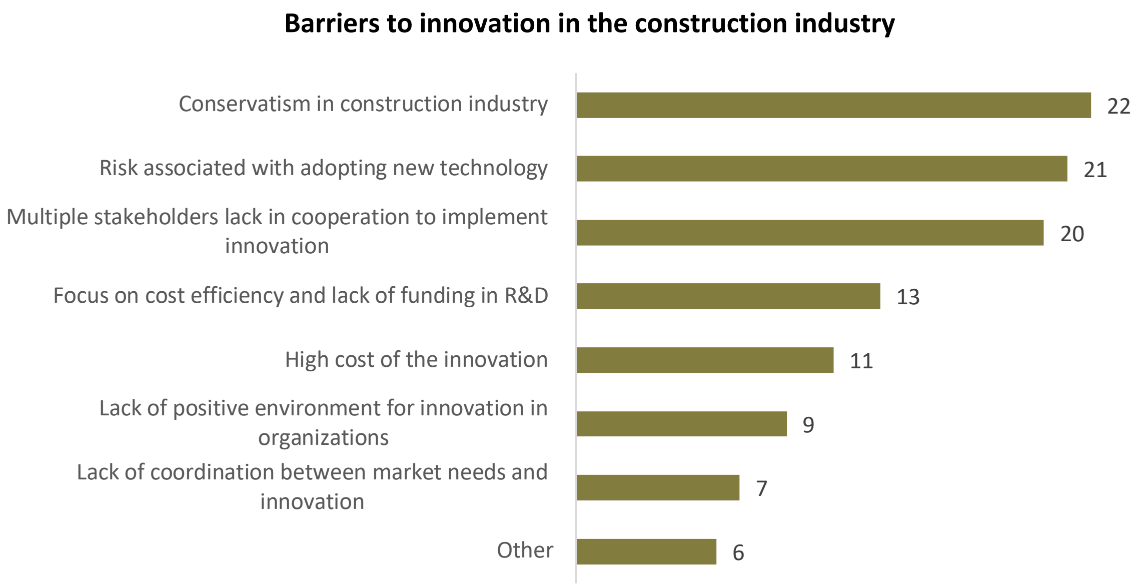

Figure 2-2: Survey results for barriers of innovation among 36 companies

Retrieved and reformatted from: (Shafqat, 2017)

Further, others have recognized challenges in the industry. Challenges were the fragmentation of the construction industry, cooperation with suppliers and contractors, recruiting a talented workforce, and knowledge transfer between projects (World Economic Forum & The Boston Consulting Group, 2016). Companies in many industries, which late has adopted new technology, have experienced loss of market share or completely disappeared from the market. An example of this is the camera and photography company Kodak (World Economic Forum & The Boston Consulting Group, 2018). The construction industry represents one step out of several in the value chain. There is a large number of stakeholders involved. The industry as a whole need to drive transformation, and the government needs to encourage this. The government's ability to influence the rest of the industry is high since it has the role as both regulator and client. Because it is a highly fragmented and horizontal industry, the challenges need to be collectively tackled. Whether this comprises new or improved forms for collaboration, the industry as a whole has a responsibility to help (World Economic Forum & The Boston Consulting Group, 2016).

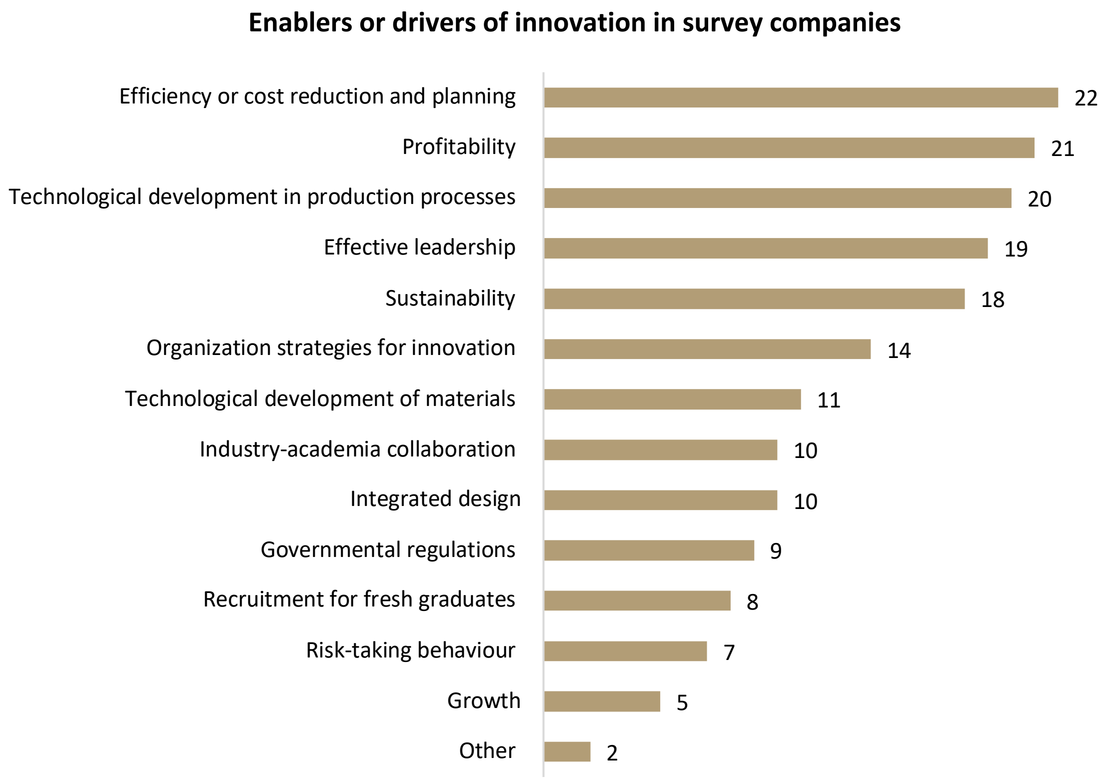

Figure 2-3: Survey results for enablers or drivers of innovation among 36 companies

Retrieved and reformatted from: (Shafqat, 2017)

The previous study about innovation and 3D printing also present drivers or enablers of innovation in the participants' companies (Shafqat, 2017). Figure 2-3 gives an overview of the result. The result shows a gradual distribution of votes for which alternatives are considered as enablers in each company. The three enablers with most votes are efficiency or cost reduction and planning, profitability and technological development in production processes.

2.2 Industrialization in Construction

Industrialization of the construction process is a sort of innovation because it incorporates technological development in the building process but also in the products used or built (SINTEF, 2018). This can be recognized by the manufacturing characteristics such as efficiency and control. A higher degree of prefabrication and off-site production, that is when the production takes place at another location than the construction site, are the construction industry's way of industrializing and a step towards being innovative. Figure 2-4 depicts a framework for classifying construction production systems in the dimensions of off-site production against product standardization and volumes (Jonsson & Rudberg, 2014). Four categories of construction are traditionally presented when the industrialization of the construction process is discussed (Gibb, 2001):

1. Traditional construction
    - "one-of-a-kind" project
    - All value-adding actions on-site
    - Mass-produced and standardized components
2. Non-volumetric pre-assembly
    - Prefabricated elements are specialized
    - Assembled on-site
3. With volumetric pre-assembly
    - Prefabrication of specific parts
    - Assembled on-site within an independent frame
4. Modular building
    - Prefabrication
    - Assembly and finishing on-site

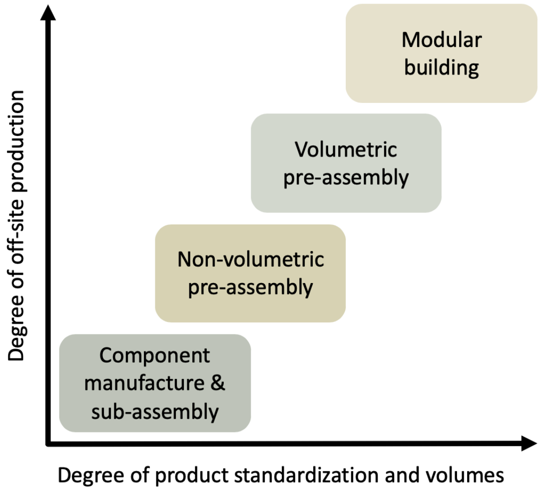

Figure 2-4: Framework for classifying construction production systems

Retrieved and reformatted from: (Jonsson & Rudberg, 2014)

By introducing 3D printing, this traditional view can change. When activities before were moved away from the construction site, they are now moving back on site. With 3D printing on site, the value-adding activities will mainly happen on-site while the production of complex elements is moved off-site. 3D printing can also be done off-site, but this method will be similar to how precast concrete works (Arica et al., 2017; SINTEF, 2018). Digital technologies facilitate or enhance many innovations, for example, prefabrication, automation, and 3D printing. It is also helpful for project management in general (World Economic Forum & The Boston Consulting Group, 2016).

Table 2-3: Definition of automation, machine and robot

Noun	**Definition**
Automation	*"the use of machines that operate automatically"*
Machine	*"a device with moving parts that uses power to do work of a particular type"*
Robot	*"a mechanical device that works automatically or by computer control"*

The difference between automation, machines, and robots can be confusing. Table 2-3 clarifies the definitions according to the online English Cambridge Dictionary (Cambridge University Press, 2019).

As the automotive industry already has entered a new era regarding industrial technology, the construction industry still sticks to man-driven machinery and mechanical equipment. Excavators, bulldozers, drilling rigs, piledrivers, cranes, conveyors, and pumps play a central role on construction sites nowadays. There is generally a low level of automation on the traditional construction sites (Arica et al., 2017; World Economic Forum & The Boston Consulting Group, 2016). The application of automation in the construction industry is limited to the site itself. There are more possibilities in off-site production where the environment is more sterile than on-site and allows dedicated production lines (Arica et al., 2017; SINTEF, 2018). However, three groups of automation are found applicable at the construction site are robotics, autonomous vehicles and monitoring/surveillance (Arica et al., 2017).

The use of robots in the construction industry is still not widely spread out. Robots have mainly been limited to repetitive or dangerous tasks. Examples of modern automated equipment are welding robots and bulldozers, which not represent any spectacular technology (SINTEF, 2018). Nevertheless, robotics become more and more normal as technology evolves and become more advanced. Other digital inventions like drones, low-cost sensors, remote operations, and autonomous control systems could be developed to fit usage on the construction site. These technologies can give extensive possibilities for innovation in the industry. Equipment classified in the semi-autonomous category can do complex tasks but is still controlled by someone. Fully autonomous equipment is more self-driven and requires only someone for monitoring. Of the type previously mentioned, new technology and digital tools can be out-of-sight drones. Advantages of all these equipment are higher quality because of fewer workmanship errors and more accuracy in the work, improved safety as a result of keeping workers out of danger zones, and clearly reduce construction costs because the delivery-time becomes shorter and productivity increases (World Economic Forum & The Boston Consulting Group, 2016).

An important precondition for using (semi-)autonomous equipment on the construction site is upfront planning. The construction site needs to be prepared for this technology to be able to benefit from it. The consideration of using automation must be taken in the design and project planning phase. A facilitator for automation is prefabrication. Automation is easier to implement by the standardized processes and components, which naturally follows from prefabrication and making of modular systems (World Economic Forum & The Boston Consulting Group, 2016). Automation, in addition to mechanization and robots, is likely to be realized in combination with prefabrication in the beginning (Arica et al., 2017).

Figure 2-5 explains the difference between standardization, modularization, and prefabrication, with respect to their benefits. Prefabrication is not a synonym for industrialization, but rather an alternative word for off-site production (Arica et al., 2017). Prefabrication is common in residential projects in Scandinavia, as well as in the construction of prisons, transportation infrastructure (bridges and elevated highways) and offshore oil and gas facilities. Prefabrication can be distinguished depending on the degree of prefabrication, physical dimensions, and integration and complexity of mechanical, electrical and plumbing systems (World Economic Forum & The Boston Consulting Group, 2016).

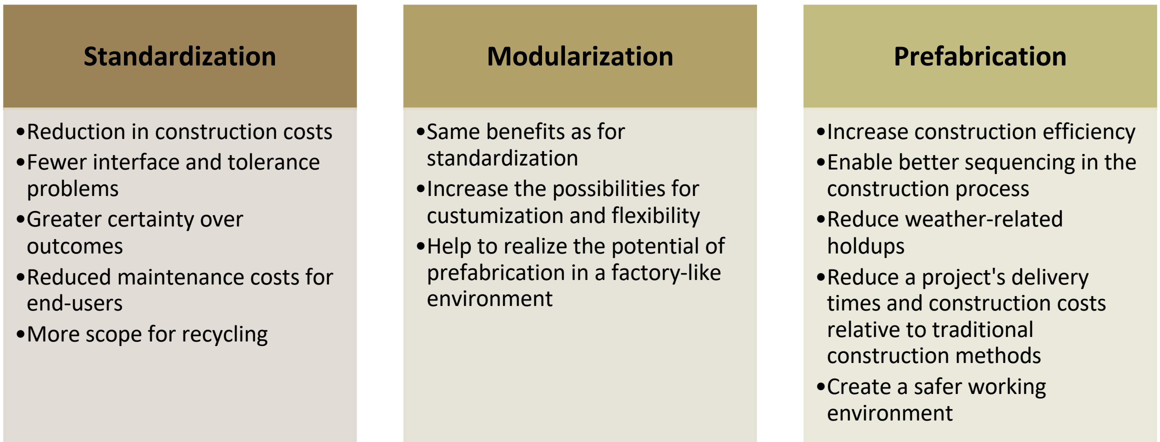

Figure 2-5: Benefits of standardization, modularization and prefabrication

Retrieved from: (World Economic Forum & The Boston Consulting Group, 2016)

Prefabrication is occasionally misunderstood in the case of quality, price and individualization potential. The concept experiences for that reason some challenges for acceptance (World Economic Forum & The Boston Consulting Group, 2016). Among others, one reason not to choose prefabrication is that the client wants an individual solution. Another one is that the project owner has technical specifications not able to be fulfilled, which therefore conflicts the concept itself with standardized processes and components. Also, by committing to an off-site supplier alone for delivering the components, the risk increases due to a little developed marked with few instantly available alternatives (World Economic Forum & The Boston Consulting Group, 2016). The demand to produce in the factories can be very variable because of the irregular nature of construction. The factory's space can from time to time be underused as a consequence of the customized orders. In cases where the prefabrication factory is far away from the construction site, the transportation costs can be high, the transportation links inadequate or challenges with oversized components can occur (World Economic Forum & The Boston Consulting Group, 2016). Hybrid approaches to prefabrication can be to build a temporary field factory within easy reach from the construction site. The field factory could produce concrete wall panels, floors, and beams (Arica et al., 2017). Large components are also difficult to handle on construction sites, which usually already are constrained by space. There are also limited experience by using prefabricated elements in high-rise projects (World Economic Forum & The Boston Consulting Group, 2016). Another limitation of precast concrete is the cost for non-standardized components. Some of the advantages of precast concrete are listed below (Arica et al., 2017):

- Rapid construction
- Reduced number of required workers on site
- Standardization of products
- Large production volumes
- Mass-production of complex shapes
- High quality and low tolerances

2.3 Global Changes & Development

The Fourth Industrial Revolution (or Industry 4.0) is realistic to happen promptly and gives the construction industry a wake-up call that it is time to change (Buehler et al., 2018). It is yet not clear exactly how it will unfold, but the reaction should be comprehensive and integrated by everyone in society (Schwab, 2015). Figure 2-6 illustrates how industrial revolutions have evolved over time. The forth industrial revolution builds upon the digitalization in the third one but includes a synthesis of technologies that makes the distinctions between the physical, digital and biological aspects more unclear (Schwab, 2015). Even entire systems of production, management, and governance are about to transform. The exponential evolving of the revolution is disrupting for almost every industry worldwide. Currently, emerging technologies are for example materials science, quantum computing, artificial intelligence (AI), Internet of Things (IoT), autonomous vehicles, robotics, 3D printing, and the list can continue (Schwab, 2015). These technologies can contribute to keeping the value-adding activities when building on the construction site, as industrialization in construction traditionally has moved towards off-site production and prefabrication (Arica et al., 2017). The technological transformation will affect economies, businesses, societies, and politics (World Economic Forum, 2019).

Because of the technology advancement in Industry 4.0, combined with transformations in the global and economic context, a new phase of globalization is also in progress (World Economic Forum, 2019). One definition of globalization is *"a phenomenon driven by technology and the movement of ideas, people and goods"* (Schwab, 2018). Globalization

4.0 commences now. It centres around digital and virtual systems, which unfold idea flows and services. Cost-effectiveness might not be the main focus in the future, but rather the ability to innovate will define the competition. Robots and artificial intelligence are increasingly replacing humans. The employment today gives the impression of being changed towards either highly skilled and highly paid or low skilled and low paid. The forth industrial revolution will enlarge the gap between winners and losers in society, where the middle class will be diluted (Schwab, 2019).

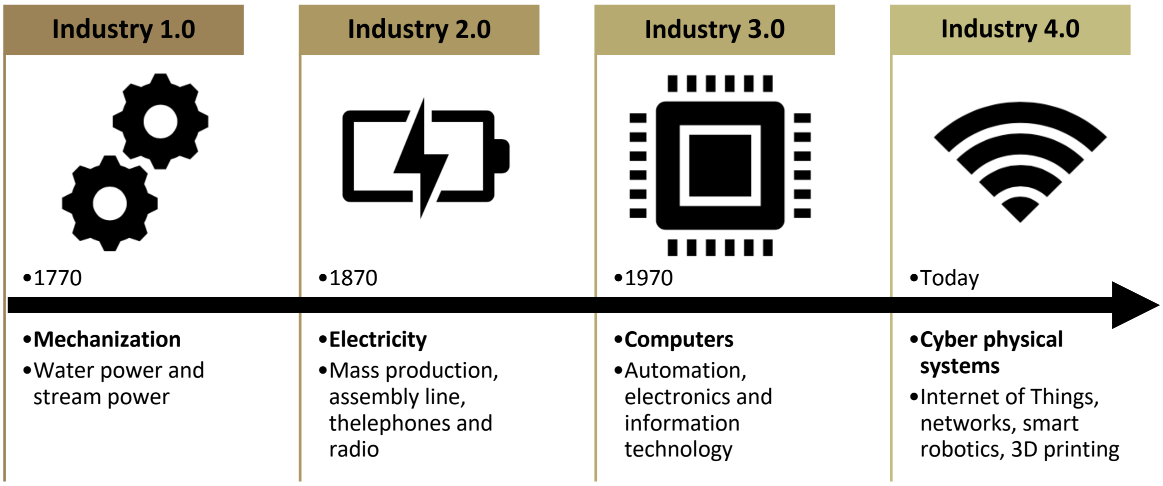

Figure 2-6: How the industrial revolutions evolved

Retrieved from: (Dyson, 2018; Schwab, 2015)

The HINDCON 3D printer is yet not market-ready. Until then, the industry has time to prepare how to welcome new technologies like this. If for example, 3D printing is going to be used in a project, it needs to be planned for from the beginning. The cost of changes is increasing through the construction phases (Samset, 2010). Innovative products often fail to penetrate the market. For instance, ABMs that have great potential and are ready for the market, fail to achieve acceptance. The initial cost for innovative products is often high, while the benefits come later. Sometimes the benefits do not pay off until over the entire life cycle. It is also riskier for project owners and decision makers to choose products without any previous records of success. The same persons may not be updated on the latest inventions. It is therefore recommended that relevant competencies are collected in each case used to put together evidence of benefits, challenges, and applicability. To involve the decision makers at the project level, the collected knowledge and information should be transferred to project teams locally. All new and relevant information is important to optimize the decisions going to be made. Risk-eager customers can in some cases favour the use of innovative and untraditional products because it makes them stick out from the rest and consequently makes a potential for greater profit (World Economic Forum & The Boston Consulting Group, 2016).

2.3.1 Alteration of the Construction Industry

The construction industry, overlapping with the infrastructure and urban development (IU) industry, face the technological changes evolving from Industry 4.0. As stated in the literature (World Economic Forum & The Boston Consulting Group, 2018):

> *"All types of IU companies must prepare for the disruption created by widespread use of 3D printing and other new technologies and business models. With the pace of change accelerating, they must act now to identify the right strategic moves to maintain their current business and develop new business models that anticipate coming disruptions. All IU industry members – from building material providers, designers and engineers, to construction companies, operators and service and maintenance companies – need this type of strategic planning."*

Areas like real estate, infrastructure, and other built assets start to change the way of designing, constructing, operating and maintaining (Buehler et al., 2018). Global trends in the four domains of markets & customers, sustainability & resilience, society & workforce, and politics & regulation are affecting the construction industry. Changing trends in these domains will cause opportunities and challenges for the construction industry (World Economic Forum & The Boston Consulting Group, 2016). Figure 2-7 shows which trends exist, categorized in the already mentioned domains. As seen in the figure, resource scarcity & sustainability requirements, urbanization & house crisis, talent shortage, and aging workforce are all considered as important with medium to high impact in the construction industry.

The new technological era has already started in industries like entertainment, shopping, and transport (Buehler et al., 2018). Innovation will improve productivity and sustainability, which is much needed in today's construction industry. The best is to prepare and shape for what is about to happen. Existing capabilities, business models and strategies are not sufficient for success (Buehler et al., 2018). A worldwide industry like construction needs to comply with the rest of the world and support economic growth, social progress and take environmental responsibility. If the government leaders do not consider the situation seriously, the changes will still take place and naturally form rules that will limit the ability to shape a positive outcome of the revolution (Schwab, 2019). Technologies such as prefabrication, BIM, automated and robotic equipment, wireless sensors and 3D printing have an impact on the entire construction industry (Buehler et al., 2018). Rewards can wait for those that dare to try, but they need to take the risk and not be too hesitant. The construction industry is slow to adapt to new technology. Combined with poor productivity it creates a challenge when it comes to urbanization. The construction industry still operates as it did 50 years ago. It relies heavily on manual labour, mechanical technology and established business and operating models. The productivity has stagnated and there is potential for innovation (Buehler et al., 2018; World Economic Forum & The Boston Consulting Group, 2018). Underperformance in the construction industry regarding product quality and productivity has impact on the whole society (Arica et al., 2017).

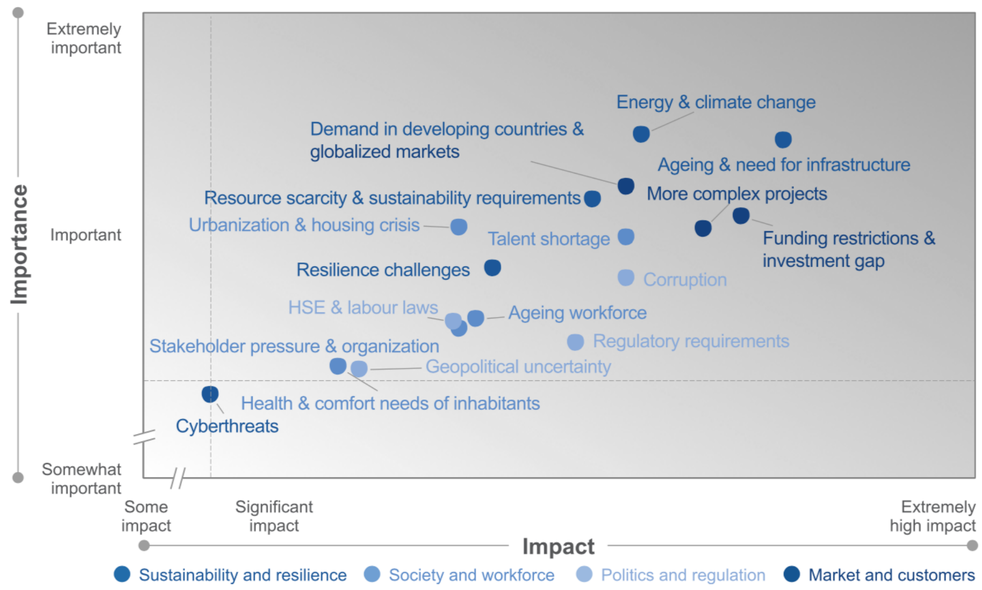

Figure 2-7: Impact-likelihood matrix of global trends in the construction industry

Source: Future of Construction Survey (World Economic Forum & The Boston Consulting Group, 2016)

Innovative technologies, digitalization, and new construction techniques make it possible for the construction industry to be more effective and efficient (World Economic Forum & The Boston Consulting Group, 2016). Today we are surrounded by technologies like BIM, autonomous equipment, advanced building materials (ABMs), drones, AR, 3D scanning, and 3D printing. Figure 2-8 shows how different technologies are likely to impact the construction industry. As examples, integrated BIM and prefabricated building components are placed on the upper right side of the figure, implying it is (extremely) likely to happen and has (extremely) high impact on the construction industry. In comparison, 3D printing of components is placed lower to the left part meaning the likelihood and impact is lower. To fully embrace the potential for new technologies, commitment from the whole industry is required. Nevertheless, the companies adopting and exploring these alternatives have the opportunity to enhance productivity, quality, safety, in addition, to streamline the project management and procedures (World Economic Forum & The Boston Consulting Group, 2016). Companies in the construction industry should rethink industry practices that have not advanced and be motivated by global megatrends. Examples of these megatrends are rapid urbanization, climate change, resource depletion and a widening talent gap (Buehler et al., 2018).

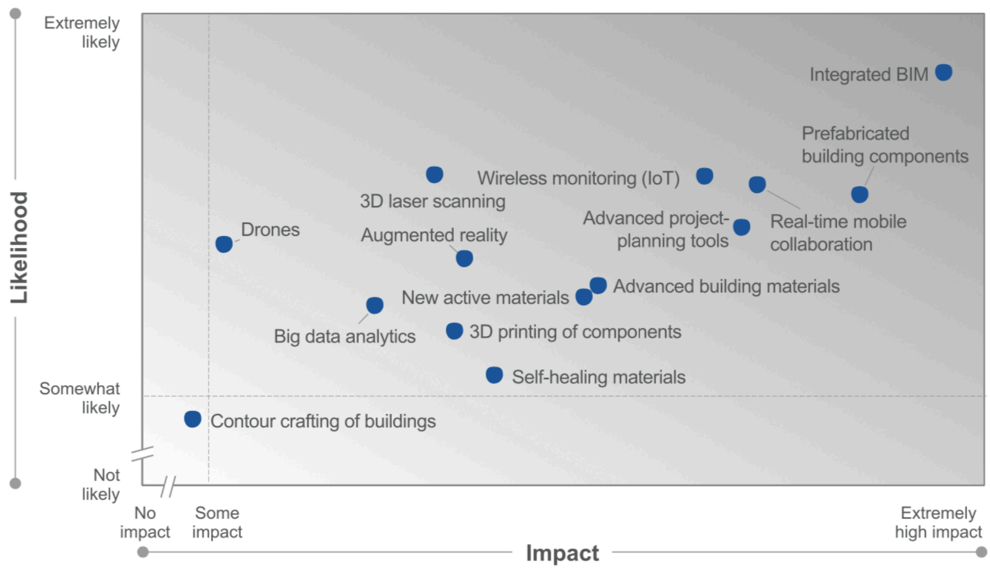

Figure 2-8: Impact-likelihood matrix of new technologies in the construction industry

Source: Future of Construction Survey (World Economic Forum & The Boston Consulting Group, 2016)

The world's population continues to get a larger share of older people, which will affect the construction industry. This can be seen as a reduction in available labour. The industry will also require more highly skilled workers in the future as technology advance. At the same time, technology will be more autonomous and self-driven and demand less human labour or low-skilled workers. The industry is however not traditionally known as glamourous, whence there might become recruitment challenges. It is crucial for the industry, as well for all the other industries, to embrace the digital talents (World Economic Forum & The Boston Consulting Group, 2016). This is about to change when digital technologies begin to enter the industry. At the 2018 World Economic Forum in Davos, the following three key actions were seen as priorities for the future by the CEOs of construction industry companies. The percentage represent how many CEOs agreed about the particular action (Buehler et al., 2018; World Economic Forum & The Boston Consulting Group, 2018).

1. Attracting new talent and improving the skills of the existing workforce (74%)
2. Improving integration and collaboration along the value chain (65%)
3. Adopting advanced technologies at scale (61%)

These actions were pinpointed as non-regret moves for actors in the construction industry to take now to remain relevant in the future (Buehler et al., 2018; World Economic Forum & The Boston Consulting Group, 2018). Regardless which direction the construction industry goes, the non-regret moves provide a positive impact when implemented (World Economic Forum & The Boston Consulting Group, 2018). Because the construction industry is based on projects, the number of stakeholders is large. All parts of the value chain need to be informed and convinced of the advantages new innovative products can give (World Economic Forum & The Boston Consulting Group, 2016). Architects, engineers, clients, contractors, subcontractors, and suppliers need to cooperate in this area. This is important strategically as well as on a project basis. Not to forget the governmental role that facilitates politics and procurement processes for innovation, for instance, industry-wide standards and certifications. Risk sharing between everyone in the industry is important (World Economic Forum & The Boston Consulting Group, 2016).

2.3.2 Pioneer Example: Skanska

Skanska is an example of a leading project developer and construction group. The company works in Europe and North America. In Norway, Skanska works as a project developer, contractor and within business fields as buildings, real estate development and specialist companies (Skanska, 2019). They want to be a pioneer for development in the construction industry. By focusing on innovation, digitalization, and new technology, they believe this can improve the quality, productivity and further innovation. This is beneficial to themselves and others in the industry (Mortensen, 2017). Skanska has spent a significant amount of resources on research and development (R&D) the past years. The close collaboration with acknowledged universities and research institutions has led to environmentally friendly constructions, alternative construction techniques and use of new materials (Stene, 2017). Nowadays, Skanska tries to cooperate closely with customers and partners with innovation in more open processes, which has revealed in a notably increased innovation speed. As a director in Skanska states, to succeed with innovation it is crucial with openness and the right attitude, as it defines how we think. It must be possible to think controversial and break out from the old and traditional mindset of the construction industry. The development of innovative solutions should be done early in the project phase, as the cost for change is low. A key factor is a collaboration with all stakeholders during the process (Stene, 2017).

Following are seven examples of what Skanska does worldwide to continue the development and innovation. All examples are taken from the report *Shaping the Future of Construction* (World Economic Forum & The Boston Consulting Group, 2016), except example 1.

1. BIM kiosks: a PC built into a stationary kiosk, strategically placed on the construction site. This idea emerged from the SamBIM project led by Skanska (Bråthen, Flyen, Moland, Moum, & Skinnarland, 2016).
2. The Skanska 3D Concrete Printing project: manufacturing of complex shaped objects in concrete by use of a 3D printer, which is impossible to make with traditional casting methods.
3. Flying Factories: this is a new construction concept where temporary factories are set up close to the construction site where lean manufacturing techniques are applied and with local semi-skilled labour. This has resulted in reduced labour costs, as well as construction time and improvement regarding productivity as compared to on-site assembly.
4. Tag & Track system: by using tags and barcodes with radio frequency identification (RFID) on products and components, the process of delivery, storage and installation can be monitored in real-time. This can reduce construction costs.
5. Wireless monitoring of buildings: sensors are recording data, for instance, vibration and temperature, while wireless equipment is used to store and transmit it. The incoming data is analysed by data analytics. This can improve the management's productivity and the buildings energy performance because the number of inspections and unexpected failures are reduced.
6. BIM & VDC: a network of professionals, experts and other staff use building information modelling (BIM) and virtual design and construction (VDC) in areas of project planning, execution and delivery. These methods base on new technologies and innovation processes.
7. Cloud-based training system: each employee's capability development in the organization is trackable in a system. This is useful for supervisors who can monitor progress and align specialized plans.
8. Improvement and innovation initiatives: a variety of initiatives have been implemented to engage employees, such as a mobile app where ideas can be submitted, a week dedicated for dialogue on safety issues, and a consultation forum for front-line workers.

2.4 3D Printing

Because the HINDCON printer utilizes the two technologies additive and subtractive manufacturing, it becomes unique compared to other 3D printers. If additive and subtractive manufacturing are combined, it becomes hybrid layered manufacturing (HLM) (Karunakaran, Suryakumar, Pushpa, & Akula, 2010). This hybrid 3D printing method can potentially produce objects of higher quality because the combined manufacturing methods will offer more options than one manufacturing method does alone. Only the relevant manufacturing techniques for the HINDCON printer are covered in this research. Thus, additive and subtractive manufacturing are described respectively more in detail in the following two subsections after the presentation of the HINDCON project.

2.4.1 The HINDCON Project

HINDCON stands for Hybrid Industrial Construction. The project was funded by the European Commission under the Horizon 2020 Framework Programme (HINDCON, 2016b). HINDCON was under the EU program called *"Technologies for Factories of the Future"*. It studied how 3D printing of concrete can be used in the construction industry. The project duration was from 2016 to 2019 and aimed to develop and demonstrate a hybrid 3D printing machine, using concrete as material (SINTEF, 2017). The HINDCON project was a consortium involving 12 companies. Figure 2-9 shows the members of the consortium. The companies were leading in their respective fields, that were (HINDCON, 2016b):

- Additive and subtractive manufacturing tools
- Robotic technologies
- Construction processes and materials
- Architectural design
- Infrastructure engineering
- Life cycle analysis

This collaborative project, with participants from around Europe, wanted to demonstrate the technology from different perspectives and underpin this by covering different aspects such as technology, economic, social and environmental. Figure 2-10 illustrates the focus areas of the project. The developed prototype's capabilities were tested in the laboratory, but also in a more relevant environment. Concerns in the construction industry particularly regarding the innovative technology, industrialization, and reduction of environmental impact and economic costs were explored (SINTEF, 2017).

Figure 2-9: Members of the HINDCON consortium

Taken from: (HINDCON, 2016b)

Among the many participants was SINTEF. Their focus in the project was to research how the construction process will be affected by the new 3D printing construction method. This was seen in the light of lean manufacturing and how the construction workers were affected by a new process (SINTEF, 2017). SINTEF helped on WP9, which this research also got inspiration from.

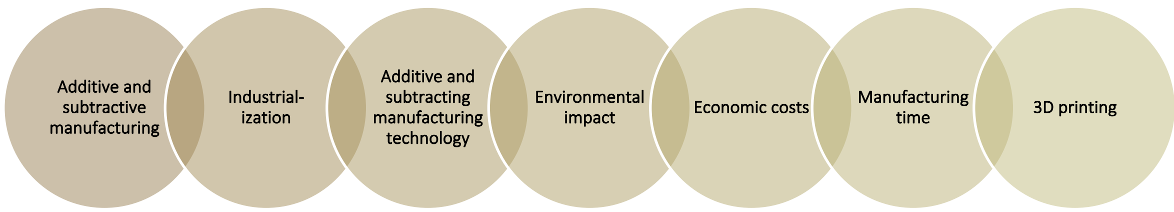

Figure 2-10: The aim of the HINDCON project

Adapted from: (HINDCON, 2016b)

A variety of materials, processes, and designs can be used when 3D printing. The hybrid 3D printing machine from HINDCON will, for instance, use a cable-suspended solution with the viscous-like material concrete. Figure 2-11 shows an illustration of how the printer was supposed to look, while Figure 2-12 shows an actual photo of the printer frame. Cable-suspended platforms have an external frame with cables connected to an end-effector with a printing nozzle. This extrusion-based process requires curing time for the material after extrusion. Multiple cables can be extended or shortened to move the end-effector around automatically by motors. The large platform provides workspace but is only intended to make one-piece constructions. This solution is affordable, easy to deconstruct and set up (Arica et al., 2017; Labonnote, Rønnquist, Manum, & Rüther, 2016).

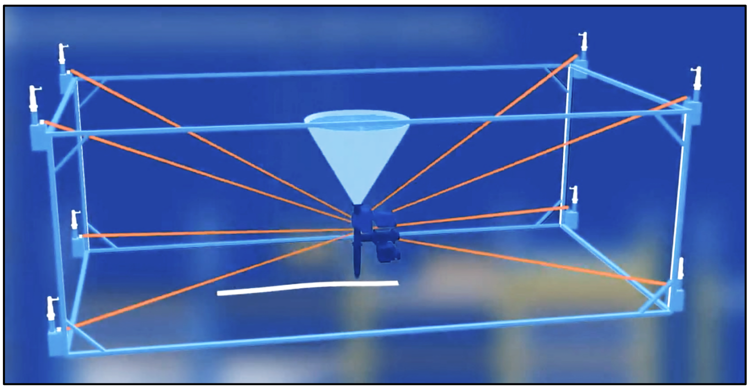

Figure 2-11: Illustration of the hybrid 3D printer from HINDCON

Retrieved from: (HINDCON, 2016b)

Figure 2-12: Actual photo of the HINDCON cable robot

Retrieved from: (HINDCON, 2019)

2.4.2 Additive Manufacturing

One technology that currently is spreading is three-dimensional printing (3D printing or 3DP). 3D printing is also known as additive manufacturing (AM) technology. The technology covers the fabrication of components based on a computer-aided design (CAD) model where various materials can be used. Other common names of the method are rapid prototyping (RP) or layered manufacturing (LM). 3D printing is the process to make an object out of a 3D CAD model by slicing the model into several 2D layers whereby each layer is realized at a time (Karunakaran et al., 2010). An illustration of how the 3D CAD model is sliced in layers and then printed is showed in Figure 2-13.

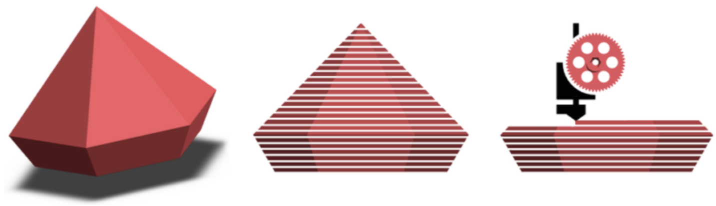

Figure 2-13: Slicing of 3D CAD models

Source: (Shropshire 3D Print, 2014)

3D printing can be used to produce objects of complex geometries and the material waste is low (Bikas, Stavropoulos, & Chryssolouris, 2016). Figure 2-14 demonstrates the amount of waste generated when 3D printing. The design of objects can have the same specifications as parts made with traditional technologies, but with less material because of the elimination of tools in 3D printing. Because of the wide range of applicable materials and customization possibilities, this process opens up for use in many industries. The possibility to produce on demand makes the 3D printing able to respond rapidly on the market (Calignano et al., 2017). However although there are several advantages, the World Economic Forum states 3D printing as follows (World Economic Forum & The Boston Consulting Group, 2016):

> *"The development of 3D printing is expected to have a disruptive impact on the construction industry."*

The technology for large-scale printing is still in an early stage of development for use in the construction industry. Several limitations and issues exist, for instance: high costs; resolution problems, meaning poor surface quality with rough and chunky outputs, resulting in reduced dimensional accuracy; and long production time because printing speed compromise with scale (Paris & Mandil, 2017; World Economic Forum & The Boston Consulting Group, 2016).

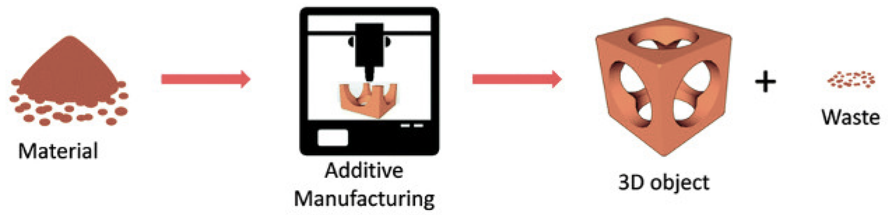

Figure 2-14: The additive manufacturing process

Source: (3Dnatives, 2018)

Due to these drawbacks, 3D printing is yet not widespread in the industry. It is currently mostly used for special parts of high value and low-volume (World Economic Forum & The Boston Consulting Group, 2016). It is yet to overcome the technological challenges to bring down costs and achieve economies of scale. An example to strive for is the common mass production of components as found in the aviation industry. Some examples of pilot projects are found in the construction industry too, where concrete and steel elements have been 3D printed for use in bridges and houses (World Economic Forum & The Boston Consulting Group, 2016). Investigation on and development of 3D printing exist all around the world. Appendix C gives an overview of experiences with additive manufacturing in Europe, Asia, Oceania and America (Arica et al., 2017). This overview indicates that most interest in 3D printing today exist in France, Spain, and the Netherlands.

2.4.3 Subtractive Manufacturing

Subtractive manufacturing (SM) is a process where objects are shaped by cutting material off a solid block of material. The material is removed by subtractive techniques to shape the final part as intended. The subtractive manufacturing process is made clear in Figure 2-15. Different types of material can be used, the accuracy level of products is high and offers the surface finish as demanded. This is especially advantageous for creating components with for example living hinges. Such features are not possible with 3D printing processes yet. The machine for SM processes uses a method called computer numerical control (CNC), that is CNC machining (Karunakaran et al., 2010). The accuracy and repeatability of a subtracting process are not as high in robots as in CNC machines. It is depending on the robot's configuration and its placement of the end effector (Doukas, Pandremenos, Stavropoulos, Foteinopoulos, & Chryssolouris, 2012). Many removal mechanisms exist for 3D printing. Because the error tolerances for concrete building elements are on the millimetre scale, it is important to optimize the quality of the objects produced.

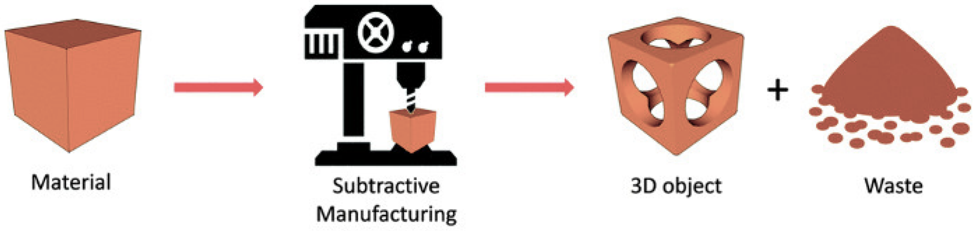

Figure 2-15: The subtractive manufacturing process

Source: (3Dnatives, 2018)

2.4.4 Experiences with 3D Printing in Construction

A previous study has discovered barriers and enablers for the use of 3D printing in the construction industry (Arica et al., 2017). Figure 2-16 summarizes the findings of enablers and barriers. As stated in the figure, one barrier statement is the uncertainty of mass customization demand. If the demand for customized elements increases, it will consequently increase the demand for 3D printing. Accordingly, the cost of printing will decrease. This will again contribute to the survival of the 3D printing technology. The barrier is therefore whether it is, or will be, a demand for mass customization in the construction industry (Arica et al., 2017).

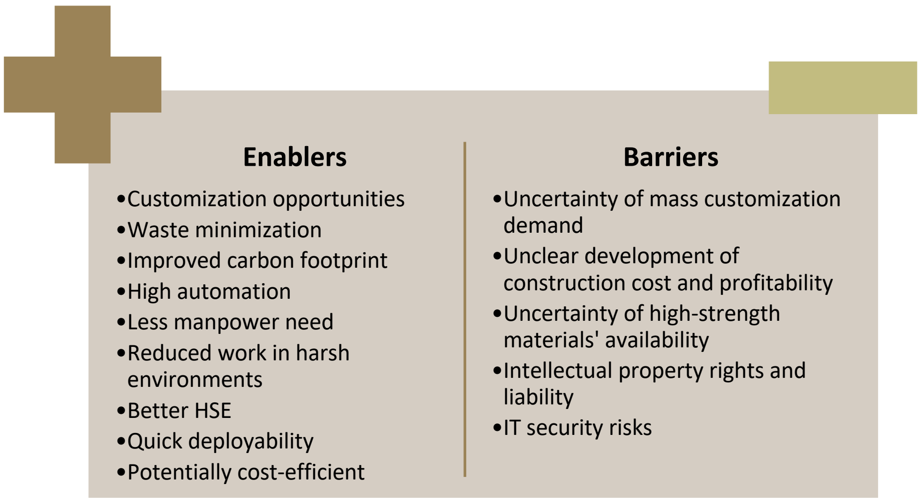

Figure 2-16: Enablers and barriers for use of 3D printing in construction

Retrieved from: (Arica et al., 2017)

Another challenge for 3D printing is whether small and medium enterprises (SMEs), which dominates the industry, will cope with the high costs related to 3D printing technology. Especially the initial cost for a 3D printer can be high. Labour, material, and plant are the cost items that require most in the construction industry. 3D printing technology can potentially reduce some costs items, but also increase others. Further studies are necessary to prove the financial performance of 3D printed projects and elements over the whole life cycle (Arica et al., 2017). The availability of high-strength materials is also a critical factor for 3D printing to be successful in construction. The material needs to be optimal for both printing and structural stability. If 3D printing technology should be used in large-scale buildings, high structural integrity is crucial for success. The low availability to such a material might hinder the use of 3D printing technology. It is also important to note the lack of regulation and standardization control over 3D printed elements, concerning both individual products and whole constructions (Arica et al., 2017). It is of substantial matter to solve regulation issues in case of fatalities due to construction failures. Contingent on a solution for this, 3D printing technology can compete with traditional construction methods (Arica et al., 2017; Gardiner, 2011). A related issue is who the responsible is if a tragedy happens. Speculations surround the manufacturer of the 3D printed element, the programmer of the machine, the responsible for the new design or material choice, or someone else (Arica et al., 2017; Campbell, Tibbits, & Garrett, 2014).

Table 2-4: Survey result of involvement in 3D printing technology

Retrieved and reformatted from: (Shafqat, 2017)

Alternative	**Participants**	**Percentage**
Not implementing	27	75%
Experimenting/pilot projects	4	11%
Prototyping only	3	8%
Prototyping and production only	3	8%
Building products that cannot be made from traditional methods	3	8%
Other	3	8%
Production of final products/components only	1	3%

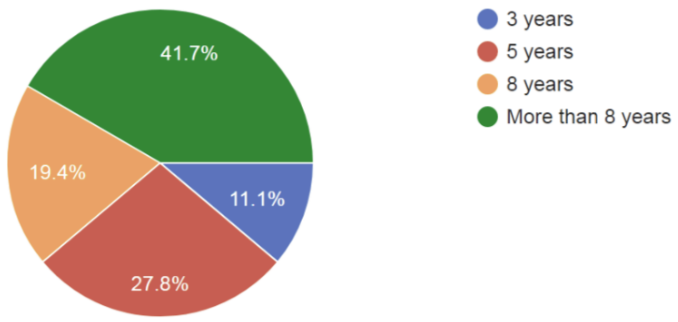

Figure 2-17: Survey result for expected time for use of 3D printing technology

Retrieved from: (Shafqat, 2017)

As previously referred to, the master's thesis about innovation and 3D printing in the construction industry investigated similar topics as this research. Some of the most interesting findings from the previous research are presented here. The survey investigated whether the 36 participants' companies were involved in 3D printing technology (Shafqat, 2017). The result was as presented in Table 2-4. The table clearly indicates that 75% of the companies in the survey are not implementing any form for 3D printing. It was also asked in the survey in how many years they expected 3D printing technology to be used widely in construction projects. Figure 2-17 depicts the result from the 36 participants in a sector diagram.

The participants were also asked about costs. First, it was asked how the participants expect the initial investment cost of 3D printing technology. Only 35 responded to this question. The majority expect it to involve high initial investment cost. Figure 2-18 illustrates expectations.

The subsequent question considered whether 3D printing technology in construction projects will be cost-efficient. Also, here only 35 participants responded. Over half of the participants were unsure and voted *"maybe"* and many were positive and voted *"yes".* 8% of the participants thought the use of 3D printing technology in construction projects not will be cost-efficient. Figure 2-19 represent the given responses.

The participants were also asked what they expect to be the primary area for the application of 3D printing products in their company in the near future (5-10 years). The result is presented in Table 2-5.

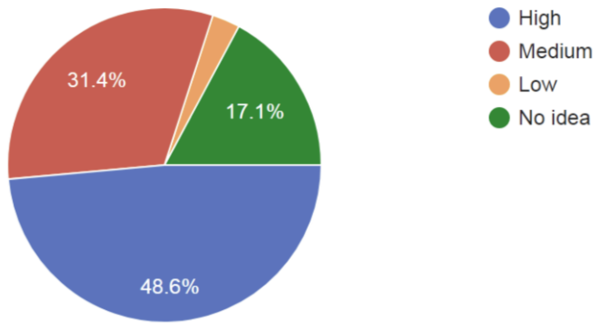

Figure 2-18: Survey result of expected initial investment cost for 3D printing technology

Retrieved from: (Shafqat, 2017)

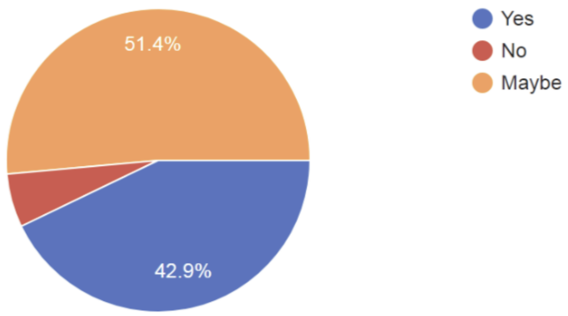

Figure 2-19: Survey result of cost efficiency of 3D printing technology

Retrieved from: (Shafqat, 2017)

75% of the companies thought complex parts would be the primary area for 3D printing in their company, closely followed by building blocks (69%) and thereafter small parts (58%). Figure 2-20 present how 3D printing technology successfully can be implemented in the construction industry. The 34 responses from the companies indicate that collaboration between suppliers and contractors are the most important factor for successful implementation, followed by research and development funding for 3D printing.

Table 2-5: Survey result for expected primary application area for 3D printing products

Retrieved and reformatted from: (Shafqat, 2017)

Alternative	**Participants**	**Percentage**
Complex parts	27	75%
Building blocks	25	69%
Small parts	21	58%
Sculptures/ornamentation and decorations	11	31%
Whole buildings	4	11%
None	1	3%
Other	0	0%

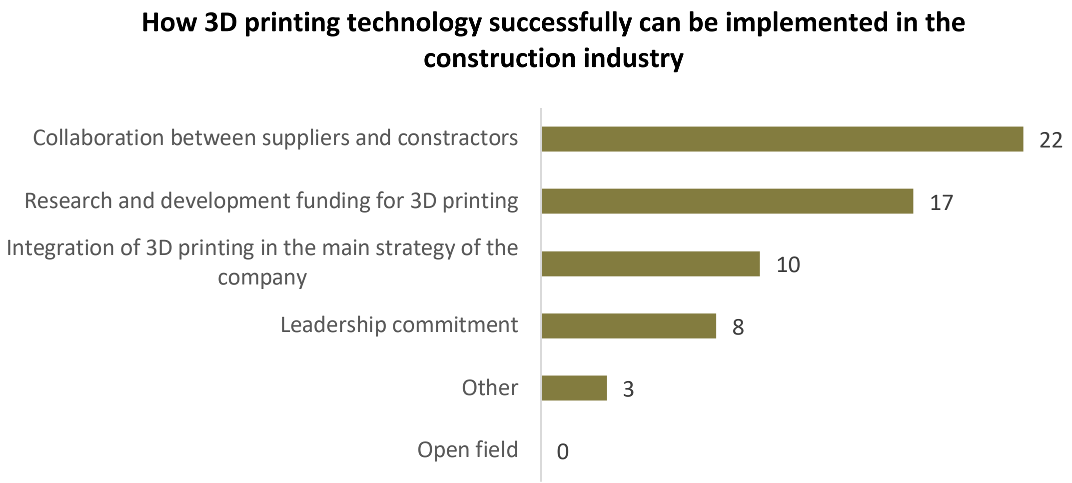

Figure 2-20: Survey result of how 3D printing technology successfully can be implemented in the construction industry

Retrieved and reformatted from: (Shafqat, 2017)

2.4.5 3D Printing of Concrete

Concrete is a well-known material in the construction industry. It has a wide range of applications and is structurally stable. Concrete itself can withstand compression but need adequate reinforcement to ensure the tensile strength. The concrete mixture is made of cement, fine and coarse aggregates, water and additional materials to obtain certain properties. The wet mixture can be poured, pumped, sprayed, extruded or put in place. The chemical process of crystallization lasts up to 28 days, which is considered the time for concrete to reach maximum strength. Depending on concrete type and additives, the curing process might be different.

Characteristic for 3D printing of concrete, is the interdependency between design, material, process and product properties. This is especially because the setting reaction of concrete affects the print speed, pump pressure, filament stacking and so forth. Another reason is that concrete is a composite material (Bos, Wolfs, Ahmed, & Salet, 2016). It is possible to categorize a 3D printing system of concrete into three parts, where different parameters and variables are grouped under each category (Bos et al., 2016):

1. Printable concrete: Composition, aggregate size, additives, admixtures, open time
2. 3D printer: Pump pressure, flow, robot speed, acceleration, system length, system friction, nozzle geometry, temperature, humidity
3. Print geometry: Filament, overall shape, dimensions, curvatures, strength, stiffness

In the case of 3D printing of concrete, it is important that the concrete retains shape after extrusion. It should also cure fast enough to carry subsequent layers without deformation. However, the strength between subsequent layers may decrease, because of the fast curing of the surface on the previous layer. The newly deposited layer is dependent on how fast the concrete cure to carry a new layer, but also the time until less reactiveness. The new layer is dependent on how fast the previous layer cure. There is a certain time window for when the previous layer becomes less chemically active and this is the reason for weaker bonds. The concerns regarding stiffness and strength of the concrete limits the flexibility (SINTEF, 2018).

When choosing the optimal compounded material for the 3D printer, some factors are more important to considerate than others. To find a fibre-reinforced high-performance cementitious material where properties like pumpability, printability, buildability and open time are important (Lim et al., 2011). Paradoxically, to stack concrete layers upon one another is difficult, because of the material's setting time, slump and flow behaviour. Printing with an angle from the vertical will need support underneath. To make cantilevering layers are thus problematic. The first cantilevering layer does not have any support underneath, and the risk for deformation because of the shift in gravity point is high. The extruded slice is also fixed to a specific thickness, therefore, it will not be enough overlap between the new and previous layers. This problem could be solved by increasing the thickness of the extruder, to keep the contact surface constant (Gosselin et al., 2016).

A challenge of 3D printing is slower build time than cast-based manufacturing, because of the layered printing approach. Reduction of build time is linked to the build complexity. The print resolution and detail level depend on the thickness of layers. To speed up the printing time can compromise on the detail level of the printed object. Higher build complexity has the most potential to reduce and minimize the print-time (Lim et al., 2011). Figure 2-21 indicates some of the challenges related to the 3D printing of concrete. Each challenge is further explained in the following paragraphs.

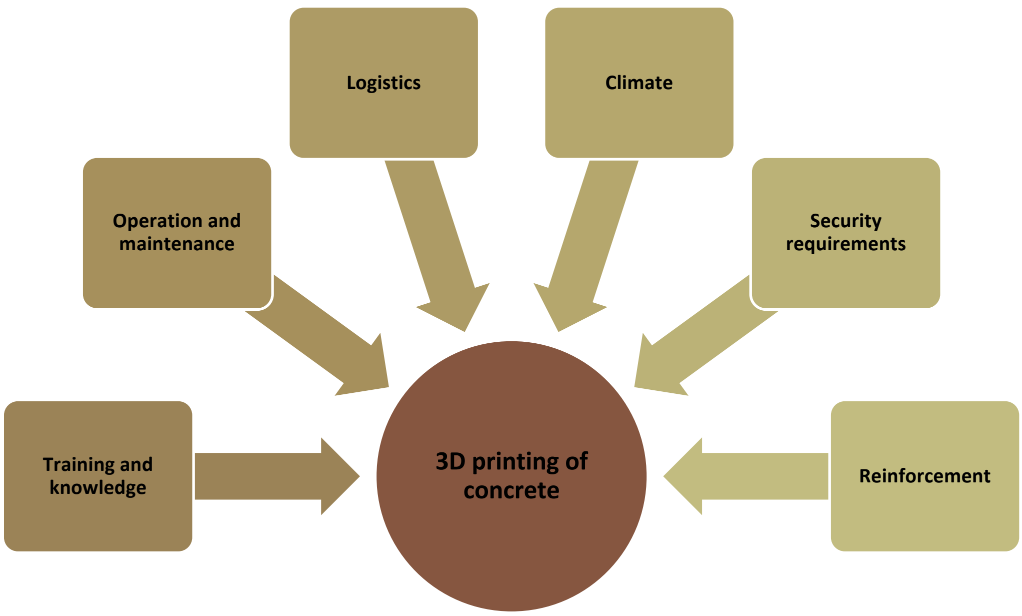

Figure 2-21: Challenges related to a 3D printer on a construction site

Training & Knowledge

When reaching the point where a 3D printer is ready to be introduced to the construction site, the workforce needs to be prepared for it. Preparation in ways of training is necessary to get an understanding of how it is working. The spread of knowledge about the new device should start before it reaches the construction site and continues when it is on site.

Operation & Maintenance

Who is going to operate the 3D printer when it arrives on site? This question appears when studying the topic of 3D printing. The 3D printer could have a high degree of independence from human interactions. For instance, this could mean that after receiving the CAD model, the printer itself understands which parts need to be printed first, start to print them automatically and conceivably move it to side to make space for printing the next element. The concrete materials likewise. As long as the printer has access to the raw materials, it could be possible for it to make the mixture itself along with the printing process. All of these features are possible if the machine is programmed and built for it. If the 3D printers using concrete accommodate such features are rather unsure. It is more likely that a team operates the printer by manually feeding in the object to be printed and mix the concrete mixture separately.

The same applies to maintenance. By making a more complex printer it is possible to add embedded maintenance features. This could cover the daily and frequently repeated tasks as simple flushing and washing of parts in contact with concrete. More technical and mechanical maintenance such as prevention of errors or replacements would most likely need traditional manpower to be solved.

Logistics

In the process of printing objects with a 3D printer, there are two possible alternatives for logistics:

1. Move the *object*
    a. *On-site printing*
    b. *Off-site printing*
2. Move the *printer*
    a. *On-site printing*

Alternative 1, *move the object*, is again divided into two possible alternatives. That is the printer is placed *on-site* or *off-site.* When elements are produced off-site, they are erected to the right place in the construction when printing and curing are completed. This alternative has similarities with the prefabricated concrete construction method. To effectively use the 3D printer to produce several objects, each object can be made on pallets and moved as soon as printed. A criterion for moving the object is that it has cured adequately to withstand any movement or vibrations occurring without deformations to happen. Even though large elements are printed, the printing process will finish before the whole concrete element has cured. To facilitate the early movement of objects, a concrete mixture with carefully selected additives should be selected. The preferred type of concrete will be a fast curing type, which also is costly. The curing process depends on the environment, that is for instance temperature and humidity. For safety reasons, all elements should achieve adequately resistance to stress before assembly on site begins. If this means more time has to be given to the production of objects due to curing time, the production of the element must start in advance to ensure the production is done before construction execution on-site starts. After printed, the elements could be moved aside for further curing, or, if the strength is evaluated to be full enough, the element could be lifted directly in place at the construction site. Other types of stress will occur in the element when lifting, from what it originally was built for. The same problem appears in prefabricated concrete elements. This issue has to be considered when designing the objects. Since precast concrete elements often are used for structural purposes, their integrity and safety are crucial (Arica et al., 2017).

Alternative 2, *move the printer*, is when the concrete elements are printed exactly on the designated area in the construction on-site and the printer moves after completion of the element. The movement of the printer can be done differently. A possibility is to place the printer on tracks or wheels to let it move around the construction. The method will be similar to a 3D printing method called contour crafting (Lim et al., 2011; SINTEF, 2018), but in smaller dimensions and probably for other usages. In this alternative, the problem with curing time is less critical because the element is not changing position after printing. Therefore, the tolerances for lifting and erection is less important.

Climate

Climate is to a certain extent an unforeseen factor affecting the printing. When the climate is examined here it involves precipitation, drought, frost, and wind. A 3D printer could be treated as a *robust* machine, comparable to an excavator or lift. The resistance to climate would then be rough. Otherwise, the 3D printer could be *delicate* as a computer implying vulnerable to climate stress. However, if the printer is robust or delicate, the need for protection can be determined by the concrete's needs. Depending on the type of protection, it will possibly improve the working environment for the printer. The concrete requires conditions for optimal curing preferably with no extreme climate impacts.

Many protection options exist, but most common is a tent, which is used as an example here. A tent can shield for precipitation and wind and retain humidity and temperature to avoid drought and frost. A protection tent is possible to use on the construction site. The tent could cover the whole construction or parts of it. In some cases, it is only necessary to protect special machines, equipment, and materials. If a 3D printer is used on-site, it could be protected by a tent. It will save the printer for extra stress and reduce the need for maintenance, but also create a better environment for the concrete to be spread out and cured. The tent could be placed on a designated place on side of the construction, where the printer is permanently placed. If the printer is placed in the construction to produce something particular directly on place, the options will be to either cover the whole construction with a tent, set up a temporary tent only over the printer if the print job is small, or attach a tent directly to the printer.

Security Requirements

Health, safety, and environment (HSE) are important factors on every construction site. When a new object is introduced, it becomes even more important to explain the area of use and clarify safe usage to those involved. Security requirements must be taken into account when introducing a 3D printer to the construction site for the first time. To identify potential hazards and to find risk-reducing measures a risk assessment method called safe job analysis (SJA) can be done. This is applicable to job procedures and practices. A meeting is held by a team to carry out the SJA (Rausland, 2011).

A large-scale 3D printer made for industrial use may not be very different from other machines regarding safety. Attention and carefulness are always necessary on site. A safety zone around the 3D printer will avoid disturbances and unwanted events. The safety zone can be physical set by the printer itself, depending on its design. Another option is to make a fence around it or place the whole printer in a tent which then constitutes the safety zone.

Reinforcement

Concrete is a material with high compressive strength and low tensile strength. Typical is a ratio of 10:1 between compression and ductility. Because concrete has low ductility, steel reinforcement is necessary to obtain a functional structural element. The safety margins for the element is greater than the tensile strength of concrete, therefore the low ductility of the concrete is not a concern. The steel bars are usually put together in a network surrounded by a frame, where the concrete is cast in. How to include the reinforcement into the printing process is a major topic when it comes to 3D printing. When the problem is sufficiently solved, it will open up for self-supporting of elements, sustainability, and free-form architecture. Because of the challenges with reinforcement in 3D printed objects of concrete, three options for making structural elements are by now possible (SINTEF, 2018):

1. Compression loaded elements only, for example, arcs, domes, straight columns.
2. Outer shells for the structures to be used as mould formworks. Filled with traditional reinforcement and concrete after printing. It can either be an integrated shell or removed after printed if it is made in support materials. This is the most common method to ensure necessary tensile strength. It is a waste of materials if the concrete is used to print outer shells when this only will work as formwork for the final object.
3. Print with integrated reinforcement (fibres or wire) in the element, along the horizontal, extruded layers and leave holes to be filled with post-tensioned steel wires or a rebar/concrete mix in vertical directions.

In 3D printed objects, steel wires can be embedded in the concrete layers to increase the ductile strength. The risk will be brittle failures in one direction when the layers separate. Fibres could be added to the concrete mixture to provide strength, but this will still only be in the individual printed layers. No practical way of providing reinforcement between printed layers in the printing process is available yet, but research is ongoing, for example in the HINDCON project. Another alternative for making structural elements could be considered. Printed concrete elements can be designed with holes in the object and left out when printing. These voids are filled with reinforcement later. The rebars are placed in the holes of the printed object before it is post-tensioned and grouted. The method is simply workable and helps to solve the tensile capacity problem for 3D printed objects. This reinforcement strategy is suitable for large components (Lim et al., 2011).

2.5 Summary of Theory

The summary contains information from the previous presented sections in the theory chapter. References to the statements can be found in the previous sections.

- The construction industry is large and fragmented with many stakeholders. This can be a barrier to innovation. Therefore, it is difficult to involve all contributors to drive transformation. Conservatism in the construction industry is also found to be a barrier to innovation. Innovation has shown to happen on company level only. Skanska is an example of a pioneer company which embrace innovation and new technology. A change is said to take place anyhow soon and will then naturally form rules that will limit the ability to shape a positive outcome of the change.
- It is riskier for project owners and decision makers to choose products without any previous records of success. Risk-eager customers can in some cases favour the use of innovative and untraditional products because it makes them stick out from the rest and consequently makes a potential for greater profit. However, innovative products often fail to penetrate the market. Late adoption of new technology has historically shown to be risky, as Kodak experienced.
- The automotive industry, which the construction industry compare against, has already entered the new era of Industry 4.0. It is time for the construction industry to wake up and follow. Most of the possibilities from the new technologies are said to be off-site where the environment is optimal for production. However, robotics, autonomous vehicles and monitoring/surveillance were found to be more applicable on-site. Prefabrication is common in residential housing in Scandinavia and is claimed to be a facilitator for automation. 3D printing can, however, contribute to keep the value-adding activities on-site, while industrialization traditionally moved production off-site.
- Advantages of advanced technology can be higher quality, more accuracy in the work, improved safety, reduces construction costs and increased productivity. Industry 4.0 will enlarge the gap between winners and losers in the society, and Globalization 4.0 affects it towards either highly skilled and highly paid or low skilled and low paid. The construction industry will require more highly skilled workers in the future as the technology advance. Technology will be more autonomous and demand less human labour or low-skilled workers. This proof the widening talent gap claimed to be happening. Three key actions have been pointed out by CEOs for the construction industry to follow.

- There exists a global aim to reduce carbon emissions. Residential housing is the largest contributor to the global construction volume. 30% of the greenhouse gas emissions are related to buildings. The construction industry is on top regarding raw material consumption, while the world experience loss of valuable minerals, metals and organic materials. 3D printing is potentially material saving, because additive manufacturing generates minimal waste.
- Enablers and barriers to 3D printing exist. The HINDCON 3D printer, being developed, is a hybrid machine using additive and subtractive manufacturing techniques together with robot technologies for large-scale use in construction. 3D printing faces challenges in the areas of training & knowledge, operation & maintenance, logistics, climate, security requirements, and reinforcement. A previous study about 3D printing in the construction industry discovered, for instance, the following findings:
    - 75% of the survey participants did not implement 3D printing.
    - 42% expected 3D printing to be widely used in construction projects within more than eight years.
    - 49% expected high initial cost for 3D printing.
    - 43% thought 3D printing will be cost efficient.
    - The survey participants expected the primary applications for 3D printing in the near future to be complex parts (75%), building blocks (69%) and small parts (58%).

3 Method

The chapter explains the method used in this study and is important for the transparency. Advantages and disadvantages associated with the research design are presented. The data collection covers the whole process from justification for choosing interviews, how the interview respondents were chosen, topics for the interview, its sequence, and clarification of anonymity and language. This is followed by the processing of collected data. Thereafter is a short explanation of the literature used. The quality of information and data was checked against validity, reliability, and generalization.

3.1 Research Design

This study investigates the phenomenon of 3D printing of concrete in the construction industry. 11 people currently working in large contractor firms in Norway were interviewed. The 3D printer used as an example in the interviews was the hybrid 3D concrete printer machine from HINDCON. Because the printer is currently under development, the focus was on the phenomenon of 3D printing of concrete and related challenges, rather than the particular 3D printer from HINDCON.

The research tries to answer how the construction industry can prepare for 3D printing of concrete. The choice of the research questions is crucial for the choice of method (Jacobsen, 2005). For this research, a qualitative approach was selected on the basis of the research questions. Since the interviews were conducted in a relatively short period of time, it can be seen as a state or snapshot at a given time in a group of people from the construction industry. This is reminiscent of a *cross-sectional study* but deviate because it does not involve many units. Triangulation of research methods is comprehensive and therefore not suitable in a master's thesis (Jacobsen, 2005). That being the case, it was chosen to only do a *small-N-study*. It gives a rich description and understanding of a phenomenon, in this case: 3D printing of concrete. The respondents were from different construction companies and to some degree spread out geographically in Norway. Due to the variation among respondents, the likelihood of obtaining different perceptions of the phenomenon is greater. The focus of the study is on the phenomenon but is evaluated by different points of view. The phenomenon in the research questions are more important than the context. By having respondents from different contexts, which here represent companies, it gives a solid description of the phenomenon rather than from one simple case. The focus is not on the respondents' companies, but on the 3D printing phenomenon. This has similarities with phenomenological study designs, where the aim is to bring out different understandings of a phenomenon (Jacobsen, 2005).

3.1.1 Advantages with a Qualitative Method

A qualitative approach will emphasize to meet the persons being investigated on their premises, rather than on the researcher's premises. This was done to create *closeness* between the two parts. Because the objective was to get the perception of the construction industry through their own words, *openness* was required (Jacobsen, 2005). The respondents were fully responsible for what information and data the researcher got since the researcher had not completely decided what to look for. As a result of few restrictions on the incoming information, the qualitative research approach makes *high relevance* (Jacobsen, 2005; Larsen, 2007). This conveys the impression of the right and correct understanding of the phenomenon being investigated. The openness in qualitative data makes it *nuanced*, ergo also favour variation and complexity (Jacobsen, 2005). Due to the complexity that follows from the variety of nuances when using exploratory issues, it requires concentration on few units. Since a few units are examined, the research becomes an intensive program. Hence, the best is to collect qualitative or open data (Jacobsen, 2005). The data highlights the specific and unique from the respondents and the phenomenon studied. A considerable information load is obtained about a few objects in qualitative studies (Dalland, 2017). The generality in the data is harder to absorb. *Flexibility* is high in the qualitative approach (Jacobsen, 2005). Thus, the process becomes interactive and blurs out the different phases of the research, such as defining the research questions, collecting the data and analysing it. The research questions were changed along with the process because new knowledge became available.

3.1.2 Disadvantages with a Qualitative Method

A challenge when interviewing people about 3D printing is their general lack of knowledge about technology. This can be explained by the common belief that the construction industry has resistance to large changes and is technology refusing. Therefore, the respondents willing to participate in the study were not expected to possess any particular knowledge about 3D printing in general. Because interviewing people is *resource intensive* in the praxis of time and cost, it limits itself to a few respondents. In fact, it means prioritizing of nuances rather than many respondents. The *intensive research approach* chosen for this research was small-N-studies (Jacobsen, 2005). *Generalization problems* occur when few respondents are included in the research. It can cause problems when it comes to how representative the collected data is. The external validity is, therefore, a challenge. This is not directly connected with qualitative approaches (Jacobsen, 2005; Larsen, 2007).

Interviewing the respondents in approximately one hour generate a huge amount of data in case of words. These data are remarkably *complex* due to the nuances. Following, it is a challenge to arrange the unstructured data in clear categories and topics. Additionally, the interviewer may make an unconscious screening of the information and therefore ignore some details and nuances of the data (Dalland, 2017; Jacobsen, 2005; Larsen, 2007). After completing some interviews, the interviewer may be too comfortable among the respondents and risk to lose the ability to reflect critically on the information. This *closeness* to the respondents is, however, limited by the time aspect of the interview (Jacobsen, 2005). The *examination effect* is to avoid measuring something the interviewer created, rather than how the respondent experiences the phenomenon. A balance between closeness and objectivity is preferred (Jacobsen, 2005). Since the respondents got interviewed in their own environment, the likelihood that they behave normally with a foreign interviewer is higher. The qualitative method offers high *flexibility* regarding changes (Jacobsen, 2005). Since new information is constantly emerging in the interviews, it is hard to quit the process. The research questions tend to change drastically from what was intended in the beginning. This was avoided in this research by limiting the number of respondents and to have a fixed format of the interview guide through all interview (Dalland, 2017; Jacobsen, 2005).

3.2 Data Collection

3.2.1 Justification for Choosing Interviews

Due to the fact that 3D printing is not widely spread out in the construction industry yet, it was decided to explore what the construction industry thinks about 3D printing, and to some degree new technology in general. This is a situation where little information is known about the area and in-depth information is needed. Data collection through interviewing people is extremely useful in such situations (Kumar, 2005; Larsen, 2007). An interview is any interaction between persons with a specific purpose in mind. Information could be collected from people who daily experience the challenges in the construction industry.

An advantage of interviewing people is the possibility of repeating or explaining questions to make the respondent clearly understand what is asked. The researcher can supplement the understanding with non-verbal reactions from the respondent to better understand the situation (Kumar, 2005; Larsen, 2007). It can also be applied to almost every type of population. If the interviews were totally unstructured, meaning flexibility in questions along with a flexible structure and content, it gives freedom in the choice of words, sequence, and formulation (Kumar, 2005). Depending on the discussion, questions could be formulated and added during the interview to get the most out of the context (Larsen, 2007). The type of unstructured interviewing suitable in this research was *in-depth interviews* (Kumar, 2005). This involved repeated face-to-face interactions between the researcher and the respondent, where the main point was for the researcher to understand the respondent's perspective. Because of the extended time spent together in the interview, with repeated contact, it leads to confidence between the persons and therefore also in-depth and accurate information (Dalland, 2017; Jacobsen, 2005). A challenge with unstructured interviews is that no specific questions are planned, in contrast to structured interviews, where a set of questions are predetermined in both wording and order. This type of interview provides uniform data which simplifies the comparability of data (Dalland, 2017; Kumar, 2005).

3.2.2 Finding Interview Respondents

A downside with face-to-face interviews are the high costs. The interviewer needs to be present in all interviews, which can be spread out geographically. It can also be hard to get the right people to be willing to be interviewed (Jacobsen, 2005). A *systematic selection* of respondents was aimed for, as it gives a random selection of respondents which could be assumed to represent everyone (Dalland, 2017). To find respondents employed in well-known contractor companies who are willing to participate in the research, the researcher used the selection criteria called the *information method (Jacobsen, 2005)*. The researcher searched among previous civil engineering classmates on Facebook and LinkedIn to discover who started working after graduation from the bachelor's degree. In this way, the researcher got an overview of their current employment. Some who worked in relevant companies where contacted. Five employees from different contractor firms agreed to participate in the interviews. These respondents were *strategically selected* because they came from different companies (Dalland, 2017; Larsen, 2007). Since these respondents had relatively little work experience, a better variation in population was sought. To get more variation in the population of intervieewees, the respondents were asked to give contact information to other possible respondents who had more work experience than themselves, but still within the same company. It could, for example, be a supervisor, mentor or another leader. This criterion of the method is called the *snowball method* (Jacobsen, 2005; Larsen, 2007). These respondents were *randomly selected* because the researcher had no idea of who was selected by the other respondents (Dalland, 2017). It opted for two employees from each chosen company. All respondents in this research were contacted directly by the researcher over Facebook or e-mail. Most of the respondents were located in the Oslo region, but some were in Trondheim. The interviews were held where it was convenient for the respondents to meet, ergo in their natural settings. The chances for disruptions are greater in natural surroundings like the respondent's office. Nevertheless, the context effect has shown that respondents tend to give artificial responses when they are in artificial surroundings (Jacobsen, 2005).

Five companies were chosen to be representative of the typical opinion of the construction industry. This is called the *typical* criteria of method choice (Jacobsen, 2005). They were selected without any background check whether they are particularly interested in or supportive to new technology in the field of construction. By selecting the companies randomly it avoids getting either too positive nor too critical perspectives. The companies were Betonmast, HENT, JM, Veidekke, and Ø.M. Fjeld. All respondents approved that the company name was presented in the research. All firms are well known in the Norwegian industry with a turnover of at least 600 MNOK in 2018 (Johannessen, 2018). The respondents in this research had different job positions in the companies. By interviewing employees with variation in both position, experience and from different companies, it gives a wider perspective of what thoughts and knowledge currently exist in the construction industry. The employees and companies are independent of each other, which gives a good presentation of the situation (Jacobsen, 2005). Figure 3-1 illustrates how the five companies were connected to the phenomenon in the study.

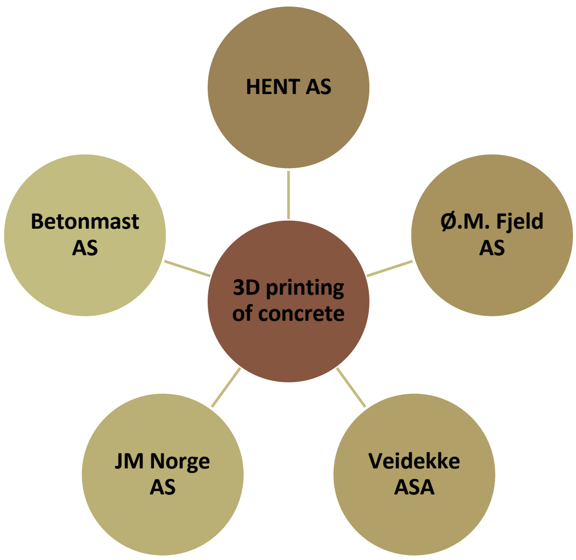

Figure 3-1: Small-N-Study of the phenomenon "3D printing of concrete"

3.2.3 Interview Topics

To provide the best possible setting for the respondent to share the information, it was chosen to do semi-structured interviews. This includes an interview guide with topics, fixed order and only open-answer questions (Jacobsen, 2005). By using semi-structured interviews with an interview guide, the comparison of information gets more complicated. Clearly, the quality of data depends on the quality of the interaction between the researcher and the respondents (Kumar, 2005). That means a significant difference in quality may occur in each interview. An interview guide was made with the four following topics:

Topic 1 – The respondent’s background and experience from the construction industry

Topic 2 – Technology in the construction industry and in the respondent’s company

Topic 3 – 3D printing of concrete

Topic 4 – Challenges with 3D printers, robots and an automated construction site in general

Each topic had relevant questions linked to it. The topics were presented to the respondents before the interview as a preparation. The interview guide was prepared by the researcher and checked by the supervisor. This was done to make sure the content was relevant, with the right interpretation and to avoid biases in the framing of questions done by the researcher. In this research, the researcher is also the interviewer. This avoids misunderstandings of the interview guide. A test interview was conducted on one respondent to check for misunderstandings, interpretations and if the purpose of the interview was as wanted. Thereafter the interview guide was completed after small adjustments in how the questions were formulated. It was decided to include the test interview in the research because the changes did not cover the interview content. In total 11 interviews were conducted, whereby the test interview is included. All interviews were conducted by the same researcher, which strengthen the reliability of the research in case of misunderstandings. During the interview, each topic was brought up for discussion where the researcher could ask some of the prepared questions if needed for the relevance of the discussion. These predetermined questions assured the content of discussion relevant. Appendix A and B contain the interview guides in respectively Norwegian and English. It was expected that respondents were able to express themselves so that information is not lost because of the open-ended questions used (Kumar, 2005). The open-ended questions allowed them to respond freely to the topics given. Such questions facilitate more freedom for the interviewer and therefore the chance for biases.

The respondents were only asked particularly about the 3D printer from HINDCON in two questions. The first time was when the HINDCON project video (1:37 minutes) was shown and they were asked to comment on the video. The second time was about the future of a

3D printer, like the one from HINDCON, on the construction site. Because of the limited project information available for the public, the research had to be more general about 3D printing. Correspondingly the research could not focus on the HINDCON 3D printer alone as a case study, but rather as an example.

3.2.4 Sequence of Interview

All interviews were done according to the detailed sequence explained here. The interviews started with an introduction of the interviewer/researcher, about the study and plan for the interview. It was also informed how all incoming data was collected and stored. Information was given of how company name, job position, age and experience were going to be used and presented in the study. All respondents accepted this. The respondents had received the four topics for the interview the day before or earlier the same day. *The first topic* was about the respondent's background and experience from the construction industry. This was a good start-topic because it was only about the respondents. It was easy for everyone to answer, and it made them feel confident and comfortable about the interviewing situation. The topic included information about the job title, age, and work experience. All interviews moved relatively quickly on to the next topic because limited personal information was collected due to the anonymity of the respondents in the report. *The second topic* was about technology in the construction industry and in the respondent's company. This topic covered what kinds of technology the company uses, experiences, lack of availability, driving forces, responsibility and influence on technology. Proceeding to *the third topic* the technology term was narrowed-in to comprehend 3D printing of concrete. First, the respondent's perceptions of 3D printing of concrete were asked. This was followed up by the short video (1:37 minutes) presenting the HINDCON project which explains the hybrid 3D printer being developed. The respondents were then asked to give comments on the video. To examine the prevalence of the phenomenon, it was discussed whether they had used, discussed, considered, been introduced to or informed about 3D printing or other kinds of robots. The respondents were encouraged to think in a wider perspective about utilization, impact and the future of 3D printing. *The last topic* narrowed-in, even more, to focus on challenges with 3D printers, robots and an automated construction site in general. Here the HINDCON printer was used as a base, to better imagine the situations. Challenges that were highlighted were training & knowledge, operation & maintenance, logistics, climate and security requirements around robots. The topic also questions ownership to the 3D printer, replacement of jobs, the outperformance of prefabricated concrete production and potential for streamlining and shortening of the construction process. Each interview was rounded up by asking the respondents if there was anything to add that was not touched upon previously or questions lacking in the interview. Most of the respondents continued the conversation about how the interview was and wondered if the interview was useful for the research. This conversation summed up the main thoughts during the interview and could be seen as a quality assurance of the information (Dalland, 2017).

3.2.5 Anonymity & Language

All respondents were personal, first-hand sources for information (Jacobsen, 2005). They were informed before the interview that they would be anonymous in the report. No personal data that could be recognized when presented were processed electronically during the project. All answers from respondents were written down by hand. No audio was recorded during the interviews, because of privacy rules set by the Norwegian Data Protection Authority. Because of the anonymity in the interviews, no individual characteristics are used in connection with the results, only a vague description of the type of person. This makes it possible to describe something about a person without revealing the identity. By using this process, it simplifies the discovery of the generality in the individuality (Dalland, 2017). This way to process the data could cause some respondents to be more honest in their answers, knowing they would not be recognized in the report. This encourages the respondents to be more personal when they speak, instead of being more careful as when speaking to the public (Jacobsen, 2005). Their own thoughts might differ from their company's image, but this will not appear in the report. This is because there is no visible connection between respondents and companies in this study. All respondents were made aware that the company names and job positions would be mentioned in the report, but with no correlation to the answers given. This was accepted.

All interviews were held in Norwegian, even though all respondents speak English. The reason was to make the interview situation less complicated for both parts when the mother tongue, Norwegian, could be used. This simplified the opportunity to express oneself better. The interview guide was also in Norwegian and the interviewer took notes in Norwegian. Afterwards, the content relevant for the report was translated into English by the researcher. Both the Norwegian and English interview guides can be found in Appendix A and B.

3.2.6 Processing of Collected Data

The interviews were not recorded in any way, so no transcription of voice recordings were necessary. All notes during the interviews were done with pen and paper. All the handwritten notes were structured in an Excel document, as the one demonstrated in Table 3-1. The table only shows an example with three questions from the first topic. The interview notes were organized by the different respondents in the columns with correlation to the questions asked in the interview listed down in rows. The column colours are randomly picked to identify the different contractor firms and consequently simplify the analysing process. The reason for the two different shades of blue for respondents 0 to 2 is that one interview was intended to be a test interview (interview 0). Since the changes after the test interview were minimal and unaffecting the content, it was decided to include the test interview together with the other interviews. Due to this, this one company was represented by three respondents compared with two from the others. This is not seen to have any impact on the research. The result was 11 interviews in total.

Table 3-1: Demonstration of how the collected data was organized

	Light blue	***Blue***		***Red***		***Green***		***Yellow***		***Grey***	
Respondents	0	1	2	3	4	5	6	7	8	9	10
Topic 1, Q1											
Topic 1, Q2											
Topic 1, Q3											

After all the information was structured in the Excel document, it was summarized in the chapter of empirical findings. It was unsystematically searched for interesting findings among the data. Thereafter, the findings were categorized according to similar themes in the discussion chapter. By using *categoric analysis*, the topics were broken up in smaller parts of data and collected under the appropriate themes (Jacobsen, 2005). These categories were a collection of questions about the same theme. This could be across the topics defined in the interview guide. This type of *open coding* or *first-cycle coding* makes it easier to understand what the data represent (Jacobsen, 2005).

As a second phase of the analysis, it was conducted *axial coding* or *second-cycle coding*. This creates categories that do not openly exist in the data and can be a new category or a collection covering several existing categories (Jacobsen, 2005). The interview respondents were divided into categories according to the alternatives below.

Alternative 1: Amount of work experience

A. Respondents with <u>less</u> work experience (maximum of 3 years)
B. Respondents with <u>more</u> work experience (minimum 5 years)

Alternative 2: Type of work experience

C. Respondents with most experience <u>on-site</u> (mainly the executing phase)
D. Respondents with most experience <u>off-site</u> (mainly the planning phase)

Alternative 3: Type of education

E. <u>Engineering</u> education (3 or 5 years of university education)
F. <u>No engineering</u> education (Apprentice experience or other education)

The detailed data obtained from the interviews can be used to express causality. This is one advantage of the qualitative approach (Jacobsen, 2005). The researcher hoped to discover causality between these alternatives and the interview responses, but it was difficult. Only one finding was found to have a relation between cause and effect. This finding was not seen to be of particular importance for the study but is still presented in a later chapter. Other than this, no causality was found. There might still exist more causality in the research, but the empirical data was too complex and nuanced to show it.

3.3 Literature

This report continues the work done in a previous research project, which was a pre-study for this master's thesis. The researcher, supervisor, and topic (3D printing and HINDCON) are the same in this project. Consequently, some parts of the theory chapters have similarities in both reports. This project is more comprehensive and covers more and new topics than the previous project. As the previous project involved a literature review, this research uses a qualitative approach for collection of empirical data through interviews.

The references used in the method chapter were recommended by fellow students and their supervisors. The literature used in the theory chapter were found mainly through the reference list in relevant reports from the pre-project and HINDCON reports received by the supervisor. One of these references was the World Economic Forum. "Construction" was used as a keyword for searching on the webpage for reports and articles. Searches in the database Google Scholar were done to supply the research with further documentation.

3.4 Quality of Information & Data

Reliability, validity, and generalization of the research are presented here. The quality of the information stated in the method, the theory and the empirical findings are also considered in the previous subsection under the section of data collection.

3.4.1 Reliability

Internal and external reliability differs in consecutively the degree of replicability and agreement in the research team about the findings (Bryman, 2016). The technology is constantly evolving and brings up new methods and tools for the construction industry. The 3D printing concept was studied to get an overview of impressions about this among constructions companies today. Interviews were done to collect the data. The interview respondents were not chosen in a *strategic selection*, but independent of technological interest (Dalland, 2017). This could be a source of error because it is not representative of everyone in the industry. The collected results from the interviews have been used to get an idea of what impressions employees in construction companies in Norway have about 3D printing today.

The researcher's pre-understanding of the phenomenon studied was mixed. It is recommended to find evidence during the interviews against the interviewer's pre-understandings (Dalland, 2017). Because of a previous study project, the researcher had insight into challenges that exist around 3D printing of concrete. This might have affected the interviewer to be more sceptical in the formulation of questions during the interview. It is likely that this could have affected the respondents to be more sceptical towards 3D printing as well. The interview questions also focus more on the challenges related to technology, and not specifically on the advantages. However, the researcher was optimistic about the usage possibilities for 3D printing technology. Due to the fact that the construction industry is known as conservative, this can be an underlying cause for the researcher, but also a possible reason for scepticism among respondents. The data found in this research was compared against previous findings, and the same result shows a high reliability (Larsen, 2007).

All interviews were done in the same sequence as explained in an earlier subsection. This gives the reader a better understanding of the circumstances for the interview and strengthens the reliability of the research (Dalland, 2017). It was taken into account that the respondents could have little or no knowledge of 3D printing. Ambiguities were explained where necessary. As the notes during the interviews were written by hand, it might have caused some information to be missed out. The notes were also written in keywords and small sentences, but it could be the case that not all relevant information was noted. All interviews and the analysis were done by one researcher alone. These examples are sources to lower reliability for the research, but is a common problem in qualitative methods (Larsen, 2007). However, the data was collected and analysed by the same researcher, restricting the possibility for misunderstandings. This again will increase the reliability of the research.

This research is cumulative because it continues from a pre-study by the same researcher and a previous study by another student on the same topic (Dalland, 2017). This previous master's thesis from NTNU in 2017 studied 3D printing in the construction industry, also in connection to the HINDCON project (Shafqat, 2017). As this is relevant for this study as well, some of the most interesting findings are presented in this study for comparison to research findings in this report. Because the previous master's thesis used a quantitative research method to obtain the results presented here, similar findings in this research done through a qualitative research method will strengthen the reliability of this study. This could also be a measure of whether the measuring is done in the correct way (Jacobsen, 2005). The possibility to check the empirical findings of this study can be done by following the interview guide, which is found in Appendix A and B. As the interviews were semi-structured and deal with personal opinions, it is more challenging to obtain the same results again in another study (Dalland, 2017). The interviews were done in the respondents' natural surroundings, which strengthen the reliability of the answers.

3.4.2 Validity

Validity can be divided into internal and external. Internal validity is how true or real the data gathered in the study is. External validity is how much the data can be generalized (Jacobsen, 2005).

The interview guide consisted of a relatively great number of questions to make sure the findings were nuanced and informative. The interviews lasted on average one hour, which created a huge amount of data. Validity is a measure of how well the data represents what the research desires. Validity is, therefore, a measure whether the right data is measured. It is also related to how the data answers the core of the research questions (Olsson, 2015). Because of the semi-structured interview with open-ended questions, the interviewer could add questions along with the discussion with the respondent. Clarifications could also be done to avoid misunderstandings. The respondents could talk freely and thus promote what interests them. This strengthen the validity of the process (Larsen, 2007). Almost all empirical findings are relevant for the research questions in this study. The respondents were free to talk during the interviews, so the generation of irrelevant information occurred. The data found to be too off-topic was not included in the chapter of empirical findings. The main topic in this research was 3D printing. It was decided to also include research about other technologies because more measurement parameters will easier indicate what is sought for and give a benefit when all the data is used together (Olsson, 2015).

Some of the respondents knew the interviewer from before. However, it is reasonable to state that this relationship did not influence the collected data from the interviews because no personal information that could be sensitive were collected (Dalland, 2017). The respondents are in addition used to interact with new people as the construction industry consists of several stakeholders. All responses were taken as equally important for the research.

3.4.3 Generality

As this research focuses on 3D printing as one phenomenon, it is an intensive research approach (Jacobsen, 2005). The research comprises a detailed and throughout understanding of how the reality is and how it is perceived by the respondents. The current development of the construction industry plays, therefore, an important part of the study because it explains how it all interrelates. The nuances studied in intensive research approaches are many. In real life studies as this research, the respondent can to some degree recognize themselves in the described problems and relate to the study. The best foundation to find universal theories is a good description of reality. The high internal validity in intensive research approaches makes them good for theoretical generalization. The generalization tells something about the transferability of findings (Jacobsen, 2005). Generalization is difficult in qualitative researches, so a generalization of the findings in this research would never be representative for all (Bryman, 2016).

4 Empirical Findings

The chapter about empirical findings presents first information about the interviews and the respondents. All respondents are anonymous, but some relevant information is given to set the circumstances. Due to the large and complex amount of data, the empirical findings from the interviews are introduced according to the topics in the interview guide. Question 1 to 3 are summarized together under Topic 1, while question 4 to 22 are presented according to each question.

4.1 The respondent's background and experience from the construction industry (Topic 1)

11 interviews were conducted in this study. The respondents' age varied from 25 to 57 years. Additionally, their relevant work experience was from 2 to 38 years. Figure 4-1 shows age and work experience in accordance, with one dot representing each respondent. Not all respondents were involved in all phases of a construction project, rather not in all phases of all projects, they were involved in. Only three respondents were not involved in all phases. This means for example that they were only involved in actions taking place at the construction site. The majority of the respondents were involved from the beginning to the end of a project. This includes, for instance, tendering, start-up, development, engineering, planning and production, implementation, visits, inspections, construction, and handover. The respondents' current job positions also differ a lot, representing project engineer, site manager assistant, site manager, project manager, logistics manager, digitalization manager, head support manager, and housing department manager.

Figure 4-1: Respondents' age and relevant work experience

4.2 Technology in the construction industry and in the respondent's company (Topic 2)

4. **What kind of technologies are used where you work? What do you want to highlight?**

The 11 respondents had to some extent different conceptions of what was meant by the technology, and the interviewer did not set any clear boundaries for this question. Consequently, the respondents used some time to think of technologies and mentioned everything that came to their mind. Some answered technological devices such as mobiles, tablets, and computers. Others were more abstract mentioning digitalization, traceability and simplification. Computer programs were also mentioned.

Seven respondents brought up BIM. This could embrace models, kiosks, related to project management or the whole department. Two respondents from the same company explain their experience with a BIM-kiosk at the construction site. It was tested for approximately 0.5 to 1 year and resulted to not be optimal. The reasons why it did not work were mixed between lack of training, worker's attitude, too few kiosks and no possibility to print. It was difficult for workers to remember details from the 3D data model and inconvenient to go back and forth if they were working on another floor or area away from the kiosk. The workers were also used to 2D printed drawings. While the BIM-kiosk concept strived for a paper-free construction site where printing was not possible, the workers went into the construction office to print drawings. The kiosk ended up not being used as it was planned for. The kiosk was probably most advantageous for the technical fields, for example, the fields electrical, ventilation and plumbing. Some of the other respondents viewed BIM-kiosk as an old-fashioned technology and claimed it was on the way out and loosing popularity. In spite of that, it is easier to accommodate in closed buildings due to climate conditions. Nevertheless, BIM and 3D models are still used in meetings where it encourages collaboration, gives a good presentation of what is built and simplifies the detection of errors. Drawings and models in one program were seen as very advantageous. 3D reinforcement was mentioned by several of the respondents as advantageous.

Other more advanced technologies mentioned were the use of robot drilling, laser scan, drones, VDC, VR and AR. Some companies use technology on-site to log concrete temperature or video equipment for interactions in meetings in office environments. Coordination of HSE and QA in a digital program and deviation handling in a mobile application were also mentioned.

Cloud-based solutions are used by several companies. The aim for paper-free sites are shared between a number of the companies and is supported by the use of tablets. The companies' practice here varies. In some companies, the team leader has one tablet and in other companies, each worker has their own tablet. The tablets are protected with covers to avoid damage. Notwithstanding this, some companies still use paper for everything. In contrast, in other companies, it is almost as natural with a tablet as a hammer.

5. **Do you experience your workplace as accommodating for new methods, especially if it involves new technology?**

All respondents answered *"yes"* to this question, but some were more in doubt than others. Those in doubt were using arguments that the industry as a whole is lagging behind, that the respondent's company is lagging behind compared to other companies and that some groups in the respondent's company are more accommodating to technology than others. It was also mentioned that the workers on site are in some cases not as accommodating to technology as the construction site management. This could be because of attitude, culture or as stated by someone: the user interface. The construction industry is an industry of all ages. It exists a culture that supports the statement *"everything was better before"*. One respondent said that they cannot be too stubborn and need to welcome innovation. Alongside this, all new methods and devices that make life easier are welcome. One respondent said it went fast to get used to tablets, as long as the user interface was good.

Those not doubting about the experienced accommodation for new methods, especially if it involves new technology, states that it only appears in certain groups or the whole company. The development of new methods and technology cannot be stopped, so everyone needs to follow. Those companies with a certain amount of young and newly educated employees experience this as positive because they are promoters interested in new things and eager to teach others about it. Cooperation between leaders and the rest of the employees, and between young and old, are also important. One respondent brought up an example with a young site manager cooperating with an old site manager who was openminded. They collaborate well and were accommodating. This project was perceived as especially forward-looking.

The respondents also mentioned that resource availability is decisive for whether new methods or technology are being accommodated for in their company. Also, it is important to understand the new method or technology, otherwise it is impossible to decide anything. The whole industry needs to collaborate and voluntary work to improve.

6. **Do you find that the projects you work on are held back in any way due to lack of access to technology?**

Two respondents clearly answer *"yes"* to this question. They state that there exists much technology which their company has not yet applied. Some of the systems used today are even old. One respondent said that it is not the technology that is lacking, but rather the competence and knowledge. Some employees even lack the right competence, thus is technology not widely spread in this company. Everything which is made is unique and can, therefore, be seen as a challenge to implement. General lack of information and knowledge is also challenging. Consequently, employees accept the current situation because they do not know what else exists. But for those who are updated with the latest news, innovations, and what is around in the market, it can be challenging to experience the lack of access to technology. In some cases, this can hinder the full expression of projects. Other respondents pointed to the difficulty for some employees to acquire new knowledge. This especially concerns digital knowledge. It was also mentioned the quality of the internet connection. If digital tools requiring internet are used on site, while the internet server is placed in the site-office, it can lead to problems. Even in the site-office, the internet connection can be poor. Another respondent was unsure whether or not a project was held back due to lack of technology but mentioned that VR-glasses could be useful. Economy contra the usefulness must be taken into consideration before choosing. Since house construction is not too complex, it does not experience to be hold back in any way either.

One respondent had never experienced any hinders due to lack of technology. Another one had never ever thought of this. Any kinds of aids that would make the job more efficient, faster and cheaper are positive. Some of the respondents that informed that they did not widely use tablets in the previous question, unfold the negativity to it here. According to them, they imagined much mess and trouble using tablets together with concrete work. One respondent made clear that the use of paper drawings on site is great and that the use of BIM-kiosks is inconvenient.

There are fast movements in many technology areas, and for example, the computer programs do not work properly together. As a respondent said, *"the different software do not speak the same language"*. Additionally, based on the continuous developing the software and technologies are quickly reaching the expiry date. These new technologies usually have a couple of years lifetime. This also includes tablets, for instance. The chosen technology will as a result never be optimal, neither now nor then. If a new technology needs to be carefully studied before chosen, the technology or device risk to be outdated already when getting permission to be tested in the company. Therefore, one respondent feels that the company often happens to lag behind. It will always be different in the beginning when introducing something new, but people get used to it. To follow up on the development front is resource demanding, but the respondent wants the company to take more risk and gamble. The same respondent points out the need for a common place for registering deviations, HSE and so on.

7. Do you experience any colleagues or players in the industry as the driving force for new technology?

The question was followed up with two subquestions distinguishing the main question between the planning phase and the execution phase. Four of the respondents only answered the main question and did not find any need to distinguish between the planning phase and the execution phase. Their answers are presented in the next paragraph, while the responses from those who divided the questions into two parts are presented thereafter.

In addition to the comments given in the following, some respondents chose to mention company names of who they experience as a driving force for new technology. One respondent gives an example of a particular company that put new equipment into use earlier than others, and after a while, this has become an industry standard. The mentioned companies and the number of times mentioned are stated below:

- Skanska (6)
- Veidekke (6)
- AF (3)
- Betonmast (2)
- Ø.M. Fjeld (1)
- HENT (1)

Planning & Execution Phase

The largest companies, including companies from plant construction, have more resources to support and are already in front regarding technology. However, one respondent claim that some large companies are digitalizing and using new technology just to show off. In some cases, the result or product from the technology is not even new or particularly helpful, but just a gimmick. A second respondent mentions the architect as a driving force for new technology in projects. Another respondent does not mention anyone in particular but expresses the importance of having enthusiasts everywhere. People to lead the way, drag the others through and follow up are very important. They also need to make things unharmed and hide the complexity in the beginning. Furthermore, the workers on site must be part of it and be able to ask questions. A fourth respondent asserts that the younger employees are most concerned about technology. Take for instance summer students, who get a task to evaluate how the company handles new technology. They compare it to other companies and try to discover what hinders the development of this company. The company has experienced a good combination of what the younger ones are interested in and what the older ones see as necessary, thereafter, exploit it. In other cases, the focus on technology development in the company can be too research characterized. The company often collaborate with universities and research institutions to let them use their projects as a testing ground for new technology. The respondent also asks, *"should we lead the research?"*. The industry must contribute, not only individual companies. Also, it is not enough with only research or to wait for other countries to discover best practices. It is clear that the companies focus on profitability, not taking too high risk and the effect from the technology on site must be planned.

Engineering consultant companies are mentioned by one respondent to be a driving force for new technology. The newly educated employees are also pushing forward, as they transfer methods and knowledge from study environments over to the workplace. But it is not always easy to realize ideas because of the bureaucracy. The developers of the technology should also promote it. One respondent admits themselves as a company to be a driving force for new technology. They act proactive and want things to happen. If someone, for example, has a proposal and are able to show how it works, how to implement it and so on, would it be possible to convince the architect and others about the idea.

Planning Phase

Regarding the planning phase, a respondent who commented on this mentioned some colleagues, where age was pointed out as decisive. Especially the younger employees in the engineering and design group. The use of new technology is more facilitated in the company's headquarter and thus in the planning phase. Five of the respondents mentioned the BIM model. The project owner demands more from 3D models now than before. The BIM technicians are a driving force as well because they give suggestions to new software and technologies. One respondent also mentions the USA specifically, because of their money.

Execution Phase

When it comes to the execution phase, one respondent mentions the uncertainty of how much they get out of new technology on site. The benefit is not optimal yet. But they need to start one place. For example, one respondent tells about a team leader who got a tablet after asking for it. Another respondent gives examples of a supplier using an excavator using GPS, logging in a mobile application which enables live updates that everyone can follow. It is also mentioned by a respondent that some construction workers, which at the same time are taking education, are often experienced as driving forces for new technology because they learn about relevant topics in parallel. When explained to the other workers, people listen but not everyone will be convinced. It is also stated by a respondent that newly educated people are less interested to start working in a company if it is not modernized. This force the company itself to strive for modernization. Following, the respondent explains that younger employees often are used as internal consultants in the company for the older generation of employees. They are in general more supportive regarding shifts as when paper drawings change to 3D data models.

Regardless young or old, the will to change needs to be present if anything new is going to happen. The companies' headquarters need to trust and believe in site management. It is also important with a dialogue between the leaders and the workers. It should also be accepted to try new methods and technologies. The workers are both busy and good at the practical job, while the management should explore more options. It is important to remember the fact mentioned by a respondent, *"this is not a sprint, but a marathon".*

8. Where lies the responsibility for using new technology?

One respondent divided the answer in three:

- The industry (organizations, companies, and employers)
- Project owners (public and private)
- Each of us individually

Many of the respondents mention the management division in the company as responsible for using new technology. The site management is also viewed as responsible. The project owners are also mentioned since they often set the requirements and have a huge influence on projects. This could, for instance, be public project owners, such as the Norwegian companies Statsbygg and Bane NOR. More general, the responsibility lies at those working with the planning and execution of projects, both on-site and off-site. There is also an agreement among the respondents that the whole industry is responsible. One respondent even stated that no one is responsible for using new technology. One respondent suggests that the four or five largest companies in the industry should go in front and lead the way towards the use of new technology. They should also share the costs.

Workers are looking up to their leaders. The management's attitude can affect workers and others. However, to be positive it is necessary to see the benefit of it. The supplier itself has a certain responsibility to promote its own technology. By showing the benefits, it is easier for others to consider it. For instance, the supplier could visit the construction site to demonstrate, because it is not easy to get the right understanding only by hearing about it. The whole industry must prepare for news and changes, while the organizations need to be built for change. Errors in the initial phase are normal. It should give a lesson for the future. A financial scope is necessary when a new technology is introduced. Often is it decisive with an open-minded management group that sees the value of new technology. The construction industry compares itself to the automotive industry, regarding technology such as robots. The respondent who stated this view the construction industry as the least developed industry regarding digitalization and new technology. As mentioned in the question above, some respondents again mention that researchers often use contractor companies as test arenas for new technology. The companies invite them in but must remember to consider the disadvantages as well. Feedbacks from projects and training are also mentioned to be of importance when it comes to using of new technology.

9. If you want, can you influence which technology is being used in today's construction sites? And to what extent?

All respondents answered *"yes"* to this question. The scope of the technology decides to what extent they could influence. The respondents explained that in such a case they need to argue for why this technology should be used. Some effort must be expected. Clever employees with respect will be taken seriously. In the same way, if the idea comes from someone else it deserves attention. Regardless if the idea is good or not, it is not always possible to spread the idea around to everyone because it is resource demanding and time-consuming. This means that some ideas never reach the right person. Another depending factor is the project itself which the technology is going to be implemented in. Not all technologies match a project. If technology is decided to be used, it is often first tested in one project. The new technology should provide benefit to be considered in a project, not used only to show off in the industry. One respondent expresses a desire that the company should be further in technology development but thinks this will happen soon.

4.3 3D printing of concrete (Topic 3)

10. What do you think of when you hear the expression "3D printing of concrete"?

The 11 respondents had remarkably different perceptions of what a 3D printer is, and some got more confused when relating it to concrete. The span in responses was from *"that is awesome, I have a 3D printer at home"* to *"what is 3D printing?"*. Several of the respondents also had difficulties to express what they thought because they did not have enough knowledge to imagine how a 3D concrete printer would look. Some of the respondents mentioned a classical robot arm laying out concrete, maybe with help from a crane or operated by a person. Some immediately commented that it would be more relevant to 3D print in a factory rather than on a construction site. One respondent also made clear that this technology would never completely replace workers on site. Some respondents had also seen videos of 3D printing on the Internet, for example from famous projects in the Netherlands or in China. Challenges that were pointed out were, for example, the printer's size and construction stability.

11. What do you think after watching the HINDCON project video?

Three of the respondents did not have anything to add which differed from the comments in the previous question. The others seemed to have gained a better understanding of the

3D printing concept and the majority of the respondents asked questions back to the interviewer to get more information. The questions from the respondents concerned the general technology for 3D printing, which then briefly was explained by the interviewer. But also, more specific questions regarding the HINDCON printer were asked. Due to restricted and limited information about the HINDCON printer, the interviewer could not give detailed answers to all questions.

The respondents who commented on the video said for instance that it was interesting, exciting and fancy. Since the printer is currently under development, it was commented that this technology will not be a normal sight in the near future. This kind of industrialization, where the construction site becomes an assembly place, will demand operators rather than craftsmen. If the 3D printer is placed off-site, it would contribute to fewer hours possible for damage, better HSE at the site, continuously work day and night and maybe more accuracy in the building.

Some asked also if this is the right way to go, meaning that concrete might not be the material for the future. Scepticism about possible time-savings and other challenges as for instance price, will decide whether 3D printing of precast concrete is chosen. As one respondent said, *"yes please, to everything that streamlines everyday life".*

12. **Have 3D printing, or other robots, been <u>used</u> at the construction sites where you have been?**

On this question, all respondents answer *"no/never"* to the use of 3D printing. A couple of the respondents mention that they have heard about other kinds of robots being used in either their own company or other companies. Such robots mentioned were a hole punching robot, a drilling robot, and a screw robot.

13. **Has it been <u>discussed</u> or <u>considered</u> 3D printing in projects you have been involved in?**

All the respondents answer *"no/never"* on this question, except one respondent who answers that it has been mentioned once, but then only to make an architectural model for visualization of the construction.

14. **Have you been <u>introduced</u> to or <u>informed</u> about 3D printing?**

Two of the respondents answered *"yes"* that they had been introduced or informed about 3D printing in a work-related setting. These two respondents were both from the same company. One had heard about it in a meeting related to company/project development, while the other had been to a seminar. The rest of the respondents had never got any introduction or had never received any information about 3D printing in a work-related setting. Eight of the respondents had done some research on their own initiative. This could, for instance, be reading about it or watch videos on YouTube. These respondents expressed more interest in 3D printing than to the last respondent who never had got introduced or done own research.

15. How do you imagine that 3D printers can be utilized on site? Or any other applications in the construction industry?

The replies on this question were characterized by variation and many of the respondents had ideas of how 3D printers could be utilized on site. In particular, it was said that 3D printers could simplify today's work methods. It could work during the night to exploit the time aspect. To achieve it, it is important to involve all stakeholders, facilitate for what the desired product is, how to perform the task, plan, implement and so on. The cost of using this construction method also need consideration. One respondent also mentions that if their supplier chooses to 3D print elements or do traditionally precast, they would maybe not notice it as long as the specifications are met. If the production method were optional, it would be a cost issue relative to the alternative methods. Applications for 3D printing mentioned by the respondents were by instance foundations, girders, balconies, stairs and columns, but it was also said that *"everything is possible".*

One respondent explains that if a 3D printer for concrete is placed on-site, it will overtake the job for several workers because concrete can be the dominant material in a project. If the machine replaces people, people do not need to do monotonous jobs or will avoid getting hurt. Ideally, the machine could replace repetitive work on-site.

Some respondents were diffuse in their answers whether they thought 3D printers could be utilized on-site or be more beneficial in prefabrication factories off-site. Those who actually mentioned that 3D printing belongs off-site justified this by claiming that the manufacturing process does not suit a construction site but is ideal for the production of small or complex parts in a factory. 3D printing is typical manufacturing because it is the production of one thing. It is mentioned by a respondent that the material chosen for 3D printing could set the limitations for product usage. To print small 3D models of the construction was also mentioned by a respondent. This could help detect deviations faster.

16. How do you think 3D printers or robots will affect the construction process in the long run?

The replies to this question were substantially nuanced. A respondent thinks 3D printers will overtake everything in a long perspective. The construction site will be more automated and standardized with robots and 3D printers on-site. Hopefully, this will lead to a more efficient site, but also provide better HSE for workers. The construction workers on site become operators for robots and machines instead. People like to be creative and when letting the robots do the job, workers can focus on being creative. Everyday life will change. Another respondent talks about fewer processes that will happen on-site. This again could eliminate human errors. If the machines have memory, the likelihood for deviations and errors would decrease over time as it avoids doing the same errors or knows what to fix. It is also mentioned by a respondent that it could be easier to plan the build time since the machine can calculate the operation time needed and avoid downtime in the project. Slack should be added in case of machine downtime. The machine can work day and night, or a combination of humans at daytime and robots at night-time.

A respondent points out the importance of facilitation and planning as a key factor for success. This can result in higher quality in a shorter time. A respondent also states that the use of 3D printers and robots in the construction process will raise the quality of information and data models. The quality assurance becomes more in focus because the project will be locked in phases. This enables to start building closer to the project planning phase, which means to start building earlier than what is done in today's projects. Another respondent mentions the possibility of increasing the popularity among potential buyers to for example a condominium complex when emphasizing the use of 3D printing. The project owners could in some cases specify the use of 3D printing to be *"cooler than the neighbour"*, which builds in a traditional way.

One respondent thinks that robots can affect the construction process, but that 3D printers will not. The respondent claims that there still is a long way to go before this technology becomes useful on-site.

17. Do you believe that a 3D printer, like the one from HINDCON, has a future on the construction site?

Five of the respondents believe that a 3D printer has a future on the construction site. There are plenty of possibilities, even though it might not be in the nearest future. It can streamline the work on-site and therefore save money in the long run. Scepticism is likely in the beginning, but the construction industry also needs to become more digitalized. One respondent compares 3D printing of objects with the tailoring of suits.

Two respondents are unsure whether a 3D printer is relevant on a construction site. There still exist challenges with the reinforcement that is a huge barrier. This relates to the structure's strength but also recesses in elements. The limited space on construction sites is also mentioned several times as a challenge. Since this is a new method for the industry, it also requires new knowledge. 3D printing would perhaps benefit the precast concrete factories more than the actual construction site. One respondent gives an example of how it could be if a 3D printer was used on-site. To gain the optimal strength in concrete elements, it needs to cure properly. As an example, the printing had to be done on a Friday to let it cure over the weekend. The project schedules would then be extremely important to comply with.

The remaining four respondents did not think 3D printing has a future on the construction site. The reasons for claiming this are that concrete is not a material for the future, due to the large carbon emissions. Then low-carbon concrete was mentioned as a possible solution. However, the construction industry, especially in Norway, aiming to reduce the concrete use and rather go for cross-laminated timber (CLT).

4.4 Challenges with 3D printers, robots and an automated construction site in general (Topic 4)

18. How to solve challenges related to a 3D printer on a construction site?

a. Training & knowledge

A respondent thinks that the developers are responsible for arranging courses and training to companies in the industry. 3D printing might seem scary at first, also it takes time to understand the comprehensiveness. Several respondents say it is important to see the machine in practice, not only in a film and to learn about it in a theoretical course. The ideal would be to present some successful examples when 3D printing has been used before. Sharing of previous experiences is also mentioned. Here it is pointed out that it is necessary with experiences from other than only the developers, which are seen as biased. This will increase interest among people. The understanding comes gradually. The most important in the beginning is to get people interested. The most interested employees could be picked out to be trained first. It would then be likely that they spread the encouragement about 3D printing to the other workers. The hardest to convince about the innovative technologies are the sceptic ones. Nevertheless, the sceptic workers are those who might give the most feedback of what is working and what is not. This is also valuable information for the developers.

In addition to the training in advance, some practical training is necessary when the 3D printer is placed on-site. A team from the construction site can, for instance, visit the developers or supplier in their factory. It is mentioned by two respondents that a training package should be delivered together with the 3D printer when it arrives at the construction site. The 3D supplier would be responsible for this. This could include someone with great knowledge about the machine, to teach the workers on site how it works. This person could be stationed at site for up to half a year. The teaching program could be divided into different levels, including how to feed info into the robot, how to operate it on a daily basis, maintenance, cleaning and so on. The training should be held in a language that everyone understands. Furthermore, the machine should have clear and easy symbols that facilitate everyone to use it. A certificate should be offered to those who complete the course and training, demonstrating they are certificated for the 3D printer responsibility.

A respondent expresses that it could be difficult to teach the workers on site, while some even find it challenging to use the computer mouse. It might be better to let someone else than the workers on-site control the 3D printer. It is mentioned that someone with a civil engineering background should be capable to handle the machine more properly.

The construction industry is a results-oriented industry. If money or work hours are saved, then it gives the motivation to continue. The economic part plays a huge role. The decision makers need to be convinced about costs and benefits with 3D printing.

b. Operation & maintenance

If the contractor company possess the knowledge themselves, they operate and maintain it themselves. However, the majority of the respondents mention that the company that offers the 3D printer should be responsible for operation and maintenance. After a while when the technology has developed more and the 3D printer has become user-friendly and reliable, the workers on site can overtake the responsibility of it. Another alternative is, according to a respondent, that it should work as with lifts and other equipment or machines hired to the construction site. Alternatively, a separate operator should have this responsibility. It is also mentioned by a respondent that the site management could have this responsibility. Depending on the complexity of the operation and maintenance needed for the 3D printer, the workers on site could also be responsible. Since the machine uses concrete as a material, one participant claim that the responsibility lies on the concrete workers.

Several of the respondents explain that their company would have made a contract agreement with the company responsible for the production of elements. It would be irrelevant for the contractor company if the supplier chooses to use 3D printing or precast concrete. It would therefore not be relevant for them to think of who the responsible for operation and maintenance of the 3D printer should be.

The respondent who told about the BIM-kiosk continues the story by telling that they did not have enough capacity to train employees to fully exploit the opportunity of the BIM-kiosk. It became an extra job to operate and maintain it. Besides this, it was also not enough resources to give the necessary training to everyone.

c. Logistics

This question asks the preferred or most likely way to handle a 3D printer and its produced objects. Almost all respondents state that it is not enough space on the construction site for a 3D printer and its related equipment. Space concerns is often a topic in almost every project. Oslo in Norway is mentioned as especially restricted regarding site space. Digging and groundwork are space-demanding activities that can happen on site alongside with construction. This might again limit the possibility for a 3D printer on-site. In other projects it might not be a problem at all to place a 3D printer on-site. To print elements on-site would eliminate the need for transportation and make the construction site to a production place. Several respondents claim that there is not space on today’s construction sites to host a small factory. However, two respondents think it might be space to place a 3D printer on-site in the early execution phase of the project. This consideration must be taken in an early phase by the project owner. Element production on-site affects the HSE and must therefore be planned for. When the 3D printer is placed on-site, a respondent claim that it should be possible to move around. Otherwise could it be placed on a factory in optimal environment. It would save time to print the elements directly in place. It would though be more difficult to let the printer have easy access to electric power and the delivery of concrete.

To place the 3D printer in a precasting factory or in a temporary factory closer to the construction site are mentioned by some respondents as better options than to have it on-site. This would require transportation of the elements and make the construction site to an element assembly place. One respondent compares this to Lego.

d. Climate

One respondent means that construction companies in Norway are used to handle different climates. Precipitation, drought, frost, and wind are everyday events. All machines at the construction site are exposed to changing weather conditions. A couple of the respondents do not see the climate as a challenge, as it is nothing new from today’s practice. A respondent claim that no machine is more exposed than others. All machines brought into the construction site needs to be robust. Even tablets have protection covers. If the 3D printer is more similar to a computer device than a robust machine, it should be possible to protect it properly. Although concrete is a widely used material for construction, the outcome from the 3D printer should be protected to some degree to avoid damage of each printed concrete layer.

One respondent state that it has never been profitable to use a tent over the whole construction. It would instead be beneficial to place the 3D printer in a tent or a factory off-site. However, a small moveable tent only covering the 3D printer is mentioned by one respondent as a good alternative to keep the flexibility. The tent could, for example, be attached to the printer itself. This could enable the machine to be permanently located somewhere on-site as well as moveable around on site. Logistics on site involving electrical power, heat, and light are brought up as important to consider by a respondent. If the 3D printer uses laser, it could be difficult to see measurements in bright sunlight, for instance. But here a tent would be useful.

e. Security requirements around robot

One respondent still claimed that the best would be to place the 3D printer in a factory where the environment is facilitated for the production of concrete elements. Presuming that the 3D printer is placed on the side of the construction site, it would not cause any harm. It would most likely have a safety zone. As long as one keeps away from this zone, no injury or damage is likely to happen. But another large machine on site increases the risk for incidents to happen. One respondent says that it would not be any difference compared to today's construction environment. As stated in a previous question, the 3D printer must be involved in the HSE plans. Risks that are evident to all machines and equipment on site are theft and stealing. The size of the 3D printer would limit this chance, but it must be considered, especially for smaller and expensive parts/devices attached to the printer. It should also be taken into account if children climb or throw objects over the fence of the construction site.

In the case that the machine is moving around on site, the risks would increase. It would, however, still be necessary with a safety zone around the machine. The 3D printer could also be connected to sensors that detect if anything or anyone comes too close to the machine. It could then send out a warning signal or simply shut down. This becomes more complicated if the machine is going to be used above ground level. Another respondent thought about the noise level of the machine. This becomes more relevant when considering printing by night.

19. Who should own the 3D printer? The contractor, the concrete supplier or hired elsewhere?

This question was to some extent mentioned in previous questions, but then with another focus. The majority of the respondents could not choose one simple answer to this question. The mentioned and discussed alternatives of who should own the 3D printer were:

- The contractor company
- A subsidiary company of the contractor
- A general supplier
- The concrete supplier
- The prefabrication factory
- A 3D printing company
- An external company

One respondent said that the 3D printer's owner could be varying along with the type of project. The lifetime of the 3D printer must be taken into account, together with the maintenance cost. How often the 3D printer will be used, is also significant to consider. No one wants to own something that is old. Therefore, it is better to rent, according to a respondent. One respondent told that the company is careful to utilize new technologies. First, they might get one to test. The initial cost might be high, but it will eliminate the hours and costs by having employees.

One respondent wondered whether companies could go together and test 3D printing in a project. If the government also supports and sponsors, would it be easier for contractor companies to try 3D printing. 3D printing of elements is seen by a respondent as a specialist service and should thus be a specialist company. One respondent speculates whether one of the large companies buy up a 3D printing company as a subsidiary. It might get more attractive to choose a supplier that utilize 3D printing in the future.

20. Will a 3D printer replace some of today's workplaces? If so, which ones?

A couple of the respondents thought 3D printing will replace some of today's workplaces and job positions. It was mentioned that the number of workplaces might not change, but the type of jobs will change. The new technologies will also demand new knowledge, which again will create new education programs. The construction industry compares itself to the automobile industry, which also has robots and humans working in a lean way. One respondent compares the case of 3D printing replacing workers at the site with what happened to technical draftsmen when BIM technology became normal. Printing agencies got less to do, but it also created new workplaces and jobs for others. A respondent mentions that the BIM coordinator job will transform into a robot coordinator responsible for the 3D printer. One respondent claim that there will always be plenty of concrete workers on site. By introducing 3D printing to the site, the respondent estimates that one or two concrete workers will be replaced. If the 3D printed concrete elements obtain the same quality as precast concrete elements, a respondent claim that 3D printing can possibly overtake the job of the precast factory. Consequently, some workplaces in the precast industry will be replaced. Because the iron rebars are of high importance for the concrete elements, it is pointed out by a respondent that the iron rebars also should be 3D printed. This could be done by the 3D printer before or simultaneously together with the concrete printing. This would, of course, require a special 3D printer. Following it could contribute to solving the reinforcement issue when 3D printing with concrete. To limit the production only to elements requiring less or no reinforcement and static calculations are also mentioned as a solution.

A respondent claimed that more robots will lead to fewer workplaces. Some of the human jobs will be replaced by robots because they have more capacity. One respondent speculates whether ten concrete workers would be replaced by one IT-master. The robots cannot replace everyone, someone has to control or monitor it. Some respondents called this new position *machine/robot operator*. An *assembler* of the concrete elements on site is also pointed out as likely in the future. Lego is again mentioned to illustrate the way of future constructing. Following is a list of job positions likely to be replaced if 3D printing is used, according to the 11 respondents. The number indicates how many times the actual job position[2] was mentioned among the respondents.

- Concrete worker (6)
- Carpenter (4)
- Craftworker (3)
- Steel fixer (2)

21. Do you think 3D printing can outperform pre-fabricated concrete?

The respondents had split thoughts of this question but differentiated mainly between 3D printing to be a competitor or aid for the precast concrete factories. At least four respondents thought 3D printing to be a competitor able to outperform prefabricated

[2] A craftworker may be a general term for the other job positions mentioned, especially in the Norwegian language (because the interviews were done in Norwegian).

concrete, while at least five respondents rather thought it will be a helpful tool and aid for the prefabricated concrete. The last two respondents were unsure or unclear, resulting in no clear opinion. One of these respondents explained that 3D printing first can be a helpful tool for the precast factories, but in the future, it has the possibility to do the same job and then replace it.

One respondent stated that *"technology will always be a competitor for those who do not believe in it".* A 3D printer does not have enough capacity to outperform precast concrete technology. A respondent mentions that it could be cheaper for the contractor to keep the 3D printer off-site in a prefabrication factory, because of the ability to better keep up the production frequency. A robot is more suitable in a factory than on a construction site. In the case that 3D printers do not become available for everyone, it most likely will be a useful aid for the precast concrete factories. It is also stated that 3D printing might better facilitate smaller projects as single house construction, rather than large complex projects. One respondent thinks that the 3D printing companies that will be created, will headhunt the best people from contractors, concrete suppliers, prefabrication factories and others. In the long run, prefabrication factories can turn out bankrupt because 3D printing technology will definitely outperform prefabricated concrete factories as we know it today. It can turn out to be a competition between the suppliers that possess the knowledge of 3D printed products.

22. Do you think a 3D printer will streamline and shorten the construction process?

Seven of the respondents answered *"yes"* to this question. The remaining respondents were unsure or had difficulties to believe in the technology since several significant issues still exist. Even some of the respondents who thought a 3D printer will streamline and shorten the construction process mentioned some challenges that must be solved properly before they fully believe in the technology.

Possible opportunities mentioned by the respondents are for instance more flexibility, easy to fix deviations and other mistakes that suddenly appear, streamlining of deliveries, no need to wait for precast concrete elements to be produced when it can be 3D printed instead. If 3D printing replaces human labour, the humans can be used to something else since there is always a lot to do on construction sites. Time and costs related to the use of crane at the site can be reduced if the construction process is faster than today with traditional construction methods. The need for improvement after construction or assembling is usually significant, but it might be reduced by implementing 3D printing.

Working at night could also be doable with 3D printers, possibly resulting in shorter construction time and costs. However, it is difficult to say whether the construction time or cost will be reduced by introducing 3D printing on construction sites.

Challenges mentioned by the respondents that are necessary to be solved before the 3D printing technology can be trusted by them are for example the reinforcement, curing time, concrete type, slow print time, all technical solutions must be done on-site and so on.

4.5 Summary of Findings

The amount of data collected through the interviews is complex and comprehensive. A summary of the most interesting data is presented here. This summary expresses the findings presented in numbers. The tables and figures presented here are addressed in the discussion chapter that follows.

Table 4-1: Findings from the interviews regarding technology

Respondents	Thought or claim	Reason, explanation or examples
11/11 (100%)	Experience their workplace as accommodating for new methods, especially if it involves new technology, but some were more in doubt than others	Those who were a bit doubtful mentioned: industry/company/groups are lagging behind, workers versus site management, attitude, culture, user interface, conservatism, stubbornness, newly educated or young employees versus older/leaders/the rest, resource availability, understand the new method/technology
11/11 (100%)	Feel they can influence which technology is being used on today's construction sites	The scope of the technology decides to what extent they could influence
7/11 (64%)	Mention BIM as a technology used in their workplace	Other technologies mentioned used in their workplace: mobiles, tablets, computers, computer programs, drilling robots, laser scan, drones, VDC, VR, AR, mobile applications and cloud-based solutions
2/11 (18%)	Find the projects they work on held back in some way due to lack of access to technology (but also lack of competence, information and knowledge)	Easy to accept the current situation. Economy versus usefulness. Expiry date of technologies, never optimal. All aids that would make the job more efficient, faster and cheaper is positive. Maybe it is not the technology that is lacking, but rather the competence and knowledge

Table 4-2: Findings from the interviews about 3D printing

Respondents	**Thought or claim**	**Reason, explanation or examples**
8/11 (73%)	Gained better understanding of what the 3D printing of concrete concept is after watching the HINDCON project video	It was seen as interesting, exciting and fancy, but not realized in the nearest future
7/11 (64%)	Thought 3D printing will streamline and shorten the construction process	It relies on a solution of several significant issues that still exist, as for example the reinforcement, curing time, concrete type, slow print time, all technical solutions must be done on-site The benefits are more flexibility, easy to fix deviations and other mistakes that suddenly appear, streamlining of deliveries, no need to wait for precast concrete elements to be produced

Table 4-3: Driving forces for new technology mentioned by the respondents

Driving forces	**Times mentioned by respondents**
Managers, leaders or other employees	5
Summer interns, newly graduated or young employees	5
Engineering consultant companies	4
Architects	3
Contractor companies	3
Developers or suppliers	3
Project owners	1
Universities or research institutions	1

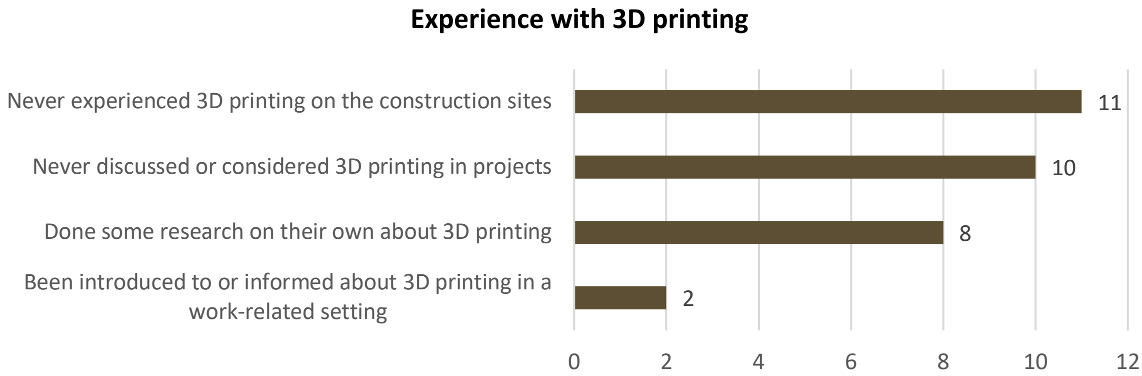

Figure 4-2: Experience with 3D printing

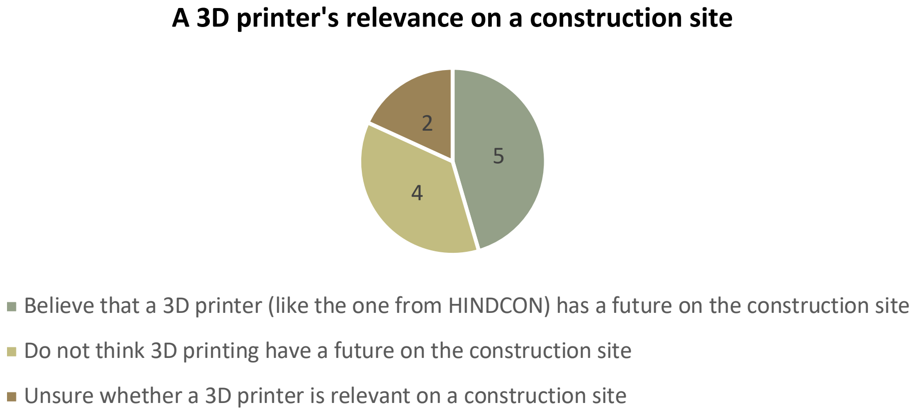

Figure 4-3: A 3D printer's relevance on a construction site

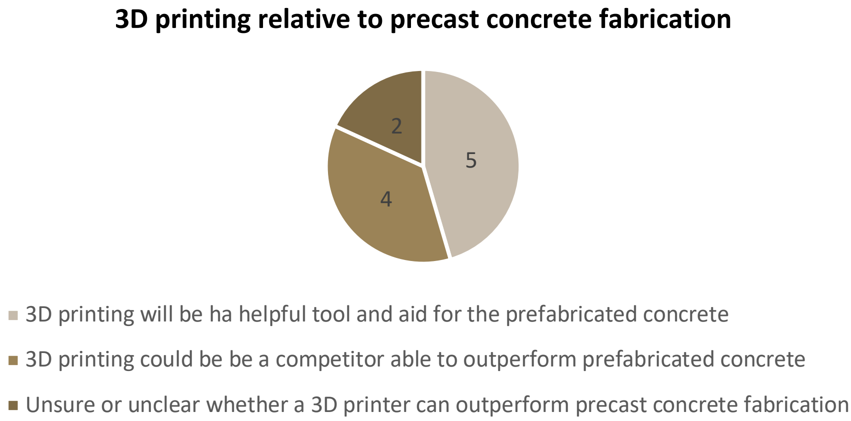

Figure 4-4: 3D printing relative to precast concrete fabrication

5 Discussion

The discussion chapter explores the empirical findings closer and compare it to the theory chapter. Justifications from the literature, previous studies, and the interview respondents are presented. The discussion chapter is divided into three sections, which aims to answer one research question each. The first section examines why the construction industry still is seen as conservative. This is connected to research question 1. The second section is about the transition to a new construction process, where research question 2 is discussed. Research question 3 about the how the construction industry is affected by a 3D printer is discussed lastly.

5.1 Conservatism in the Construction Industry

This section addresses research question 1 about new technologies in the construction industry. The construction industry is perceived by many as conservative. The theory confirms this in both the literature and a previous study (Shafqat, 2017; World Economic Forum & The Boston Consulting Group, 2016). As the previous study discovered, the top three barriers to innovation in the construction industry are conservatism, the risk associated with adopting new technology and multiple stakeholders lack in cooperation to implement innovation (Shafqat, 2017). Because the construction industry is experienced as conservative, it can partly be the reason for the slow adaption into Industry 4.0. According to studied literature and results from the interviews, the construction industry usually compares against the automotive industry, which has already entered the new industrial era. The construction industry still uses a lot of man-driven machinery and mechanical equipment with a low level of automation (Arica et al., 2017; World Economic Forum & The Boston Consulting Group, 2016). This is confirmed by the interview respondents. They also commented on the significant use of paper drawings on today's construction sites. The use of tablets among team leaders and workers on site are increasing. One respondent stated that it almost was as common with a tablet as a hammer for the construction workers. Technologies that are spreading around nowadays according to the literature are for instance related to materials science, quantum computing, artificial intelligence, Internet of Things, autonomous vehicles, robotics and 3D printing (Schwab, 2015). These technologies can contribute to keeping the value-adding activities on the construction site when building. Industrialization in construction has traditionally moved towards off-site production and prefabrication. It is stated in the literature that there exist more possibilities for production off-site where the environment is optimal (Arica et al., 2017; SINTEF, 2018). But on the construction site, for instance, robotics, autonomous vehicles and monitoring or surveillance were found as applicable (Arica et al., 2017). Fully autonomous equipment requires someone for monitoring, such equipment could be out-of-sight drones, while semi-autonomous equipment can do complex tasks but is still controlled by someone (World Economic Forum & The Boston Consulting Group, 2016). Drones were mentioned in the interviews as tested on a construction site. Advantages of all the equipment are higher quality because of fewer workmanship errors and more accuracy in the work, improved safety as a result of keeping workers out of danger zones, and clearly reduce construction costs because the delivery time becomes shorter and productivity increases. The literature also found prefabrication to be a facilitator for automation. Prefabrication is common in residential housing in Scandinavia. Residential housing is the largest contributor to global construction volume (World Economic Forum & The Boston Consulting Group, 2016). All the respondents in the research were experienced with residential housing and the use of prefabricated elements.

Digital inventions like drones, low-cost sensors, remote operations, and autonomous control systems could be developed to fit usage on the construction site. Much of this technology is likely to take place, according to the literature (World Economic Forum & The Boston Consulting Group, 2016). The changes occurring when introducing new technologies will naturally form rules that will limit the ability to shape a positive outcome of the revolution. Late adoption of new technology has historically turned out crucial for some companies, for example, Kodak (World Economic Forum & The Boston Consulting Group, 2018). This is likely to happen construction companies as well if they continue the down the conservative path and not towards innovation. In fact, loss of market share or disappearance can happen to construction companies if they are not willing to try new technology. Rewards can wait for those that dare to try, but the risk needs to be taken while at the same time not being too hesitant. A previous study showed that enablers to innovation were cost reduction and planning, together with profitability and technological development in production processes (Shafqat, 2017). At this point, planning and preparation is the key to survival and success. It was pointed out during the interviews that planning always is important.

A previous study discovered areas where innovation was experienced in the construction industry (Shafqat, 2017). The study pointed out the top three experienced innovations to be IT (including BIM and communication) with votes from 72% of the participants, followed by construction materials with a share of 58% and the last one 47% of the participants voted to be production processes. Table 4-1 summarizes important findings from the interviews regarding technology in the construction industry and in the respondents' companies. The table shows that 64% mentioned BIM as a technology used in their workplace. This technology is already spread out in the industry. The literature showed integrated BIM to be extremely likely to happen and will have an extremely high impact on the construction industry (World Economic Forum & The Boston Consulting Group, 2016). However, some respondents thought BIM-kiosk were old-fashioned technology, on the way out of the market and losing popularity. This can be an example of a situation where it is time to take action and proceed forward. As one respondent expressed, the contractor company spend too much time to examine the possibilities of new technologies, that when the decision is made, the technology is already outdated. Consequently, the technology they use will never be up to date. This shows an innovative attempt by some of the companies. As stated in Table 4-1, all respondents feel they can influence which technology is being used on today's construction sites. But because of the decentralized decision makers, the process takes too much time. One of the respondents admitted experience with good ideas newer reaching the right persons in the company. This can also be one of the reasons why the industry is perceived as conservative. If companies accept more risk regarding new technology, they can help to turn the industry towards more innovative acceptance. This will reward the whole industry in a longer perspective.

As seen in the Table 4-1, 100% of the respondents experience their workplace as accommodating for new methods, especially if it involves new technology. Following did 100% of the respondents feel that they could influence which technology is being used on today's construction sites. Alongside this, only 18% of the respondents found the projects they worked on held back in some way due to lack of access to technology. According to the respondents in this study, the contractor companies seem to provide a good environment for innovation and new technology. These findings are affirmative to what the literature discovered about innovation (World Economic Forum & The Boston Consulting Group, 2016). It was stated that some companies have tried to be innovative, but this have only been on a company level. It is still possible that the overall construction industry still is conservative. However, there is not enough evidence in this study to claim that the construction industry as a whole still is conservative or not.

The pioneering example presented in the theory about Skanska uncovers an eager to explore, develop and embrace new technology. The active role in the construction industry might be the reason why Skanska is mentioned by six of the interviewed respondents as a driving force for new technology. Veidekke was also mentioned six times, but this company had been presented to the respondents before the interview started as one of the five participating contractor companies in the research. Therefore, it would be easier to mention

Veidekke than Skanska, because it was already mentioned earlier for the respondents. The same condition applies to the other companies that were mentioned (AF, Betonmast, HENT and Ø.M. Fjeld). Because of the interview setting, it is a possibility that these companies were mentioned by the respondents to be fair and not to distinguish between the contractor companies in the study. However, although these companies were mentioned once, Skanska (and Veidekke) sticks out. The theory gave examples of developments and innovations that Skanska participate in (Bråthen et al., 2016; World Economic Forum & The Boston Consulting Group, 2016). Among many were BIM-kiosks and a 3D concrete printing project presented. Other driving forces for new technology, experienced by the respondents, are summarized in Table 4-3. The table shows that managers, leaders or other employees were mentioned five times by the respondents. The same was summer interns, newly graduates or young employees. Following was engineering consultant companies mentioned four times by the respondents. According to this, it seems like the top and bottom of the hierarchy within, for instance, a contractor company are those most involved in innovations and new technologies. There could be a connection between these groups because older employees tend to use younger employees as consultants. This could happen within a company or between companies. This situation was mentioned in the interviews as common practise internal in the companies.

The respondents were also asked where the responsibility for new technology lies. It emerged that if anyone at all has the responsibility, it can be divided into three equally responsible parts as shown in Figure 5-1. The respondents highlighted others with a responsibility to be public project owners (for example Statsbygg in Norway), the management division in contractor companies, the site management, the four or five largest companies or more generally those doing the planning and execution of projects, both on-site and off-site. If there exists a mentality in the construction industry that someone else than themselves needs to take the responsibility to drive transformation, it can end up with no one doing anything. This passiveness to innovation and new technology can contribute to the conservativeness of the industry. A respondent stated that there exists a culture in the industry supporting the statement *"everything was better before".* This culture is deeply rooted in the industry. It favours the past and is more sceptical about the present and especially the future.

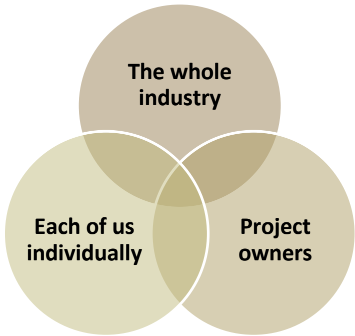

Figure 5-1: Division of the responsibility for using new technology

The literature presented more barriers to innovation in the construction industry than the ones introduced at the beginning of this subsection. The fragmentation of the construction industry and cooperation with suppliers and contractors are two challenges mentioned (World Economic Forum & The Boston Consulting Group, 2016). Since the industry consists of many contributors, it is hard to involve everyone. The respondents also marked the importance of collaboration between stakeholders in the industry to drive transformation forward. But the value chain in the construction industry can be comprehensive. This can, therefore, be another reason for the perceived conservatism in the industry. The government needs to encourage all participants in the industry to collectively tackle the challenges that come, especially related to innovation and new technology.

Construction projects often experience challenges such as high costs, long build time, lack of innovation, a product with low quality, low productivity, inefficiency, work injuries, rework and disputes. As the productivity in the construction industry has stagnated, the theory chapter explains that it is necessary with a wake-up call for the industry (World Economic Forum & The Boston Consulting Group, 2016). The construction industry needs to follow its comparison, the automotive industry, into Industry 4.0. Skanska is upfront and the rest of the industry should follow, at least prepare for changes to come. Otherwise, construction companies are risking ending up like Kodak.

5.2 Transition to a New Construction Method

This section discusses how feasible 3D printing is in the construction industry. The feasibility of the 3D concrete printer from HINDCON is also elaborated. 3D printing is in the initial phase when it comes to usage in the construction industry. Research and development are currently ongoing, for example in the HINDCON project. Because it is relatively new for the construction industry, it is difficult to predict how it will evolve. The respondents in this study were asked about 3D printing. The current level of knowledge turned out to be low. This was not surprising, because it can be seen as a radical innovation in the construction industry (Shafqat, 2017). Figure 4-2 depicts the respondents' experiences with 3D printing. Each alternative represents one statement and shows the corresponding number of respondents that agree. This clearly shows that no respondents had ever experienced 3D printing on the construction site. No one had ever discussed or considered 3D printing in projects, except one respondent who had heard about it in a meeting. 73% of the respondents had done some research about 3D printing on their own, while only 18% had been introduced to or informed about 3D printing in a work-related setting. The low level of knowledge about 3D printing can affect how the development and spread of 3D printing in the industry will be. As mentioned in the previous section, the responsibility for using new technology is shared between all the actors in the industry. The companies could be more active to inform employees of innovations and what exists. It could also be questioned whether this is each individual's responsibility. The companies have the possibility to create an environment for the employees where innovations, methods, and technologies are shared.

75% of the participants in a survey were not implementing 3D printing in their companies, according to a study (Shafqat, 2017). When the interview respondents in this research were asked about 3D printing, the first thoughts of 3D printing were differentiating a lot. The responses varied between no knowledge of what a 3D printer is to those who had a 3D printer at home. 73% of the respondents thought the short video of the HINDCON printer made it easier to continue the discussion about 3D printing as they had seen an example. The video was only 1:37 minutes, therefore it was impossible for the respondents in the given setting to get comprehensive information about the printer. The two questions that referred to the HINDCON 3D printer in the interviews were answered in a general way. It was also investigated whether the respondents thought 3D printing will streamline and shorten the construction process. 64% of the respondents thought so. But this will bring positive and negative impacts, which needs consideration. Table 4-2 gives more information about these two findings regarding 3D printing.

As stated by a previous study, 49% of the participants expect a high initial cost for 3D printing (Shafqat, 2017). Alongside this, 52% thought 3D printing *may* be cost-efficient and 43% thought it *will* be cost-efficient. The same study discovered the expected primary applications for 3D printing in the nearest future to be complex parts (75%), building blocks (69%) and small parts (58%). The respondents' imaginations of how 3D printing can be utilized on-site were, for instance, small 3D models of the construction or let the 3D printer work during the night. The respondents highlighted that a 3D printer ideally could replace repetitive work and is ideal for the production of small or complex parts in a factory. Mentioned by the respondents were also the importance to facilitate for what the desired product is, how to perform the task, plan and implement. What the 3D printer's developer think is useful for the industry might differ from what the industry needs. If the developers of 3D printers focus only on large-scale construction objects, while the industry expects or demand smaller and complex parts, it could occur a gap between supply and demand. When this gap occurs, it could already be too late for the developer to readjust to fit the actual market need. Therefore, the developers need to inform the industry of the possibilities with the new technology, while at the same time listen to what the industry wants. No matter if the technology is seen as useful when no one is interested in using it.

Another issue to consider is the aim to reduce carbon emission, which was presented in the literature (World Economic Forum & The Boston Consulting Group, 2016). One respondent brought up the concern about concrete as the right material for 3D printing. According to the respondent is timber materials more sought after nowadays. Concrete is widely used in the industry, and up to 40% of the total carbon emissions in the world are because of constructed objects (World Economic Forum & The Boston Consulting Group, 2016). It could, therefore, be questioned whether more research should be done for 3D printing in other materials than concrete. The world experiences loss of valuable minerals, metals and organic materials. Resource scarcity and sustainability requirements are considered as important with relatively high impact in the construction industry (World Economic Forum & The Boston Consulting Group, 2016). The construction industry is on top regarding raw material consumption. In spite of that, an ordinary 3D printer uses an additive manufacturing technique, which leaves behind minimal waste. The 3D printer from HINDCON will, in addition, use a subtractive manufacturing technique, which however generates significantly more waste. The HINDCON project focused, for instance, particularly on the environmental impact of the 3D printer.

An overlapping answer in this research with the previous study was the involvement of stakeholders (Shafqat, 2017). Great collaboration between suppliers and contractors are the most important success factor for implementation, followed by research and development funding for 3D printing. A study that asked several CEOs discovered that improving the integration and collaboration along the value chain was seen as important for 65% of the participants (World Economic Forum & The Boston Consulting Group, 2016). 61% of the CEOs also recommended the adoption of advanced technologies at a large scale. This could be 3D printing. Possible applications for 3D printing mentioned by the respondents in this research were foundations, girders, balconies, stairs, and columns. In the long run, they thought 3D printers or robots will affect the construction process significantly. For instance, 3D printing technology has the possibility to overtake everything in a long perspective. One respondent claimed that robots, in general, can affect the construction process, but particularly not 3D printers. More automated and standardized products, better HSE, workers who focus on being creative, fewer processes happening on-site, eliminate human errors, minimize the likelihood for deviations and errors, easier to plan build time, higher quality in shorter time, raise the quality on information and data models, start building earlier than today and increased popularity among potential buyers.

The theory presented about standardization, modularization and prefabrication, highlights advantages as fewer interface and tolerance problems, greater certainty over outcomes, increased possibilities for customization and flexibility, increased construction efficiency, better sequencing in the construction process, reduced weather-related holdups, reduced delivery time and construction cost as well as creating a safer work environment (World Economic Forum & The Boston Consulting Group, 2016). The same advantages are mentioned by the respondents in relation to 3D printing. A previous study found out that 42% of those asked expected 3D printing to be widely used in construction projects within more than eight years (Shafqat, 2017). This study indicated that 46% of the participants believed that a 3D printer has a future on the construction site. Furthermore, 36% of the participants thought the construction site will not be a future place for 3D printing. Figure 4-3 illustrates the distribution of thoughts related to 3D printing on-site. The three respondents without engineering education were more sceptical to how 3D printers could be utilized on-site or in any other applications in the industry. They had more difficulties to express themselves and to imagine a 3D printer on-site. There is not necessarily a reason for this, but it could be because of less technological background.

5.3 How the Construction Industry is Affected by 3D Printing

In this section the challenges arising from 3D printing of concrete are discussed together with how it could be handled. It was mentioned by a respondent that 3D printing could seems scary at first, so it must be presented in a thoughtful way. The respondents in the research claimed that the developers of the technology are responsible for spreading the knowledge about the new technology. The developers should for example offer courses for employees and other workers to participate in. A course could be held for a group of employees in one company at a time. The courses should include theoretical material, videos of the particular technology and present successful projects. Experiences from others than only the developer itself was seen as important by the respondents. The courses should be held either in the developer's location or in the participants' location. An important factor is to hold the course in a language the participants understand. After a theoretical course, the 3D printer should be demonstrated for the participants. Employees who participate in courses and training will get more knowledge about the technology. Increased knowledge will also increase the likelihood for increased interest, thereafter the chances for spreading the encouragement about the technology to other workers is greater. It can be challenging to choose who should participate in the courses, but it was mentioned by the respondents that the most interested employees should be first out. The sceptical ones might ask constructive questions and give more feedback to the developers, who then can improve the technology. To deliver a package together with the 3D printer when it arrives on site was mentioned several times by respondents. This could include a person with great knowledge about the 3D printer to teach the workers on site how it works. This training period was suggested to last up to half a year. The training period should lead to a certification for the other workers to independently qualify to do the 3D printer job. To let someone with for instance civil engineering background control the machine was brought up by a respondent.

Ownership and availability to the 3D printer were brought up for review in the interviews. If procurement of a 3D printer is considered, the initial investment, maintenance cost, life time and frequency of usage are factors affecting the decision. Several options for ownership or access to the 3D printer were mentioned. The different alternatives were the contractor companies, a general supplier, an external company, the concrete supplier, a 3D printing company, a subsidiary company of the contractor and the prefabrication factory. It was mentioned by the respondents that the company that offers the 3D printer also is responsible for the operation and maintenance. It would be advantageous if someone in the contractor company also possesses knowledge about a 3D printer. Depending on the user-friendliness, the workers on site can overtake the responsibility of it after training. It was also mentioned by the respondents that it most likely will be irrelevant for them to consider who the responsible for operation and maintenance is. The reason is that they will make a contract agreement telling who the responsible is anyway. The literature also addressed a possible issue regarding who the responsible should be in case something happened in conjunction with 3D printing (Arica et al., 2017).

Space concerns were mentioned by the respondents to always be a challenge on construction sites. To include a 3D printer on an already crowded site was seen as a challenge by many. The early execution phase was mentioned to be the best time able to fit a 3D printer on site. However, this decision needs to be taken early in the planning phase to prepare the best possible way. If the 3D printer is not moveable on site, it was claimed that it rather could be placed in an off-site factory instead of occupying space on the construction site. The environment for production would also be better in a factory, than on-site where it can be more disturbances. The printer could be placed in a precasting factory or in a temporary factory close to the construction site. Prefabricated building components were presented in the literature as likely to be used and with extremely high impact on the construction industry (World Economic Forum & The Boston Consulting Group, 2016). In comparison, 3D printing of components was predicted to be less likely to be used and with a lower impact in the industry. It was brought up in the interviews that the long print-time for 3D concrete elements was challenging. Additionally, each layer requires an optimal time before the next layer should be printed. The long curing needed for concrete elements made one respondent mention that it would be necessary to print on Fridays, so the elements could cure properly over the weekend. The elements would then be ready for assembling when workers are back on Monday. Whether this will be an actual issue on construction sites depends on the type of printer and chosen concrete mixture.

If the 3D printer was placed on the construction site, a fixed place or moving around, it would require a safety zone. This would not be anything new for the workers on site but increase the risk for incidents. Equipping the machine with sensors detecting if the safety zone is overstepped was mentioned by the respondents as useful. This could cause a warning signal, alarm or machine shutdown. The noise from production would be disturbing if 3D printing happened on sites with close neighbours. The respondents said it would not be different to accommodate a 3D printer on the construction site than any other kind of machine. Companies today are used to handle all kinds of equipment, from rough excavators to delicate tablets. Anyhow the 3D printer should be as robust as possible. A tent was mentioned in the interviews as possible protection for the 3D printer but had never before been profitable for the whole construction site.

A statement in the literature was that 3D printing will have a disruptive impact on the construction industry (World Economic Forum & The Boston Consulting Group, 2016). This could be in connection to for instance jobs. 3D printers will increase the automation on construction sites if they are introduced. Notwithstanding innovative products often fail to penetrate the market (World Economic Forum & The Boston Consulting Group, 2016). This could happen to 3D printers as well since the development process still is ongoing. It is also riskier for project owners and decision makers to choose products without any previous records of success. The same persons may not be updated on the latest inventions that exist. It was mentioned in the interviews that risk-eager customers can in some cases favour the use of innovative and untraditional products. This is because it makes them stick out from the rest and consequently makes a potential for greater profit.

A report presented in the theory chapter uncovers enablers and barriers for the use of 3D printing in construction (Arica et al., 2017). An enabler is, for instance, the customization opportunities with 3D printing. Despite this, uncertainty exists whether it is or will be a demand for mass customization in the industry. SMEs might experience a larger barrier due to the high costs of investment. Because the widespread of 3D printers is not great, it still remains to see financial performance over the whole life cycle. The respondents in this research were asked to elaborate on 3D printing in relation to precast concrete fabrication. 46% of the respondents thought 3D printing will be a helpful tool and aid for the prefabricated concrete. In contrast, 36% thought that 3D printing could be a competitor able to outperform prefabricated concrete. Figure 4-4 represent the result.

The theory chapter explained about Globalization 4.0, where a change is likely to hit workers either towards highly skilled and highly paid or towards low skilled and low paid (Schwab, 2019). Industry 4.0 will enlarge the gap between winners and losers in the society, where the middle class will be diluted. The world's population continues to get a larger share of older people, which will affect the construction industry. This can be seen as a reduction in available labour. The industry will also require more highly skilled workers in the future as technology advance. At the same time the technology will be more autonomous and self-driven and demand less human labour or low-skilled workers (World Economic Forum & The Boston Consulting Group, 2016). As brought up in the interviews, it was experienced that newly educated people were more interested to start working in modernized companies. The industry is however not traditionally known as glamourous, whence there might become recruitment challenges. The literature presents a study where CEOs recommend key actions to prepare for the future (World Economic Forum & The Boston Consulting Group, 2016). The majority of the CEOs (74%) thought that attracting new talents and to improve the skills of the existing workforce was important. The respondents in this study were asked if 3D printing could have an impact on current and future jobs, or whether they thought some jobs will be replaced if new jobs appear. Those who thought 3D printing will overtake jobs mentioned precast factories, that increased use of robots lead to fewer workplaces, but that someone needs to control or monitor it. Specific job positions discussed were the concrete worker, who six respondents thought could possibly be replaced, the carpenter (mentioned by four respondents), the craftworker and the steel fixer who respectively three and two respondents mentioned. The replacer was thought to be for example an assembler.

6 Conclusion

The previous chapter discussed topics related to the research questions. The conclusion chapter will summarize it and answer the research questions more clearly. The conclusion is based on what the researcher found as the most interesting and valuable results. The research has shown an overview of the current situation of technology used in the construction industry, the feasibility of 3D printing and challenges arising from it. This research gives the industry an overview of the current situation, especially for contractor companies, but at the same time prepare the whole industry for the 3D concrete printing technology.

6.1 New Technology in the Construction Industry

The construction industry is known as a conservative industry. This could, however, be doubtful when all the 11 respondents claim their company is accommodating for new technology. They also feel they can influence which technology is being used on today's construction sites. There are only two respondents claiming their projects are held back in some way due to lack of access to technology. It was found that the respondents thought managers, leaders, summer interns, newly graduated and young employees are driving forces for new technology. The responsibility for using new technology was claimed to be divided between the whole industry, the project owners and each of us individually. The innovative perception created by the contractor companies' respondents could to some extent be misleading. Some respondents mentioned technologies as, for example, drones, VR and AR. But the respondent mostly explained about trivial technologies like tablets and BIM. The interview respondents in this research indicated an interest to be innovative and embrace new technology, but it is unclear whether the contractor companies as a whole strive for the same.

6.2 3D Printing in the Construction Industry

It is hard to conclude whether 3D printing is feasible in the construction industry because the knowledge level among the 11 respondents from the contractor companies is low. None of the respondents had ever experienced 3D printing on the construction sites. Only one respondent knew it had been discussed or considered in projects. Eight of the respondents gained a better understanding of the 3D concrete printing concept after watching the HINDCON project video. Five of the respondents believed that a 3D printer, like the one from HINDCON, has a future on the construction site. It was difficult for the respondents to have an opinion about the 3D printer from HINDCON when limited project information was shared due to publishing restrictions. Apart from this particular printer, seven respondents thought 3D printing will streamline and shorten the construction process. Eight of the respondents had done research on their own about 3D printing, while only two had been introduced or informed about 3D printing in a work-related setting. Due to the related challenges and unsolved matters, many respondents struggled to imagine 3D printers as feasible for the industry today.

6.3 Challenges Arising from 3D Printing of Concrete

This research covered six challenges related to 3D printing of concrete. The challenges were training & knowledge, operation & maintenance, logistics, climate, security requirements, and reinforcement. Reinforcement was not elaborated in the interviews but mention several times by the respondents as a challenge of great importance for the technology’s development. Each of the other challenges was examined by the respondents. The respondents claimed that the developer of the 3D printing technology is responsible for spreading the knowledge of their particular technology to the industry. Training must be done in collaboration with company management if a 3D printer should be introduced on a construction site. Several options for ownership or access to the 3D printer were mentioned. The different alternatives were the contractor company, a general supplier, an external company, the concrete supplier, a 3D printing company, a subsidiary company of the contractor and the prefabrication factory. The owner of the 3D printer was claimed to be responsible for operation and maintenance, especially at the beginning of projects before the other workers hold the necessary knowledge. Concerning logistics, climate, and security, the 3D printer was evaluated whether it best fits on-site or off-site, in addition, whether the printer should be movable on site. The respondents claimed that the best environment for production would be off-site, stationed in a factory. Space concerns, climate protection, workers’ safety, and possible theft were barriers that would restrict 3D printing to be on-site, moveable or not. Five of the respondents thought 3D printing will be a helpful tool and aid for the prefabricated concrete. Some respondents thought 3D printing technology will overtake current job positions at the site and replace it with a job position as an assembler of 3D printed elements.

6.4 Value of Research

The research has practical value for the construction industry because it gives an insight to what technologies and thoughts that circulates today. Anyone can use the research to get a better understanding of the phenomenon 3D printing of concrete. The research can also be useful for companies interested to try 3D printing because it discussed different viewpoints of contractor employees that can be beneficial to know before implementing. The discussed challenges related to 3D printing are valuable to know and especially important to be prepared for. The research can supplement the HINDCON project with viewpoints from five contractor companies about 3D printing technology.

6.4.1 Limitations

This is the first master's thesis done by the researcher. The phenomenon 3D printing was new for the researcher before the work on the pre-study and this thesis started. The supervisor has been helpful with guidance and support throughout the work. The research questions limited the scope of this research. Limitations of the study must be understood in accordance with the findings. The researcher had never done interviews before. It turned out to be comprehensive because of large and complex data from the 11 interviews, all done with hand notation. The researcher alone designed the interview guide, conducted the interviews, analysed and discussed the collected data. The research must be understood as a contribution to understanding the 3D printing phenomenon and how to prepare for it. The collected data from the interviews are personal opinions of the 11 respondents from five contractor companies in Norway. Findings that comply with existing literature strengthen the reliability and validity of the study. This research presents one way to prepare the construction industry for 3D printing of concrete, but this is not the only possible way nor a final solution.

6.4.2 Further Work

Suggestions to further work are based on the research's theory and results. It is recommended to continue the researching on 3D concrete printing for large-scale use in the construction industry. This research only used a qualitative method. A quantitative method could be used to study the same topic, for example, by a larger survey covering more of the construction industry. The study could be done in the same field again, to see if the findings are similar. It could also be done again with a qualitative approach, but with more respondents or companies. The same topic could also be studied within another group than only contractor companies from the construction industry. A research about 3D printing including representatives from precast concrete factories is interesting because it could confirm the findings in this research or give a totally different view.

It was mentioned in the theory that it is of substantial matter to solve regulation issues in case of fatalities due to construction failures. Because 3D concrete printing still is under development, there exist research gaps in the theory. The terminology about 3D printing is varying. More investigations of how 3D printed elements work in large-scale constructions, particularly produced by the HINDCON hybrid 3D concrete printer, would be beneficial. This could in the future be done in a life cycle perspective. There exists uncertainty about how cost-efficient 3D printing is, which could be elaborated.

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Appendix

A - Interview guide in Norwegian

B – Interview guide in English

C – Overview of worldwide experiences with 3D printing

A – Interview Guide in Norwegian

Intervjuforberedelse til intervjuobjektene

Tema 1 – Intervjuobjektets bakgrunn og erfaring fra byggebransjen

Tema 2 – Teknologi i byggebransjen og i intervjuobjektets firma

Tema 3 – 3D printing av betong

Tema 4 – Utfordringer med 3D printere, roboter og generelt en automatisert byggeplass

Innledning

- Presentere meg selv og studieprogrammet
- Bakgrunn med studien og intervjuet
    - Målsetting: Teknologi blir stadig mer og mer vanlig på byggeplass, men 3D printere, som er en type robot, er ennå ikke utbredt. Kan 3D printere bli en viktig resurs på byggeplass?
    - Formål: Formålet med intervjuet er å kartlegge oppfatninger hos et variert utvalg ansatte i noen av de største entreprenørfirmaene i byggebransjen i Norge, om 3D printing kan benyttes på byggeplass, og eventuelt hvordan.
- Forklaring om hvorfor intervjuobjektene er interessante for akkurat denne studien
    - Variasjon i firma, stillingstittel, erfaring, antall intervjuobjekter
- Praktisk informasjon om intervjuet
    - Intervjuener på norsk, deretter oversatt til engelsk i rapporten
    - Anonymisering av intervjuopjektene
- Spørsmål i forbindelse med intervjuet?

Intervjuet

Tema 1 – Intervjuobjektets bakgrunn og erfaring fra byggebransjen

1. Hva er din alder og stillingstittel?
2. Hvor lenge har du jobbet i byggebransjen?
3. Hvilke faser av et byggeprosjekt er du delaktig i?

Tema 2 – Teknologi i byggebransjen og i intervjuobjektets firma

4. Hva slags teknologi blir brukt der du jobber? Hva vil du trekke frem?
5. Opplever du din arbeidsplass som imøtekommende til nye metoder, spesielt hvis det inneholder teknologi?
6. Opplever du at prosjektene du jobber med hindres på noen måte på grunn av manglende tilgang på teknologi?
7. Opplever du noen kollegaer eller aktører i bransjen som pådrivere for ny teknologi?
    a. I planleggingsfasen?
    b. På byggeplass?
8. Hvor ligger ansvaret for at ny teknologi skal tas i bruk?
9. Hvis du vil, kan du påvirke hvilken teknologi som tas i bruk på dagens byggeplasser? Og i hvilken grad?

Tema 3 – 3D printing av betong

10. Hva tenker du på når du hører uttrykket «3D printing av betong»?
11. Kort videosnutt om HINDCON prosjektet: https://www.youtube.com/watch?v=Y9AskMrvS5k&feature=youtu.be
12. Har det blitt brukt 3D printing, eller andre roboter, på byggeplassene hvor du har vært?
13. Har det blitt drøftet eller vurdert 3D printing i prosjekter du har vært involvert i?
14. Har du fått innføring eller orientering om 3D printing?
15. Hvordan ser du for deg at 3D printere kan utnyttes på byggeplass? Eller andre bruksområder i byggenæringen?
16. Hvordan tror du 3D printere eller roboter vil påvirke byggeprosessen på sikt?
17. Har du tro på at en 3D printer, som den fra HINDCON, har en fremtid på byggeplass?

Tema 4 – Utfordringer med 3D printere, roboter og generelt en automatisert byggeplass

18. Hvordan kan man løse utfordringer knyttet til en 3D printer på byggeplass, når det gjelder:
    a. Opplæring og kunnskap
    b. Drift og vedlikehold
    c. Logistikk
    d. Klima (nedbør, tørke, frost, vind)
    e. Sikkerhetskrav rundt roboten

19. Hvem skal eie 3D printeren? Entreprenøren, betongleverandøren eller innleid?
20. Vil en 3D printer erstatte noen av dagens arbeidsplasser? I så fall, hvilke?
21. Tror du 3D printing kan utkonkurrere prefabrikert betong?
22. Tror du en 3D printer vil effektivisere og forkorte byggeprosessen?

23. Er det noe du har lyst å si som vi ikke har kommet inn på tidligere? Eventuelt noen tema eller spørsmål du føler mangler i dette intervjuet?

B – Interview Guide in English

Interview preparation for the respondents

Topic 1 – The respondent's background and experience from the construction industry
Topic 2 – Technology in the construction industry and in the respondent's company
Topic 3 – 3D printing of concrete
Topic 4 – Challenges with 3D printers, robots and an automated construction site in general

Initiation

- Presentation of myself and my study program
- Background for the study and the interview
    - <u>Objective</u>: Technology gets more and more common on the construction site, but 3D printers, which is a kind of robot, are still not widespread. Can 3D printers become an important resource on the construction site?
    - <u>Purpose</u>: The purpose with the interview is to map beliefs within a variety of employees in some of the largest contractor companies in the construction industry in Norway, whether 3D printing can be utilized on the construction site, and eventually how.
- Explanation of why the respondents are interesting for this particular research
    - Variation in company, work title, experience, amount of respondents
- Practical information about the interview
    - Interviewing in Norwegian, thereafter translating into English in the report
    - Anonymization of respondents
- Any questions regarding the interview?

The interview

Topic 1 – The respondent's background and experience from the construction industry

1. What is your age and work title?
2. How long have you been working in the construction industry?
3. Which phases of a construction project are you involved in?

Topic 2 – Technology in the construction industry and in the respondent's company

4. What kind of technologies are used where you work? What do you want to highlight?
5. Do you experience your workplace as accommodating for new methods, especially if it involves new technology?
6. Do you find that the projects you work on are held back in any way due to lack of access to technology?
7. Do you experience any colleagues or players in the industry as the driving force for new technology?
    a. In the planning phase?
    b. On the construction site?
8. Where lies the responsibility for using new technology?
9. If you want, can you influence which technology is being used in today's construction sites? And to what extent?

Topic 3 – 3D printing of concrete

10. What do you think of when you hear the expression "3D printing of concrete"?
11. A short video of the HINDCON project: https://www.youtube.com/watch?v=Y9AskMrvS5k&feature=youtu.be
12. Have 3D printing, or other robots, been *used* at the construction sites where you have been?
13. Has it been *discussed* or *considered* 3D printing in projects you have been involved in?
14. Have you been *introduced* to or *informed* about 3D printing?
15. How do you imagine that 3D printers can be utilized on site? Or any other applications in the construction industry?
16. How do you think 3D printers or robots will affect the construction process in the long run?

17. Do you believe that a 3D printer, like the one from HINDCON, has a future on the construction site?

Topic 4 – Challenges with 3D printers, robots and an automated construction site in general

18. How to solve challenges related to a 3D printer on a construction site when it comes to:
    a. Training and knowledge
    b. Operation and maintenance
    c. Logistics
    d. Climate (precipitation, drought, frost, wind)
    e. Security requirements around the robot

19. Who should own the 3D printer? The contractor, the concrete supplier or hired elsewhere?
20. Will a 3D printer replace some of today's workplaces? If so, which ones?
21. Do you think 3D printing can outperform prefabricated concrete?
22. Do you think a 3D printer will streamline and shorten the construction process?

23. Is there anything you want to say that we did not touch upon before? Any issues or questions you feel lack in this interview?

C - Overview of Worldwide Experiences with 3D printing

Following are examples of investigations, developments, and projects using additive manufacturing techniques (3D printing) in Europe, Asia, Oceania, and America. The examples are presented according to the country of origin. The specific example of technology or project is stated alone or with the responsible institution or company presented first. The overview is summarized from: (Arica et al., 2017).

Europe

UK:

- Loughborough University: 3D Concrete Printing

France:

- Lille University of Technology: Automated Additive Manufacturing applied to Building Construction
- Nantes University: BatiPrint3D, INNOprint3D printer
- XTreeE: large-scale 3D printing technology

Spain:

- IAAC: Mini-builders, Pylos
- Tecnalia & IAAC: On Site Robotics
- 3DCONS

Sweden:

- Umeå University of Technology: 3D printing houses
- Lund University of Technology: moveable 3D printer

Germany:

- Dresden University of Technology: CONPrint3D

Italy:

- D-shape
- WASP

Slovenia:

- Betabram

The Netherlands:

- 3D Print Canal House
- MX3D
- DUS Architects: Amsterdam cabin and bathtub
- Universe Architecture: Landscape House
- CyBe Construction
- Pixelstone
- Eindhoven Technical University: 3D Concrete Printing (3DCP)

Asia

Russia:

- Specavia
- Brylin

China:

- WinSun: 3D printed apartment buildings
- Qindao Unique: world's largest 3D printer to construct houses
- Beijing HuaShang Tengda: 3D print house

Singapore:

- 3D center: The Singapore Center for 3D Printing

Oceania

Australia:

- Fastbricks robotic: Hadrian X
- FreeFAB

America

The USA:

- Apis Cor: Construction 3D printer
- Berkeley University: Bloom
- Emerging objects: 3D Printing MAKE-tank
- Contour Crafting Corporation: Robotic 3D construction printers
- Total Kustom: High-tech construction system
- Vesta Printer: Printer
- Branch Technology: Minimal material solution
- Oak Ridge National Laboratories: The Additive Manufacturing Integrated Energy (AMIE)
- SHoP: Flotsam & Jetsam
- EnvisionTEC & Viridis3D: The Robotic Additive Manufacturing System

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NTNU
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