Construction Automation – Assessment of State of the Art and Future Possibilities

Master thesis work
Advanced level, 30 credits

Product- and process development

Patrik Folkesson
Robert Lönnroos

Commissioned by: Skanska
Tutor (company): Lars Pettersson
Tutor (university): Jessica Bruch
Examiner: Antti Salonen
ABSTRACT

The world of automation has grown rapidly for the last four decades and it is driven by higher demands from users, technology development and maturity of technologies of industrial processes. Companies all over the world have automated their manufacturing processes which have led to billions of dollars in productivity and quality improvements. In the construction industry innovation transpires extremely slowly and a reluctance to implement new strategies and a low research and development budget also contribute to the slow innovation rate. Because of this, technical innovations such as automation solutions are uncommon in the construction industry. Methods and concepts from the manufacturing industry, such as lean principles and mass customization, have for some time tried to be implemented the construction industry to reach higher productivity. However, despite those efforts, automation solutions are not yet commonplace on the average construction site.

The purpose of this thesis is to investigate existing and emerging automation solutions that could be used to automate on-site construction operations with the use of digital technologies. Empirical and theoretical studies were conducted. A literature study was conducted to gain knowledge regarding the construction industry and its digitalization and general level of automation. This was then complemented with an interview study, where Skanska AB’s Technical Specialist was one of the interviewees, in addition to being the company’s mentor for this thesis. Skanska served as an example of a representative construction company since it is one of the largest construction companies in the world. To widen the data collection, the interview study included several relevant companies where their representatives were interviewed regarding their own state of digitalization and automation.

For guiding the purpose of the thesis, three research questions were formulated. The research for answering these questions led to the resulting findings regarding what is possible to automate on the construction site, what the benefits could be from implementing such solutions and what the challenges are which needs to be overcome.

The results of these studies show that the construction industry is facing challenges regarding the implementation of automation solutions. Examples of this are the lack of data in general, safety concerns and project planning operations. The currently existing industrial robots, for example, are generally heavy with low lifting capacity to weight ratio which is not much of a problem in a manufacturing setting, but it makes for an imperfect fit in the construction industry, since movability and high lifting capacity is of interest for such implementations. This thesis provides knowledge of available technologies that can be used for implementing automation at the construction site as well as what benefits can be expected from successful implementations of such solutions, such as higher productivity, increased profitability and increased safety for both equipment and personnel.

Keywords: Construction Automation, Building Information Modelling (BIM), Robotics
SAMMANFATTNING


For att leda syftet med denna studie formulerades tre forskningsfrågor. Forskningen för att svara på dessa frågor ledde till de resulterande upptäckterna om vad som är möjligt att automatisera på en byggarbetsplats, vilka fördelar det innebär samt vilka utmaningar som behöver övervinnas.

Resultaten från dessa studier visar att byggindustrin möter utmaningar gällande implementeringen av automationslösningar. Till exempel industrirobotar, som idag är bland de mest lovande hjälpmedlen för automationslösningar, används för flertalet nya sådana lösningar. Trots deras användning i byggindustrin visar det sig att de inte är helt optimala för användning i byggindustrin på grund av att de generellt sett väger mycket i förhållande till hur mycket de kan lyfta. Detta är inte ett problem i tillverkningsindustrin, men gör robotarna opassande för byggindustrin därför att det där krävs att robotarna ska vara lätta att flytta på och ha en hög lyftkapacitet. Denna studie ger kunskap om tillgänglig teknologi som kan användas för att implementera automationslösningar samt de fördelar som dessa lösningar kan ge, såsom ökad produktivitet, ökad lönsamhet och bättre säkerhet för både utrustning och personal.
ACKNOWLEDGEMENTS

The authors want to thank Skanska and Robotdalen for the opportunity to look into automation possibilities in the construction industry.

A special thanks to Lars Pettersson at Skanska for his guidance, knowledge and innovative mindset that served as an inspiration to us.

The authors also want to express gratitude to Jessica Bruch at Mälardalen University for her support and guidance.

Thanks to ABB and BIM Alliance for inviting us to their conferences and the companies that were a part of the interview study.
5 ANALYSIS .................................................................................................................................................. 37
  5.1 RESEARCH QUESTION 1 – WHAT IS POSSIBLE TO AUTOMATE ON THE CONSTRUCTION SITE WITH TODAY’S TECHNOLOGIES? ................................................................. 37
  5.2 RESEARCH QUESTION 2 – WHAT ARE THE BENEFITS OF AUTOMATION ON THE CONSTRUCTION SITE? ............................................................................................................................... 39
  5.3 RESEARCH QUESTION 3 – WHAT ARE THE CHALLENGES FOR IMPLEMENTING AUTOMATION ON THE CONSTRUCTION SITE? ............................................................. 40
  5.4 AUTOMATION CONCEPT CASE ...................................................................................................... 41
    5.4.1 Requirements ................................................................................................................................. 41
    5.4.2 Industrial robot ............................................................................................................................. 41
    5.4.3 Machine vision ............................................................................................................................. 41
    5.4.4 BIM .............................................................................................................................................. 42
    5.4.5 Mobile Platform ........................................................................................................................... 42
    5.4.6 Execution ..................................................................................................................................... 42
    5.4.7 Solidworks Layout ........................................................................................................................ 43
    5.4.8 Safety .......................................................................................................................................... 43
    5.4.9 Automation concept regarding the RQs ....................................................................................... 43

6 DISCUSSION AND CONCLUSIONS ........................................................................................................ 45

7 REFERENCES ............................................................................................................................................... 48
  7.1 GLOBAL ANALYSIS REFERENCES ................................................................................................. 52

APPENDIX – ADDITIONAL RENDITIONS OF CONCEPT CASE ..................................................................... 55
ABBREVIATIONS

AI – Artificial Intelligence
BIM – Building Information Modeling (or Building Information Management)
CA – Construction Automation
CR – Construction Robot
HRC – Human Robot Collaboration
IoT – Internet of Things
IIoT – Industrial Internet of Things
UAV – Unmanned Arial Vehicle
UGV – Unmanned Ground Vehicle
1 INTRODUCTION

In this chapter, differences between the construction and manufacturing industry is described to give light to some important aspects that sets them apart, such as general productivity and digitalization. This is then followed by the problem formulation, which was the basis for this thesis. Thereafter, the research questions are presented. Finally, the scope subchapter describes what is included into this research.

1.1 Background

The manufacturing industries and construction industry had similar productivity in the 1990s, but since then the manufacturing industry’s productivity have increased and the construction industry’s productivity have decreased (Bock, 2015). Reasons for the increase of productivity in manufacturing could be due to the benefits from automation, as identified by Frohm et al. (2006), benefits from automation in manufacturing are efficiency improvements, cost reductions and enhanced competitiveness and productivity.

The world of automation has grown rapidly for the last four decades and it is driven by higher demands from users, technology development and maturity of technologies of industrial processes (Mehta & Reddy, 2015). It’s a balance of quality, productivity, flexibility and cost that permits companies to use automation as a strategic advantage (ibid.). Fully automated processes yield excellent results while in semi-automated and manual processes the results will vary, due to the inconsistencies of human nature (Sharma, 2011). Digital technology provides data for automated manufacturing technologies (Eastman et al., 2008). According to Mehta & Reddy (2015), automation benefits from interconnected control systems and information throughout a factory so that the control of operations can be fully integrated.

The construction industry is behind other industries in digitalization and automation (Oesterreich & Teuteberg, 2016). Digitalization is an important enabler for automation. According to Richards (1994), computer models, containing all the necessary information to produce information databases for usage in the following construction stages, are needed for automation and robotics to become more prevalent in the construction industry. Furthermore, the construction industry is acknowledged to be lagging behind many other industries in terms of productivity improvements (Fulford & Standing, 2014). García De Soto et al. (2018) states that the reasons for the decrease of productivity, globally, in the construction industry are several, such as resistance to change which stems from the fact that the construction sector is very traditional. Moreover, the construction industry is suffering from poor collaboration, low data exchange and high levels of turnover making implementations of new methods challenging. Furthermore, innovation transpires extremely slowly in the construction industry (Bock 2015; Bogue 2018; Wu et al. 2016). Wu et al. (2016) adds that the construction industry is seen as a low-tech industry. The reasons behind the slow innovation rate can be because of long life-cycle, the products having high variations and complexity, diversity of dimensions and a fixed site of the construction (Bock, 2015). A reluctance to implement new strategies and a low research and development budget also contribute to the slow innovation rate (Bock, 2015). The worldwide construction industry has achieved little in technological advancement (Smith & Tardif, 2009).
Although the development and use of automation in construction is low compared to other sectors, robots in construction is not entirely new. Already in the late 1980s some robots were in use for demolishing concrete, drilling tunnels, grinding concrete, carrying loads and cleaning floors (Rahm, 1988). According to Fulford & Standing, (2014) there are great potential for productivity improvements in the construction industry and collaboration is one aspect that can improve productivity.

Seeing the benefits from using automation in the manufacturing industry, one can easily begin thinking about what automation could implicate in the construction industry. There could be much to gain from such implementations, as Vähä et al. (2013) report that automation in construction should lead to higher productivity, performance, safety, quality and value. Bouge (2018) states that the use of construction automation (CA) has the potential to return substantial operational, environmental and economic benefits. Some have seen these potential benefits and, according to Bonev et al. (2015), methods and concepts from the automotive industry have for some time tried to be implemented into research in construction to reach higher productivity.

In a complex and labor intense area such as the construction sector, the need for automating time consuming, hazardous and repetitive tasks has been in increasing demand (Panda et al., 2017). Workers with the right education or exceptional skills have never been more important than today since they can create value from the use of technology (Autor, 2015). Regarding the safety aspects of the construction sites, it is common for construction workers to suffer from injuries in the musculoskeletal system that affects movement in the human body which is commonly known as musculoskeletal disorders (MSDs) (Dzeng et al., 2017). MSDs are often caused by stressed motion that are cumulative and repeated or lifting heavy equipment suddenly, resulting in fatigue (Dzeng et al., 2017). The construction industry is in many countries one of the most dangerous industry for workers (Poh et al., 2018). The construction industry exposes workers to a dangerous and harsh working environment and have high occurrences regarding injuries and deaths compared to all other sectors (Barker et al., 2004; Zou et al., 2017). 65,000 construction workers were seriously injured and 35 with fatal injuries were reported in 2014-2015 in the UK (Health and Safety Executive (HSE), 2016). There is a substantial financial cost along with accidents in the construction sector which was reported to be £0.9 billion in 2013-2014 (Health and Safety Executive (HSE), 2016). Sharma (2011) states that, among other benefits, automation increases safety for both equipment and personnel.

Robots can work around the clock without a break and can be used for repetitive and heavy lifting tasks which increases ergonomics for workers, according to Usmanov et al. (2017), leaving more suitable work tasks for the construction workers. Robot systems have become more advanced which makes them able to work in unstructured environments and in several diverse fields (Bock, 2015). As such, these safety aspects could be improved by the use of automation, where machines can perform the heavy lifting and strenuous work tasks.

Conventional construction methods may have reached its limits according to some indicators such as performance, defect rates and growth. To conquer these limits, the construction industry could implement consequent automation, comparable to what other manufacturing and service industries has already done successfully (Bock, 2015). Automation in construction is currently in the beginning stages and can soon enter the
growth phase with implementations on a larger scale (Bock, 2015). Automation in construction can be on-site, in logistics and off-site where parts can be prefabricated (Vähä et al., 2013). A substantial part of the construction activities can be performed off-site due to advancement in Information and Communication Technology (ICT) (Vähä et al., 2013). The automation solutions surveyed for this thesis focused on the on-site fragment of CA.

Computers are continuously becoming more powerful and they are acquiring skills that can automate simple work tasks which reduces the need for workers with ordinary abilities and skills (Autor, 2015). Automation is typically substituted for labor, but it is also a complement that can lead to a higher demand for labor which can increase profit and productivity (Autor, 2015). Previously in construction, powered tools and earth-moving equipment has displaced manual labor (Autor, 2015).

1.2 Problem Formulation

A construction site is highly dynamic due to rapid changes and many moving parts (Papaioannou et al., 2017). Common problems on-site are poor communication between project phases and actors, lack of information sharing, uncertainties, reliable deliveries and material flows (Thunberg et al., 2017; Dupont et al., 2017). The construction industry has also struggled with high material wastage, costs, flat productivity, safety and shortage of labor (Bouge, 2018).

Construction projects are unique in many ways, with varying build dimensions, works tasks and also with differing project budgets. This means that automation solutions in the construction industry is challenging to implement. A major challenge with automation implementations in the construction industry is that it is an ever-changing environment and few work tasks are identically performed at each occasion (Vähä et al., 2013). One may wonder why the construction site still does not have a high level of automation, even though research in automation in construction began several decades ago.

The manufacturing industry’s counterpart which in some ways resembles the construction industry’s way of working is the low volume, high variation manufacturing, this becomes clear when comparing the two. What characterizes low volume high variation manufacturing production is, according to Jina et al., (1997), that the production volumes are between 20-500 units per year and the production planning often includes the whole make-to-order planning. Jina et al., (1997) also states that in a low volume high variation manufacturing, the products which are manufactured are of high complexity with a high amount of technology, parts and components and its production systems are often characterized by a high level of flexibility. An example of this type of production is reported by Webb, et al. (2015), where they state that, compared to other industry sectors such as pharmaceutical and automotive, the aerospace manufacturing makes relatively little use of automation, the product volumes are usually small, and its product parts variation is very high. Therefore, it can be beneficial to see what challenges that particular manufacturing sector is facing as well as how they have overcome past hurdles.

With these current problematic characteristics of the general construction industry where there is a lack of data, deeply rooted traditions regarding the way of working, slow innovation rate and a resistance to change as well as complex products and processes, the implementation of automation are undeniably challenging.
1.3 Purpose and Research Questions

The purpose of this report is to investigate existing and emerging automation solutions that could be used to automate on-site construction operations with the use of digital technologies. In order to guide the research and focus the research objective, three research questions were formulated as follows:

RQ1: What is possible to automate on the construction site with existing technologies?
RQ2: What are the benefits of automation on the construction site?
RQ3: What are the challenges for implementing automation on the construction site?

The goal is to find suitable and existing technologies that can be used and combined for implementation on-site in the construction industries.

1.4 Scope

This thesis focuses on technologies which can be relevant in the implementation of automation in the construction industry. The authors set out to find existing, or emerging, automated solutions suitable for the construction site. However, some of these solutions could also be of interest in other areas in the construction industries, an example is Building Information Modelling (BIM), which can be used in the project planning stages of construction. Theories for this research was focusing on digitalization and automation in the construction industry, as well as industrial robotics and state of the art technology related to automation.

The interview study for this thesis included information from Skanska, which focused on construction site operations. On-site construction operations imply physically oriented tasks such as handling of material, mounting, or assembling, of building material and landscaping. The companies for the interview study where chosen and included for their expertise, available technology and related business sectors.

Construction project design automations are not included in this study. Construction prefabrication is included since similarities can be found between prefabrication processes and on-site processes. Naturally, this thesis only covers technology and automation solutions available at the time of this research. This report will not address, in detail, how much labor hours will be reduced from certain automation implementations. This means that the results from the research will not report comparisons between automation implementations and its traditional counterpart in exact labor hours. Furthermore, an example case of automation implementation is suggested and explored in this thesis, where gathered information regarding technology of sensors, robotics, artificial intelligence, prefabrication and construction will be used as support for this suggested automation implementation. This example case addresses the on-site construction of so called sandwich walls, consisting of a polystyrene core, rebar and concrete.

Other business sectors may also benefit from this report if their work tasks are labor intense and dynamic, meaning that their tasks are physically demanding and the work environment and/or the task execution itself is changing for every iteration. These other business sectors would most likely benefit most from having similar preconditions as the construction industry, such as high flexibility, low volume and a high variety of products.
2 RESEARCH METHODOLOGY

According to Dadhe (2016) the research methodology is what bridges the gap between problem and solution. The methods for doing so in this thesis is covered in this chapter, where it presents an overview of the methods used in order to find solutions to the three research questions previously stated as basis for this thesis. A description of how the results of the research was interpreted is also included in this chapter, as well as a discussion of the validity and reliability of the research.

2.1 Research Design

The research methods utilized for this thesis were both theoretical and empirical. Gagnon (2010) explains that if the researchers have some preliminary ideas and conceptions of the research questions, then the research can be considered exploratory in nature, whereas it would instead be considered raw empirical if no such ideas regarding the research questions exists prior to the research. The research purpose was exploratory where the thesis sought to understand a problem or phenomenon. The research began with a literature study to gain knowledge about the construction industry and its state of automation. A global analysis was also performed to find relevant companies and technologies which were state of the art regarding construction automation. Saunders et al. (2016) states that interviews are common practice for answering questions of an exploratory nature, where the research questions often starts with “What” or “How”, which fits the research questions for this thesis. Therefore, an interview study was performed as a complement to the literature study, because it was deemed a suitable strategy for answering the research questions formulated for this thesis, where the research would benefit from multiple sources of information. As for the interview as a method for gathering data, Gagnon (2010) states that it is among the most important sources of information. In the interview study, Skanska AB’s Technical Specialist was one of the interviewees, in addition to being the company’s mentor for this thesis. Gagnon (2010) advises researchers to not become too dependent on the information provided by the interviewees, which is why the interview study in this research is a complement to the literature study.

The research for this thesis was done in close reconciliation with Skanska, since the Technical Specialist was experienced and had expertise regarding the construction industry. This was a valuable asset to the authors which helped to keep the research relevant and gave validation to many of the research findings. Skanska as a company was also an important reference to the construction industry since their position on the market makes them a substantial representation of a rather typical construction company. To widen the data collection, the interview study included several other relevant companies where their representatives were interviewed regarding their own state of digitalization and automation. From the data conceived an automation case concept was modelled in the computer program Solidworks 2017-18. This was to illustrate a possible case of near-future on-site CA, using already existing technology. In the final stages of the thesis, two conferences were attended, Utblick med BIM Alliance 2018 and Automation Scandinavia 2018. The conferences provided valuable data regarding the construction industry’s state of digitalization and automation. However, since these conferences occurred late in the thesis time span, these conferences served most to validate already gathered data.
2.2 Research Process

The research began with the literature search from which knowledge was gained regarding the construction industry and its overall level of automation. This was essential for defining the problem and assisted in generating the three research questions for this thesis. Performing a global analysis, a broad sweep of Google and YouTube was also carried out. Further information from these companies were then found through the respective companies’ web pages if such existed. In this global analysis several interesting companies were found and provided insight as to what kind of automation implementations are currently being developed. In order to gather knowledge regarding how a major construction company sees the prospects of CA, an interview study was conducted where Skanska AB was the main interviewee of the study. As a complement to the literature study, an interview study was performed where information was gathered from multiple companies, which were of interest for the authors of this thesis.

Towards the end of the research period two conferences were attended, one of which was about digitalization in the construction industry, where BIM and sustainability were central. The other one was about automation and digitalization in the manufacturing industry, where the focal point was about improving already established automation and aiming towards increased equipment connectivity and efficiency, these conferences brought validity to the previously found data in this research.

_Figure 1_ illustrates an overview of the data collection methods and their timeframes in relation to each other and the data collection period as a whole. The figure includes the analysis and report writing to show that the literature study was continued throughout the entire length of the thesis time span.

![Figure 1: Data Collection Process](image-url)
2.3 Data Collection

Data for the research was primarily gathered from the literature study, global analysis and the interview study, with two conferences attendances as complement to the aforementioned studies. These are explained in more detail in the following subsections. The results from these are presented in chapter 4.

2.3.1 Global Analysis

This analysis was conducted by utilizing Google’s and Youtube’s search engines. Search words used in this search were construction automation, construction automation and robotics and robotic construction.

The inclusion criteria were that the automation solution had to be already established or promising enough for it to be a feasible solution for the near future. With the near future being within the next ten years. Results from this search can be found in section 4.1.

2.3.2 Literature Study

The literature study provided great knowledge on the construction industry’s general operation routines and common challenges, such as safety issues and low productivity. This also provided a background of the history of construction and its overall level of digitalization and automation. Obstacles hindering automation solutions on the construction site was shortly made clear since connections could be found between early articles and articles written in the modern era, showing that some issues are deep rooted and require extensive effort to overcome. Fortunately, the literature study also exposed technologies and advanced automation solutions made to combat these issues.

In the literature study, the databases Emerald Insight and ScienceDirect served as the main sources of articles and conference proceedings. The international journal Automation in Construction, which provided many helpful articles which inspired further research. Another valuable source of literature was the proceedings of the 34th International Symposium on Automation and Robotics in Construction (ISARC 2017), which was the latest issue of ISARC at the time of this research and its contents could therefore be considered state-of-the-art. However, this issue’s content also inspired further research elsewhere, such as the 16th issue of ISARC.

Keywords for the literature search can be found in Table 1. Resulting papers ranged from a time span from 1988 to 2018, where the majority of the papers were between 2010 and 2018 since the more recent papers where of most interest for discovering state-of-the-art implementations of CA and technology. Through the snowball system, commonly used concepts and terminology was discovered. The inclusion criteria for the literature was that it had to be relevant to the topic of this research and it must be peer reviewed. Both qualitative and quantitative studies was deemed ok to include.
2.3.3 Interview Study

The interview study consisted mainly of weekly Skype meetings, of about one hour each, with the authors’ mentor, Skanska’s Lars Pettersson, technical specialist for the section Large Projects. During these meetings, the key topic was to discuss how Skanska works with automation in their construction projects and to see what research and development efforts are being made to advance digitalization and automation in the construction industry. Furthermore, in these meetings knowledge of emerging technologies and companies were shared to give light to some of the known state-of-the-art at that particular time and to promote further research. Additional interviews were held with representatives from different companies. The purpose of doing so was to gain insight into the construction industry, important applicable technology and to see what the companies’ views and state were, regarding digitalization, automation and its challenges and benefits. The interviews were open-ended with a general theme of discussion which were guided by the thesis authors. The reason for doing so was because the different companies, which was partaking in the interviews, had differing key business concepts, which was hypothesized to influence the interviews. This means that a standard questionnaire, typical for structured interviews, had undoubtedly been very difficult to establish, perhaps leading to unfruitful interviews where the interviewees would have trouble answering most of the questions. This open-ended interview structure meant that the data retrieved from each interview was mostly specific to the companies of the interviewees. However, since the topics of the interviews were similar, general trends and discussion outcomes were still easily recognizable. The authors took caution to not immediately generalize the data from the interviews, but instead sought to the other data collection methods to support the interview findings.

The companies and the title of the interviewees can be seen in Table 2. They were contacted based on their technologies and expertise which added knowledge into this report. Some of the companies chose to remain anonymous and are referred to as Company A, B etc. Note that Unibap AB was interviewed twice, but with a different company representative. All interviews were conducted for at least an hour, but no longer than one and a half hour.

---

Table 1: Literature search key words and hits

<table>
<thead>
<tr>
<th>Keywords</th>
<th>Database hits – Emerald Insight</th>
<th>Database hits - ScienceDirect</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Automation in Construction”</td>
<td>27</td>
<td>3,822</td>
</tr>
<tr>
<td>“Construction Robotics”</td>
<td>1850</td>
<td>256</td>
</tr>
<tr>
<td>“High Variation”</td>
<td>24304</td>
<td>6</td>
</tr>
<tr>
<td>”Low Volume Production”</td>
<td>27</td>
<td>255</td>
</tr>
<tr>
<td>BIM for Construction</td>
<td>580</td>
<td>3,555</td>
</tr>
<tr>
<td>“Machine learning”</td>
<td>177</td>
<td>1666</td>
</tr>
<tr>
<td>“construction industry”</td>
<td>27</td>
<td>255</td>
</tr>
<tr>
<td>“Artificial intelligence”</td>
<td>177</td>
<td>1666</td>
</tr>
<tr>
<td>“manufacturing industry”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
main interview topics were digitalization and automation benefits and challenges, where the focus was on the interviewed companies’ own states and prospects regarding digitalization and automation. The interviews took place at an office at the respective company except in two cases. The interview with FANUC Nordic AB was held at Mälardalen University and Skanska Rental responded to questions via email correspondence.

The intent was to conduct interviews with at least two companies that have similar businesses. However, this turned out to be challenging because of lack of responses and complications from geological locations.

<table>
<thead>
<tr>
<th>Company</th>
<th>Main Market Role</th>
<th>Title of interviewee</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unipab AB</td>
<td>Supplier of technical solutions, for use with industrial robotics</td>
<td>Development Manager</td>
<td>2018-03-01</td>
</tr>
<tr>
<td>ABB Robotics</td>
<td>Supplier of industrial robotics</td>
<td>Sales Manager</td>
<td>2018-03-02</td>
</tr>
<tr>
<td>Trimble Solutions Sweden AB</td>
<td>Supplier of advanced software for the construction industry, as well as total stations</td>
<td>Sales Manager</td>
<td>2018-03-06</td>
</tr>
<tr>
<td>Company A</td>
<td>Construction planning contracting (BIM)</td>
<td>Structural Engineer</td>
<td>2018-03-07</td>
</tr>
<tr>
<td>byBrick Interface AB</td>
<td>Supplier of technical solutions such as cross reality experiences (e.g. VR and AR)</td>
<td>Team Leader</td>
<td>2018-03-13</td>
</tr>
<tr>
<td>FANUC Nordic AB</td>
<td>Supplier of industrial robotics</td>
<td>Technical Director</td>
<td>2018-03-14</td>
</tr>
<tr>
<td>Company B</td>
<td>Prefabrication of concrete walls, plus transport and mounting of those</td>
<td>Production Engineer</td>
<td>2018-03-23</td>
</tr>
<tr>
<td>Smederna Sverige AB</td>
<td>Project planning, drawing, manufacturing and installation of steel constructions</td>
<td>Calculation/Sales Manager</td>
<td>2018-03-27</td>
</tr>
<tr>
<td>Build-r AB</td>
<td>Specialized drywall contractor, currently developing robotic solutions for this</td>
<td>CEO</td>
<td>2018-04-04</td>
</tr>
<tr>
<td>Skanska Hus</td>
<td>Developing and constructing houses</td>
<td>Project Manager</td>
<td>2018-04-06</td>
</tr>
<tr>
<td>Skanska Rental</td>
<td>Rental of construction equipment</td>
<td>Regional Manager, central Sweden</td>
<td>2018-04-12</td>
</tr>
<tr>
<td>Company C</td>
<td>Prefabrication of villas</td>
<td>Production Manager</td>
<td>2018-04-12</td>
</tr>
<tr>
<td>Unibap AB</td>
<td>Supplier of technical solutions, for use with industrial robotics</td>
<td>Senior Sales Director</td>
<td>2018-04-12</td>
</tr>
</tbody>
</table>
In relation to the interview study, four study visits were made. The first visit was to a company that makes prefabricated walls, the second was to a company that builds villas in modules in a factory, the third visit where to Smederna that manufacture and build steel structures and the final visit was to Munktell Science Park to observe a prototype of an automated rebar station that was developed by Skanska and Robotdalen. During the visits, qualitative interviews were held with the worksite supervisors and observations was made. This served as a means to provide further insight to a physical construction case which was helpful to the thesis and it demonstrated the validity of the research.

2.3.4 Conferences

Two conferences were attended. One was held by BIM Alliance Sweden through Smart Built Environment and the other by ABB, called Automation Scandinavia 2018. Smart Built Environment is a strategic innovation program that is financed by VINNOVA, Energimyndigheten and Formas, there are also 50 companies behind the program. BIM Alliance is a nonprofit association that is sector driven which is working with the help of BIM for a better urban development. The topics at the conference was mainly about the digitalization in the construction industry, but also about the development of BIM, artificial intelligence, sustainability and how the industry can learn from those that are ahead. The speakers in the conference was from the construction industry, Linköping University, Jönköping University, Formas and several other companies.

The ABB conference was about how companies can convert digital technology to quality, productivity and availability. The topics were several and it was not possible to attend all speakers since they were divided into several rooms. Those topics that were attended was about digital transformation in reality, digitalization in reality, and optimizing your plant. The speakers were from ABB, energy sector companies, other company representatives and a professor from KTH, the Royal Institute of Technology. During the conferences, the authors took notes and recorded both videos and audio clips for later review and analysis.

2.4 Visualization

Utilizing the gained knowledge from the interview study and literature study a visualization was made using Solidworks 2017-18. Solidworks is a program commonly used for designing and modelling products. The purpose of this visualization was to illustrate a potential future case of implemented CA, to help answer RQ1.

The visualization illustrated the robotic on-site construction of villa walls using polystyrene, rebar and concrete.

2.5 Data Analysis

Miles & Huberman (1994), defines data analysis as consisting of three parallel activities which consists of data reduction, data display and conclusion drawing. Data reduction is regarding writing summaries and making clusters, data display is the organized assembly of information and conclusion drawing implies deciding what things mean and noting regularities and patterns. These analysis activities were followed during the compilation and analysis of the gathered data for this thesis.
The analysis was built on the data collected from the literature study, the global analysis, interview study as well as the conferences. Since the conferences took place well after the other data collections, they served most to support already gathered data. The analysis was iteratively performed with the findings from the literature study in mind. This was to see any potential equivalences between the different data collections made. The extent of the matching between the gathered theories and the collected data were evaluated and discussed to see that the results correspond to reality, i.e., that they are valid.

The gathered data from the literature, the interviews, the global analysis and the conferences were filtered, compiled and analyzed separately. The digitalization and automation challenges and benefits were the focus of the analysis since it was of most interest for the authors. The compilations were thereafter cross referenced to each other in order to find similarities. From the compiled data, conclusions were drawn.

2.6 Validity and Reliability

According to Yin (2014), in any social empirical research, four tests are commonly used to establish the quality of the research. These tests are construct validity, internal validity, external validity and reliability. Clarifications of these, as well as how they were approached in this thesis is documented in the following two subsections.

2.6.1 Validity

Construct validity discusses the quality of the translation or transformation of an idea, behaviour or concept, to a functioning reality, establishing ideas of cause and effect (Trochim, 2006). To strengthen and ensure construct validity the research findings should be shared and discussed with subjects of the research, to decrease the likelihood of reporting false findings and misinterpretations (Yin, 2014). Furthermore, to strengthen the construct validity, multiple sources of data should be collected, where the findings can be triangulated to see if they point towards the same result (Yin, 2014). This method of triangulating results from different data sources enhances the credibility of research work, eliminates bias and gives light to differences between results (Ghrayeb et al., 2011). Therefore, the data collection for this thesis included both literature, interviews, global analysis and conference attendings. The thesis research findings were also continuously shared and discussed with the Skanska mentor to ensure construct validity. This process served to keep the data which was of relevance to the research questions and the answering of them and to discard data which was not relevant. This served to validate the results from the data collection and his technical expertise helped to continuously guide the research in the right direction.

The research for this thesis was exploratory in nature, for this reason internal validity was not a concern, as explained by Yin (2014), that internal validity is mainly a concern for explanatory studies, where the causal relationships between events and their outcomes needs to be addressed i.e. how and why event x leads to event y. This logic is not applicable to exploratory studies since those are not concerned with this type of causal situation.

External validity however, is applicable regardless of research method and concerns the generalizability of the research findings. This means that for an externally valid research, the findings should be valid for both the specific study conducted and beyond, again
regardless of the research method used. With this in mind, conducting both a literature study and an interview study for this thesis served to provide opportunities to triangulate findings to strengthen the external validity of the results, since the literature findings were not specific for this thesis but holds true even if used for another, similar study. The conduction and findings from the multiple interviews helped breadth the gathering of data and the resulting findings. This contributed to a wealth of data from several types of companies, all of interest regarding the construction industry. This breadth helped to find patterns in the findings, leading to increased validity of the results since it corresponded well to the real world.

The conferences that were attended gave validity on how BIM and digitalization is used in the construction industry, since many of the speakers were experts in digitalization, construction and BIM.

A potential validity risk of this research could be the authors’ lack of personal experiences regarding on-site construction work. This means that the authors’ relied on collected data to assess the current state of digitalization and automation in the construction industry. On the other hand, this also helped the authors to not have presumptions and biases prior to the research.

### 2.6.2 Reliability

Reliability in research indicates that a later investigator should be able to conduct the same research and arrive at the same findings. A requirement for this is the documentation of the research methods and procedures. The purpose of research reliability is to reduce biases and errors in a study (Yin, 2014).

In this research only one employee from Skanska AB, Technical Specialist for the section Large Projects, partook in the interview study which could be considered a weakness in both validity and reliability since there is a risk concerning bias. However, according to the Head of Research and Development at Skanska AB claims that this Technical Specialist is one of the most experienced employees at Skanska AB (Skanska, 2017). The Technical Specialist has a M.Sc. at KTH in Civil Engineering and a Ph.D. at KTH in bridge engineering. The previously mentioned iterative sharing and discussion with the Skanska mentor also served to demonstrate the reliability of the results from the data collection.

Through the collection of data from additional interviewees from several other companies, the authors sought to increase reliability in the findings. The authors kept in mind that there was a potential risk that the employees from the interviewed companies were not entirely objective. Therefore, the data gathered from the literature study, other interviewees, global analysis and conferences was closely examined to see if the data from the employees matched the other collected data.

For reliability regarding this thesis, the procedures and findings were documented for the purpose of enabling a later investigator to follow the research steps and hopefully arrive at the same results.
3 THEORETICAL FRAMEWORK

This chapter starts with a description of automation in the manufacturing industry. This is then followed by a description of the construction industry in general and how the construction companies operate on-site. Benefits with automation, as well as challenges with automation implementations are also included in this chapter. Thus, the purpose of this chapter is to give an overview of automation benefits and challenges, as well as to provide information regarding relevant technology.

3.1 Industrial Automation

Industrial automation encompasses a broad area of different discipline such as machinery, process, software, information system and electronics that works together to common goals. These goals are improved quality, increased production, maximum flexibility and lower costs. Furthermore, these goals are in conflict with each other and it is difficult to balance these goals to a strategic advantage (Mehta & Reddy, 2015). The primary reason for automation is to increase productivity and efficiency which will lead to higher competitiveness (Frohm et al., 2006). Competitiveness, quality and reliability cannot be achieved without automation of manufacturing of processes or products (Sharma, 2011). The purpose of automation is to perform tasks more reliable with higher accuracy and more efficiently than humans at a lower cost (Frohm et al., 2006).

Automation can be classified into two categories dedicated and flexible automation, where dedicated automation is performed by specially made machines for a specific product, capable of producing large volumes at low costs and flexible automation can be utilized by an industrial robot since robots can be adjusted to a variety of changes such as flexibility in capacity, products, manufacturing and equipment (Bolmsjö, 2006). Industrial robots today are used in various sectors due to their flexibility and versatility that allows them to perform various tasks together with humans or substituting them (Carbone & Gomez-Bravo, 2015; Bolmsjö, 2006). The number of industrial robots has increased over the years and has a significant role in industrial automation and are vital to increase the level of flexibility and automation in modern production system (Bolmsjö, 2006). An industrial robot can be defined as an automatically controlled reprogrammable universal manipulator which can be programmed in a minimum of three joints that can be either mobile or fixed installed for use in industrial automation (Bolmsjö, 2006).

Common tasks which are suitable for automating are tasks which involve poor ergonomics and large production volumes, hazardous processes such as high voltage, toxic and nuclear where it is unsuitable for humans to operate (Frohm et al., 2006), complex processes such as heavy computing where the reaction time for a human is far too high and also sequential shutdown and startup of plants which is time consuming for human and error is a large risk (Sharma, 2011). However, situations where automation implementations are challenging are production processes involving of a high variation of products and manufacturing of products with short life cycles (Frohm et al., 2006).

Production volumes that are less than 500 units per year is considered low volume manufacturing (Jina et al., 1997). Furthermore, what characterizes low volume production is the production planning which often includes the whole make-to-order planning. Also, the products which are manufactured are of high complexity with a high amount of
technology, parts and components and its production systems are often characterized by a high level of flexibility (Bellgran et al., 2016)

Technical advancements in industrial automation have been made possible by faster computers, better networks, more reliable software (Sharma, 2011), advanced materials and smarter devices (Mehta & Reddy, 2015). In times of fast changing technologies and rapid development, maturity and replacement of products, many companies are turning to automation to become strong competitors on the demanding market (Frohm et al., 2006). Companies all over the world have automated their manufacturing processes which have led to billions of dollars in productivity and quality improvements. Consumer demands are driving these changes since they prefer more variety, better products, lower cost and fast deliveries (Mehta & Reddy, 2015).

Robots should have user friendly interfaces, be easy to use, proactive safety and sharing work space together with workers. Moreover, automated work tasks should not be a copy of how human workers execute work tasks, but rather be built on robot-oriented planning, management, engineering and labor training (Vähä et al., 2013).

3.1.1 Automation Benefits

According to Sharma (2011) the benefits with automation are faster results and response, higher reliability and security, increased safety for equipment and personnel, contributing to higher profit and revenue, higher availability and optimization of resources. According to Lundeen (2017), industrial robots in the construction industry have potential benefits such as improving quality, shorten project lead time, lowering project cost and increasing safety. All these benefits lead to higher operational efficiency and reduced overall operational costs (Sharma, 2011). The safety benefit could be due to the fact that operators are kept out of the automation system and thereby are humans protected (Frohm et al., 2006). According to data from a study made by Frohm et al. (2006), the major benefits from using automation in manufacturing, is that it empowers higher efficiency, lower costs within production, increases competitiveness, quality. Chu et al. (2013), agrees and adds that automation in manufacturing enables improvements regarding the working environment by handling the monotonous and physically heavy work tasks so that the human workers do not have to. As an example of automation, a brick laying robot can place 800-1200 bricks per day and humans can place 300-500 bricks per day which increases productivity (Usmanov et al., 2017). In research by García de Soto et al. (2018), they found that building complex walls with robotic construction have higher productivity than with manual labor.

3.1.2 Automation Challenges

Challenges with automation in the past was limited communication between the system and its users, large inventories were planned due to nonexistent real-time information, there was limited sharing of information between other peer industries on how the best practice is performed, the lack of non-coordinated system and limited information sharing to the executives from the plant floor lead to increased energy costs of operations. Challenges according to Bolmsjö, (2006) in the past where flexibility because of increasing demand for shorter product cycles. All these past challenges have been handled due to different trained operators and technology. The technology made data more available much faster and more affordable (Mehta & Reddy, 2015).
Current challenges of automation are more efficiency, demands for less waste, improved tracking, better quality, fewer human resources, higher demand for increased production with the same or fewer resources, reduction of energy usage and Blomsjö, (2006) agrees and adds that flexibility and the level of automation are increasing challenges. Challenges in automation and control are, engineering, improving machine uptime with safety applications, remote diagnostics, motion, process, multidisciplinary control systems, plant floor to enterprise connectivity and web access (Mehta & Reddy, 2015).

Technology trends are to move to modular and scalable system instead of a single large uniform solution. This approach makes the plant able to grow with the operations which reduces capital investment at the beginning. Collecting information from automated systems have become more qualitative to support business decisions and are collected more and more in real-time (Mehta & Reddy, 2015).

3.2 Construction Industry

The construction industry sector is an enormous sector which is of high importance to the worlds’ economy. With a revenue of approximately 10 trillion USD per year, the engineering and construction industry stands for circa 6% of the global GDP (García de Soto et al., 2018). As an example, in the year of 2004, the United Kingdom’s construction industry employed about two million people spread over 168,000 firms and contributed approximately £80 billion to GDP, yearly (Barker et al., 2004).

The construction industry is facing several urgent challenges that have become more important due to increases of environmental aspects such as reducing raw materials and energy throughout the life cycle of a building (Smith & Tardif, 2009). The construction industry is frequently considered as an industry with struggling with inefficiency, poor technological advancement (Lundeen, et al., 2017), excessive use of raw materials and energy (Smith & Tardif, 2009; Bock, 2015). Buildings are one-of-a-kind products that have become more and more complex (Oesterreich & Teuteberg, 2016; Eastman et al., 2008), it requires multi-disciplinary fabrication and design skills. The construction industry needs to develop more efficient, better, faster and less expensive ways to build, design, manage, use, operate, repair, maintain and demolish buildings (Smith & Tardif, 2009). Prefabrication and pre-assembling is increasing due to economics of scale and specialization in different areas in the construction industry (Eastman et al., 2008).

The construction industry has generated information in different forms for a long time, with examples such as construction drawings, scale models, building permits, bills of materials, field reports, photographs, warranties, as-built drawings, material disposal certificates, punch lists and many other documents. These documents have not been integrated into a single platform and there is a risk that the same mistake will be repeated with digitalization (Smith & Tardif, 2009). For 50 years ago, a documentation of a building consisted of between 30 to 40 sheets and today there are about four times as many (Krygiel & Nies, 2008). Design documents of an entire building can be stored in a database by utilizing BIM (Krygiel & Nies, 2008). The construction industry’s primary challenge is more on how to exchange and organize information that are created instead of deploying modern technology (Smith & Tardif, 2009).

Most of the construction takes place on-site but up to one-third of the construction processes are carried out in factories (Smith & Tardif, 2009). Aspects that are hard to control are
weather conditions and the quality and supply of labor (ibid.). The construction industry is regarded as a craftmanship (Smith & Tardif, 2009) and is a reason why the construction industry has low a low level of automation (Bolmsjö, 2006). There is a lack of statistical data in the construction industry which makes it impossible to measure effect on productivity when implementing new technologies or making improvements. Since the implementation of new technologies is so hard to measure, the likelihood for innovation to transpire is low since there is a risk that the new implementations’ success or failure cannot be measured (Smith & Tardif, 2009). The slow innovation rate in the construction industry could be the absence of reliable business data. Furthermore, the overall construction industry suffers from deficient technological advancement and productivity gains, compared to other sectors, even farming (ibid.).

In the construction industry an industrial robot has working condition of loose tolerances, imperfect measurement and large workpiece uncertainties where for example in the manufacturing industry the requirements are tight tolerances, accurate measurement and rigid workpieces (Lundeen et al., 2017). The construction industry does not have ideal condition to implement industrial robots due to high variety of tasks performed and are encircled by disorganized materials (Chu, et al., 2013).

Tower cranes are commonly used equipment on construction sites for moving equipment, materials and personnel in a horizontal and vertical way. Since cranes are deployed outdoor it makes them sensitive to external disturbances (Chen et al., 2017). Cranes demand a large workspace and have a high impact on the efficiency and safety of the overall construction project. Crane systems are imprecise which make them difficult to control (Chen et al., 2017). Crane operators have significant responsibility since accident have a catastrophic effect on fatalities, injuries, cost and schedule delay (Fang & Cho, 2017).

### 3.2.1 Automation in Construction

An industrial robot that operates in the construction industry must model and sense their actual environment despite having access to the virtual model of the building, BIM (Lundeen et al., 2017). The purpose of Lundeen et al., (2017) research was to develop the means for a construction robot to perceive its environment could make adaptive decision to perform work tasks autonomously. Feng et al., (2015) used a single camera and designed an algorithm to enable a manipulator on a mobile robot to identify and grip a building components autonomously and assemble the components into modular structure that are pre-designed. A robotic beam assembly system is presented in Chu et al., (2013) research where a vision system could track the positions of the bolting of the steel beam to which the robot bolted the steel beams together. Navigating a Unmanned Ground Vehicle (UGV) in a dynamic and cluttered environment is performed by providing sensory information to a Fuzzy Inference System (FIS) for solving navigational challenges (Almayyahi et al., 2017).

Labonnote et al., (2016) research shows that 3D printing technologies be implemented for large-scale structures in the construction industry successfully. A new routing method of 3D printing ultra-high performance concrete is performed by using a 6-axis industrial by extruding concrete layer-by-layer through an extrusion printhead (Gosselin et al., 2016). Construction of a complex concrete wall in the modular research building called the DFAB HOUSE in Switzerland, using an industrial robot for the process steps: erect formwork, install reinforcement, place concrete and strip formwork (García de Soto et al., 2018).
Anna Kochan (2000) wrote that during the 16th International Symposium on Automation in Construction, 1999, Stefan Moser presented a paper he had been working on, where he had been developed a manipulator for spraying concrete on to a surface in a way that a minimum amount of concrete rebounds off the sprayed wall. This manipulator can be operated manually, semi-automatic or fully automatic.

In Usmanov et al., (2017) research an industrial robot that uses data from BIM for bricklaying which include, gripping, gluing, applying mortar and cutting bricks, and depallitizing.

There is a challenge in the construction industry to implement digital technologies and in Teizer et al., (2017) research Internet of Things (IoT) is used for integrating localization and environmental data into a cloud based BIM platform. Furthermore, in their research, data could be collected and visualized in real-time from actual projects. In a paper by Kochovski & Stankovski, (2018), they developed an computer architecture for facilitation of IoT applications for useages in the construction industry which could be used to support monitoring, control, safety, collaboration, supply management, etc. in real-time.

3.3 Existing Technologies

The technologies in this section are relatively new and are either implemented in the construction industry at various degrees and in different ways, or emerging technologies which can be of use in the construction industry. Several of the modern technologies are digitally based and will need computers, sensors and data to be functional. The technologies for this thesis were chosen because they were prominent in many articles found during the literature study, which lead to further study of those, leading to their inclusion.

3.3.1 Artificial Intelligence

Artificial Intelligence (AI) communicate with programs that have the abilities to make decision to solve problems. AI can be used for interpretation, perception, learning, reasoning, decision making and communication (Kumar, 2017). Key characteristics of AI are better handling, adaptive control and stored knowledge that can be reused. AI system have been developed for virtual reality, computer vision, robotics, image processing, automation, automated reasoning, pattern recognition, process planning, etc. (ibid.). Machine learning (ML) are increasing in industrial settings and low barriers are allowing for innovations that the manufacturing industry are starting to gain benefits from (Sharp et al., 2018).

3.3.2 Additive Manufacturing

3D-printing have been attempted several times in construction for the purpose to reduce construction time, increase customization and improve affordability (Wu et al., 2016). Cementitious material that can be 3D printed is a promising and innovative construction method that have been growing in recent years (Ma et al., 2018; Wu et al., 2016). The 3D-printing process works by adding material in layer by layer which builds a structure up via a computer designed file (Ma et al., 2018; Gosselin et al., 2016). Previously, additive manufacturing has only been used in biomedical and aeronautical industries due to high cost for materials (Gosselin et al., 2016). Additive manufacturing can reduce construction time,
increase customization, reduce construction cost and manpower. Additive manufacturing is limited by the lack of development of BIM and large-scale implementation, life cycle cost and mass customization requirements (Wu, et al., 2016). Contour crafting is when the external and internal skins of the wall is 3D-printed and is later filled with a concrete substance (Wu, et al., 2016). Factors that must be considered are availability of printing materials, accuracy of the printing, printing time and the printing process cost (Wu et al., 2016).

### 3.3.3 Drones

Unmanned Ground Vehicles (UGV) are purpose-built transportation machines that are programmable and by using sensors information can be gathered and extracted from its surrounding without human intervention (Almayyahi et al., 2017). According to Tatum & Liu (2017), drones, or Unmanned Aerial Vehicles (UAVs), are aircrafts which are unmanned and controlled by a pilot on the ground. Drones can also, more broadly, refer to equipment which is operated independent of human control. In recent years UAV have been easier to control, more reliable and less expensive due to technology advancements (Tatum & Liu, 2017). UAV can be used to inspect structures, quantifying material in landfills, construction monitoring and deterioration analysis (Freimuth et al., 2017). According to Tatum & Liu (2017) 61% of the construction industry in the U.S use UAVs in some way and mainly for video and photos and Bouge, (2018) said that in the UK the number is 12%. Some risk can be avoided when using UAVs instead of for example inspections on scaffolds (Tatum & Liu, 2017).

According to Tomita et al. (2017), drones can be used for a task in building equipment works in which air volume is measured. This task is conventionally performed by workers where they have to manually approach the ceiling and take measurements of the air volume just under the air diffuser, using a handheld anemometer. This is a process which has low productivity and require extensive safety management. Tomita et al. (2017) found that measurements, of satisfactory accuracy, can be made using a UAV in place of a worker, which is less time consuming and presents less risk of injury.

For complex tasks that will be carried out by a machine, a vision system should be installed. Artificial vision systems can be used in automated inspection, vehicle guidance, surveillance, biometric measurement, traffic control and monitoring, robot assembly and analysis of remote images (Davies, 2012).

### 3.3.4 Internet of Things (IoT)

IoT’s relevance when discussing digitalization and automation in construction is evident, as Kochovski and Stankovski (2018) states, that IoT elements such as electronic signalization, robotics, sensors, actuators and other internet connected devices may soon make available innovative smart applications in the construction industry. Bouge (2018) states that robotics is expected to play a leading role in technological innovation for overcoming the current limitations in the construction industry, such as material waste and poor productivity.

There is no uniform and clear definition of what IoT is since it is constantly changing (Zhang & Tao, 2017), but there is a simple definition of the Internet of Things according to Wafer, (2015, p.32) is:
“The IoT is what we get when we connect, Things, which are not operated by humans, to the Internet.”

This definition correlates to four components which are connection that are linked to communications protocols, things are linked to actuators, sensors, controllers, etc, non-operation by humans to provisioning and the internet are linked to security, authorization, interoperability and more (Wahe, 2015).

IoT constitutes of different devises such as sensors, Radio-Frequency Identification (RFID) tags, mobile devices, embedded computers, actuators and computers that are interconnected through a world-wide network. IoT can be used to build decentralized systems with smart objects that can exchange information and cooperate with other computing devises, humans and have some autonomy (Ochoa & Fortino, 2017; Zhang & Tao, 2017). IoT provides real-time data to be collected and communicated within a system which makes it more intelligent and increase transparency and flexibility (Zhang & Tao, 2017). IoT provides solutions and standards that are Internet-based and open source and can gather data from all machine or devices (Georgakopoulos et al., 2016). Important part of IoT communication system is interoperability, connectivity and integration (Buyya & Dastjerdi, 2016). Reliable computing system is important to build so that the system can operate without failure which is a requirement for scientific and business community (Buyya & Dastjerdi, 2016). Key challenges of IoT is advancing the use of AI, interoperability between different platforms, creating simple user experiences and data protection (Briodagh, 2017). The IoT devices needs to talk to each other and the internet based on the current situation (Buyya & Dastjerdi, 2016). IoT needs AI to analyze and interpret data and since a large volume of data will be generated which cannot be handled manually since instant decision making is critical (Briodagh, 2017).

Trillions of IoT could in the future be connected which is much more than the regular internet who serve billions (Hofmann & Rusch, 2017). There are more than 2 billion smartphones connected to the internet and IoT is expected to reach 50 billion by 2020 according to Buyya & Dastjerdi, (2016) and 20 billion according to Kochovski & Stankovski, (2018). In the construction industry the use of IoT can enable smart applications for usage in the near future such as sensors, robots, electronic signals, actuators etc. which could support monitoring, control, safety, collaboration, supply management, etc. (Kochovski & Stankovski, 2018).

Confidential information should only be accessed by authorized entities such as company members, gateway and security system which means that data transfers must be secure so that it provides end-to-end security (Buyya & Dastjerdi, 2016). Development challenges of IoT are among other things about the security which the industry and the research community are trying to solve (Ochoa & Fortino, 2017). Service provider have their focus in interoperability and availability which is why the security aspects has been mainly unattended. IoT sensors and devises can gather large amount of data but are very limited in battery, memory and computational power (Buyya & Dastjerdi, 2016).

Industrial Internet of Things (IIoT) is used by high-tech companies and it consists of big data analysis, machine to machine (M2M) communication and machine learning techniques. M2M allows for machines to relay and communicate information (Briodagh, 2017). Companies that use IIoT can find and correct problems faster since humans are not as
accurate in data collection and communication which saves time and money (Buuya & Dastjerdi, 2016).

Internet of Vehicles (IoV) is communication between vehicles and vehicles, vehicles and roads and vehicles and cities by using different kinds of mobile-communication technology. IoV makes it possible for collecting and sharing data about roads, vehicles and the surroundings. These data can be used to supervise and guide vehicles. IoV can also support intelligent vehicles control, intelligent traffic management etc. There are several different researches in IoV such as cloud computing, autopilot vehicles, intelligent transportation and mobile computing. Application for IoV are efficient service, driving safety, information services and intelligent traffic management. IoV will revolutionize changes in both functionality and technology (Buuya & Dastjerdi, 2016).

When setting up a simple IoT infrastructure, key requirements that must be considered are that the hardware and software should have a low cost, choosing high-level programming languages, possibility for enterprise scalability, hardware should be available and commodity and some experience in computing and electronics is required (Buuya & Dastjerdi, 2016).

### 3.3.5 BIM Building Information Modelling/Management (BIM)

BIM is a digital representation of functional and physical appearances of a facility (Dupont et al., 2017; Krygiel & Nies, 2008), and it has information about spatial relationships, geographical information, geometry, properties of building components, quantities and light analysis (Vähä, et al., 2013). Even when an accurate model is created there is a risk that human errors could occur during the installation and finding these early are of immense value (Eastman et al., 2008). BIM also have the ability to gather all design process stages of a building into a database (Krygiel & Nies, 2008). A digital model can be created with BIM technology that contains data to support the construction, precise geometry, procurement activities and the lifecycle of a building that can provide a ground for new construction capabilities (Eastman, et al., 2008). A definition of BIM is the use and creation of computable, consistent and coordinated information about the design in a building project, parametric information is used for cost estimations, production of construction documents, decision making, building performance and construction planning (Krygiel & Nies, 2008). The research of BIM is growing and there is a rapid adoption and development in BIM technologies (Zou et al., 2017; Krygiel & Nies, 2008). Building Information Modeling (BIM) is used in Architecture, engineering and construction (AEC) and is developing the most (Eastman et al., 2008; Krygiel & Nies, 2008). BIM can be seen as a collaborative process that cover design, construction and also the maintenance process which provides information to all parties that are involved in the project (Ghaffarianhoseini et al 2017; Krygiel & Nies, 2008). BIM has been seen as a solution to collaboration in the construction industry but in Liu et al., (2017) research they found that in some projects in collaborative design and construction that collaboration is limited despite working with BIM technology.

BIM is an empowering technology, although its implementation is more of a business decision than a technical decision, which use has several potential benefits such as improve the quality of information for decision making, improve communication between business partners, reducing cycle time, improving the quality of delivered services as well as cutting costs at every stage in a building’s life cycle (Smith & Tardif, 2009). To unlock the most of
these benefits many businesses must change their processes and workflows, since BIM itself will not provide these benefits, only provide the possibilities of these benefits (ibid.). Advantages with BIM is reduced project duration, lower cost and better-quality buildings (Eastman et al., 2008), predict collisions, calculate time and material quantities and show environmental values on building designs (Krygiel & Nies, 2008). When using BIM better decision regarding costs can be made than of a system that is paper-based (Eastman et al., 2008). BIM can also be used for simulation purposes that reveals for each day how the building will look like which leave rooms for improvements and potential problems such as safety problems, equipment, conflicts, crew, site, space etc. (ibid.).

Temporary construction objects can be added into BIM, such as scaffolding, shoring and cranes and be linked to schedules (Eastman et al., 2008). Today BIM is generally used for planning since it does not typically contain as-built information (Vähä et al., 2013). BIM could provide a precise model, scheduling and planning could be performed with high accuracy (Krygiel & Nies, 2008), with just-in-time arrival of equipment, people and materials (Eastman et al., 2008). Benefits from using BIM for fabricators and subcontractors are reduced cycle-times, data for automated manufacturing technologies, enhanced rendering and marketing and improved prefabrication and pre-assembly (ibid.). Close collaboration with construction and design teams is possible when adopting BIM, which will make construction deliveries more reliable, less costly, reduces errors and enables faster processes (Eastman et al., 2008; Krygiel & Nies, 2008). There are several benefits for facility managers and owners when using BIM such as using the as-built information as a database for spaces, rooms and equipment to optimize facility maintenance and management and improve overall building performance through energy analysis and design (Eastman et al., 2008), furnishing and scheduling in the project (Krygiel & Nies, 2008).

Utilizing BIM in the construction industry has major advantages that saves resources (Eastman et al., 2008). With the utilization of BIM, the scattered documentation system can be replaced by an intelligent system with a central database that is able to analyze data instantly (Krygiel & Nies, 2008). A building model that is as-built benefits the project team and all members in it (Eastman et al., 2008). It reduces conflicts and errors and the planning process becomes smoother (Eastman et al., 2008; Krygiel & Nies, 2008). In the project planning phase contractor’s knowledge is seldom utilized due to traditional design-bid-build method which they could have add significant value, those contractors that are working in collaboration during the design phase with project teams encounter fewer BIM related barriers in adoption (Eastman et al., 2008). In a design-bide-build process the consultant and architect design the building and then send to contractors who place a bid on the job (Krygiel & Nies, 2008). Typically, collaboration does not start until the low bid contractor has been awarded the job when working in a design-bid-build environment (Eastman et al., 2008). Documents are usually sent back and forth between project members which increase the risk of errors and miscommunication (Krygiel & Nies, 2008). It is important that contractors must try to involve fabricators and subcontractors in an early stage in the project (Eastman et al., 2008). Close contractor coordination is one of the most important aspects since clash detection and correction of these can be avoided before problems occurs which also allows for increased prefabrication which improves accuracy and reduces field time and cost (ibid.). A strong point of BIM is the sharing of information, as Smith & Tardif (2009) points out, where they put emphasis on the fact that creating a single building model is not the end goal with using BIM, but rather to compile all-inclusive accessible and reliable building information which should be easily exchangeable for anyone who desires it, at any point in the building’s life cycle. However, a challenge in sharing BIM online is cyber

21
security since data is accessible to team members which means that copyright infringement and unauthorized access could become a problem (Ghaffarianhoseini et al., 2017).

BIM is commonly used in the engineering and design phase and there have not been many attempts to combine BIM with sensors for the purpose to have a real-time data storage of the building (Vähä et al., 2013; Dupont et al., 2017). Successful BIM implementation should be done throughout the whole company and it requires that management and other key employees attains full understanding of how work processes are supported by BIM (Eastman et al., 2008). In order to expand the use of BIM in operation, adaptive and flexible data collection systems need to be created that can provide physical data into a software system (Dupont, et al., 2017). The BIM technology is not the current bottleneck but rather the absence of knowledge in employees stands in the way of widespread implementation (Eastman et al., 2008). It is a significant learning curve in using BIM technology and contractors should be aware of this (Eastman et al., 2008). The transition from drawings to a digital model is not easy since changes must be made in almost every business relationship and process. Furthermore, to make the transition as smooth as possible it is important to attain consultants that can help to guide the transition and plan changes carefully (ibid.).

Technologies that can be used with BIM are for example machine-guidance, laser scanning, GPS and RFID. Machine-guidance can be used by earthwork contractors by extracting information from BIM to verify and guide excavation activates. Laser scanning can report measurement data directly into BIM to capture as-built information. GPS gives the contractor the ability to verify locations of the building model. RFID can be used to track installation and component delivery on-site and can provide contractors with field progress and installation (Eastman, et al., 2008). Sensors can be used by robots to obtain as-built information and update that information automatically into BIM (Vähä et al., 2013). Advance sensors and BIM will have a large part in automation in logistic, prefabrication and on-site operations (ibid.).

BIM is a work in progress and developments of it makes it more widespread. The cost of a digital model of a building is estimated to around 0.1 % of the total construction cost which is offset by savings in fewer workers on-site, shortened project durations, improved collaboration and better prefabrication options (Eastman et al., 2008). Building processes have been developed in the construction industry through many years and few of these “standard” procedures and practices have been documented (Smith & Tardif, 2009). Activities that involves information exchanges and all activities that are required to construct a building must be documented. It demands too much resources for a single organization to do this job which means that the whole industry must work together to accomplish this (ibid.).

Migilinskas et al. (2013), states that the implementation of BIM technology will lead to benefits such as improved efficiency in the construction industry, through increased collaboration between the different parties involved in the projects, as well as fewer collisions and a lowered need for corrective work and adjustments.
4 EMPIRICAL FINDINGS

In this section, Skanska and the results that have been obtained from empirical facts and the data collections are presented.

4.1 Introduction of Skanska

Skanska was formed in 1887 in Sweden and is one of the biggest construction companies in the world with 40,800 employees in ten countries in Europe and in the U.S. 9,200 employees are located in Sweden. Skanska’s core function is to build, develop and to maintain buildings, infrastructure, hospitals, schools, maintenance etc. In Sweden Skanska is divided into four main areas which are residential development, construction, infrastructure development and commercial real estate development. Residential development is targeting specific markets and groups and the core is to increase the quality of life. With every new project, substantial analysis is carried out and Skanska adjust their proposition based on people’s needs and dreams. Construction is the oldest and the largest branch which renovates and builds factories, houses, housing and infrastructure. Infrastructure development are developing sustainable solutions for hospitals, schools and roads. Commercial real estate development invests, initiates and develops commercial real estate. The projects are long-term and can take between five to ten years from idea to finished building (Skanska, 2018).

Skanska has a vision with zero injuries at the work site which is their top priority and they have been working on increased safety since the year 2000. Skanska also has a vision to be climate neutral in their entire value chain in 2050 and is working hard to reach this goal (ibid.).

Skanska searching for automated solution to implement that can increase productivity and safety and reduce heavy and repetitive task for construction workers which is the reason behind this thesis.

4.1.1 Skanska’s Automation State

Skanska generally has no automation that is widespread and fully implemented. However, Skanska have begun to use advanced technologies for aiding in different construction phases. Skanska is funding several research projects and one of these is called ARRAY (Automation Region Research Academy) which is an industry research school for Ph.D. students. The research school is in collaboration between Mälardalen University, ABB, Volvo CE, Skanska, Sandvik, First Control, Automation Region, Robotdalen and RISE SICS Västerås and will start in the fall of 2018 (Sektionen för kommunikation och externa relationer, 2017).

Skanska, Volvo CE, Swedish Energy Agency (SEA), Mälardalen’s and Linköping’s universities have established a collaboration in developing construction machines that are running on electric batteries instead of diesel. The cost of the project is €22 million and will be tested in 2018 and Volvo estimates that energy usages will be reduces by 71 %. The machines will be used in a quarry for testing since it has a less dynamic environment than a construction site. Machines that are fully electric could be used in the future to be fully autonomous, guided by computer (Volvo CE, 2017).
Skanska has, in collaboration with Robotdalen, developed an automatic rebar station in scale 1:3. The purpose of the station is to build prefabricated reinforcement cages on the construction site and then lift the cages into place, one by one. There are three industrial robots mounted in a gantry that are collaborating in lifting the rebars and lashing them into place. Building these cages manually on-site is heavy and not ergonomic and is therefore an optimal work task to automate. The plan is to build an automatic rebar station in full scale and use it for large construction projects.

When Skanska was reproducing a bridge in the city Arboga which was finished 2012, they worked only with digital drawings. The digital model was updated on-site if there were any changes. Skanska had a BIM department that used the program Tekla Structures on-site for aiding the construction workers and making adjustment in the digital model as the work progressed. Tablets were used to view the drawings instead of on paper.

In Sweden, the project planning is typically not finished when the on-site construction begins which means that many questions must be solved on-site. Skanska uses BIM in visualization and planning since several years back and all employees have access to it. Skanska can reduce a lot of disturbances with BIM and it is a natural part in their projects. However, the use of BIM generally stops after the project planning, but Skanska have made several projects where the BIM-model was updated and alive throughout the entire construction phase. Skanska has a global expert group that have regular meetings where they share information and experiences among the countries.

Skanska Hus is a subdivision of Skanska that constructs buildings in the range of 30 million SEK or more. Skanska Hus prefers to build new buildings since refurbishing projects often adds unforeseen costs. During the construction phase, they use building methods that are well established. Skanska Hus tries to implement digital tools in the process and wants to set the bar high regarding digitalization. Before every building project starts they decide which tools and machines will be necessary for the project. These must then be rented from Skanska Rental or purchased from a retailer. Skanska Hus mostly uses prefabricated construction elements since it is usually cheaper and smoother to work with than casting on-site. Skanska has a meeting every week where sometimes new technologies is discussed, and how leftover material can be used from finished projects.

Skanska Rental is one of the big actors in Sweden when it comes to rental of machines and equipment. Their machine portfolio contains everything from an electric screwdriver to cranes and elevators. Their equipment and machines are leased to many actors in the construction industry, including Skanska. Skanska Rental acts as a guide and work closely with their customer. Currently Skanska Rental does not currently possess any automated equipment or machines, but they are constantly updating their machine portfolio. The customer demand is an important factor when choosing equipment and machines and all project are unique.

During the thesis work, Skanska expressed interest in exploring the possibilities of using existing technology for automating the on-site construction of villa walls, of the type referred to as sandwich. These walls are utilizing a zigzag rebar technique in prefabricated blocks of polystyrene which, after the assembly, gets covered in concrete on both sides of the wall. This example case was used to create a near-future concept of implemented CA, illustrated with Solidworks 2017-18.
4.2 Global Analysis - State-of-the-art implementations

These state-of-the-art implementations companies are either new or already established in the construction industry at various degrees and in different ways, or emerging and will likely be established in the construction industry in the near future.

Fastbrick which is an Australian company is currently developing the Hadrian X that will soon be launched onto the construction site and will build brick houses with a crane that is mounted on a truck. According to Fastbrick they will improve safety, cost, accuracy, waste management and speed in the construction industry. Hadrian X have millimeter precision due to a multi-axis stabilization system that stabilize the motion of the long boom. CAD-files are used to guide to robot (Fastbrick Robotics, 2018). Caterpillar Inc. and Fastbrick have signed Memorandum of Understanding (MOU) for collaboration on how Fastbrick Robotics technology can be developed and are discussing questions regarding manufacturing, service and sales. The MOU spans for twelve months which can be expanded when the term has ended or terminated at any time by both parties. Fastbrick deals exclusively with Caterpillar during the MOU for commercialization and development with Fastbrick’s technology (Caterpillar, 2017). Caterpillar is a company from USA and is leading in natural gas and diesel engines, manufacturer of mining and construction equipment, diesel-electric locomotives and industrial gas turbines (Caterpillar, 2017).

nLink is a company from Norway which uses an industrial robot together with a mobile platform from Alitrak and a scissor lift to drill holes with high precision in the ceiling on the construction site. The holes coordinates are based on a BIM model or construction drawings and all holes are registered to keep BIM models and drawings updated. The robot is controlled by an app and a laser and work alongside with construction workers. Safety will increase, and project completion will be faster by using nLink drilling robot which are in demand all over the world by mechanical, electrical and plumbing contractors (nLink, 2017). Alitrak is a manufacturer of electric vehicles that runs on batteries and their product DCT-450 is a remote controlled electric vehicle on caterpillar treads. DCT-450 have a loading capacity of 450 kg and a weight of 463 kg (Alitrak, 2018).

Build-r is a company from Sweden that uses an industrial robot mounted onto a mobile platform to install drywall on the construction site which increases the productivity and relieves workers from monotonous and heavy tasks. Build-r’s robot will work alongside workers and be used to unlock the night shift (Build-r, 2018). There are currently two-thirds of the day and night that the construction is standing still. Build-r’s drywall robot will increase production in the construction industry by installing drywall at night. There is a need for higher production in the construction industry since 700,000 new housings are to be built by the year 2025. Many contractors such as painters, electrician, plumbers depend on the drywall installation being done on-time since their work tasks are done afterwards (Smart Built Environment, 2017). Build-r are collaborating with both ABB and NCC and have received grants from Smart Built Environment (Build-r, 2017).

MX3D is an additive manufacturing company located in the Netherlands and use industrial robots for creating new ways for robots to 3D print metal in any shape and size. MX3D are collaborating with ABB, Autodesk, Air Liquide & Oerlikon and several other companies to make their technology available to industry. They are currently 3D printing a steel bridge in a factory that will be installed in 2019 in Amsterdam. They believe that machine learning and AI will make robots better to perform their tasks and that automation will become a
standard in producing unique computer-generated structures and part within 10 years. The aim of MX3D is to build robust machines for heavy-duty industrial use outside and on-site construction. Their software would be adapted to all the different manufacturer of robots and welding machines (MX3D, 2018).

ETH Zürich is a university for technology and science in Switzerland (ETH Zürich, 2018). ETH Zürich are currently building a three-story building with 200 m$^2$ floor space called DFAB HOUSE (digitally fabricated house). This house is the first building in the world to be planned, built and designed using mainly digital processes. Several experts, scientists and engineers from ETH Zürich are collaborating with business partners to take new digital technologies from the laboratory into practice. When using several digital building technologies together it is possible to use their individual advantages and their synergies. Technologies that will be used are 3D printing for formworks for ceiling slabs and industrial robots that builds walls. ETH Zürich use a two-meter-high robot mounted on a platform that moves around with caterpillar tracks. The robot fabricates a curved steel wire mesh wall that acts as a reinforcement of the concrete and formworks. Cooperating robots will prefabricate two individual rooms using Spatial Timber Assemblies. A large 3D sand printer will be used to form the formworks of the ceiling slab. The purpose for this project is to examine how construction can be more efficient and sustainable as well as how to improve designs with the use of digital technologies (ETH Zürich, 2017).

Komatsu, which is a Japanese company and one of the largest manufacturer of mining and construction equipment, have chosen NVIDIA from USA as a partner for introducing artificial intelligence to the construction site for increasing productivity and safety. Nvidia will analyze and visualize the entire construction site with their Graphic Processing Unit (GPU). Nvidia have an AI platform called NVIDIA Jetson that will function as a brain for the heavy machinery on-site. Nvidia’s CEO and founder Jensen Huang said that mining and construction industries will benefit in both efficiency and safety since heavy machinery will be able to perceive their surroundings. Improvements made by AI will be suitable for the construction industry since construction sites are considered hazardous due to uneven terrain, heavy equipment and continuous activity. As an example, in Japan 2016 there were 15,000 injuries and 300 deaths in the construction industry (Nvidia, 2017).

Construction Robotics from USA have developed and implemented a brick laying robot called SAM100 on the construction site for setting up the final wall. SAM100 increases productivity by three to five times and reduces lifting by 80 percent. In addition, it also reduces labor by 50 percent and increases safety and health. It is a collaborative robot that work alongside with masons and have worked together with 148 masons at 29 different construction sites (Construction Robotics, 2018). SAM100 has the capability to lay 2,000-3,000 bricks in a day, which can be compared to a human worker’s average of circa 400-500 bricks per day. (Bouge, 2018)

Odico Formwork Robotics from Denmark can produce affordable and fast, complex, architectural geometries which would otherwise be expensive. Odico claims that their technology can improve the efficiency up to 100 %, compared to existing solutions. They are the first company to use industrial robots to cut advanced casting molds in expanded polystyrene with their own developed software. Odico provides hot-wire cutting, hot-blade cutting, milling, clay cutting, abrasive wire cutting and coating technologies which is all done with an industrial robot, or several robots working in collaboration (Odico Formwork Robotics, 2018).
4.2.1 State-of-the-art summary

A summary of the state-of-the-art implementation can be seen in Table 3.

Table 3 – Summary of the state-of-the-art

<table>
<thead>
<tr>
<th>Company</th>
<th>Key area of business</th>
<th>Possible to automate in construction</th>
<th>Automation benefits in construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastbrick</td>
<td>Automatic bricklaying</td>
<td>Bricklaying on-site</td>
<td>safety, cost, accuracy, waste management, speed</td>
</tr>
<tr>
<td>nLink</td>
<td>Drilling holes on-site with coordinates from BIM</td>
<td>Drilling on-site</td>
<td>High accuracy, speed</td>
</tr>
<tr>
<td>Build-r</td>
<td>Automation in construction</td>
<td>Installation of drywalls, screwing</td>
<td>Increase productivity, reduce heavy and monotonous task</td>
</tr>
<tr>
<td>MX3D</td>
<td>Additive manufacturing</td>
<td>3D printing of steel bridges</td>
<td>Complex shapes</td>
</tr>
<tr>
<td>ETH Zürich</td>
<td>University: digitally fabricated house (DFAB)</td>
<td>3D printing for formworks for ceiling slabs, industrial robots that builds walls, Spatial Timber Assemblies,</td>
<td>Possible more efficient and sustainable</td>
</tr>
<tr>
<td>Komatsu</td>
<td>Construction equipment</td>
<td>Autonomous construction vehicles</td>
<td>Increase productivity and safety</td>
</tr>
<tr>
<td>Construction Robotics</td>
<td>Bricklaying</td>
<td>Semi-automatic bricklaying</td>
<td>increases productivity, safety, health and reduce labor</td>
</tr>
<tr>
<td>Odico</td>
<td>Produce complex architectural geometries</td>
<td>Cutting and milling complex shapes</td>
<td>Improve speed and efficiency</td>
</tr>
</tbody>
</table>

4.3 Industrial robots

Industrial robots from ABB Robotics have a lifting capacity from 0.5 kg up to 800 kg and can today both feel and see objects with the aid of Force Control and True View. Typical work tasks for industrial robots are packing, welding, serving machines, lifting, painting and grinding, usually tasks that are heavy and unhealthy for workers. ABB’s robots can be placed on the wall, floor or on a rail. ABB’s industrial robots must be able to work fast and precise and handle fast accelerations and decelerations. The robots have a precision of 0.7 millimeter up to 0.07 millimeters (ABB, 2018). ABB’s smallest robot have a weight of 38 kg (ABB, 2017) and the largest a weight of 4574 kg and their lifting capacity is 0.5 kg and 800 kg respectively (ABB, 2017).

FANUC’s industrial robots have a lifting capacity from 1 kg up to 2300 kg and the weight are about 20 kg and 11000 kg respectively (FANUC, 2018). IRB 4600 have a weight of 435 kg, reach of 2.55 meters and a payload of 40 kg (ABB, 2018). M-710iC/45M have a weight of 570 kg, reach of 2.6 meters and a payload of 45 kg (FANUC, 2017).
4.4 Work Tasks Required for Building Sandwich Walls

The material that a sandwich wall consist of is a core of polystyrene plates that have stainless steel zigzag wire throughout the entire plate and both sides of the wall consist of concrete. The tools required to manually install these sandwich walls is a saw, a brick trowel, a cutting plier and a rebar tie tool. Manual work task for construction of sandwich walls are placing the polystyrene plate on the concrete plate and attaching it to a stud with the rebar tie tool. The rebar net is then placed on both sides of the polystyrene plate and are attached with the rebar tie tool by folding the zigzag wire that sticks out of the polystyrene core over the rebar net at several places. The wall is then sprayed with concrete on both sides and lastly the concrete is smoothened out with the finishing trowel. The polystyrene plate is cut with the saw and the zigzag steel wire is cut with the cutting plier when the polystyrene plate need adjusting.

4.5 Interview Study

A total of 11 interviews was conducted with 10 different companies, some of them was in the construction industry and some were in the manufacturing industry. The results are presented company by company since the companies are operating in different business sectors and therefore differ significantly, although digitalization an automation is a relevant topic of discussion for all of them.

4.5.1 Unibap

Unibap AB has developed a vision system for industrial robots. The long-term goal of Unibap is to teach robots to mimic a human workers way of working, i.e. they are enabling the robots to see, learn and to become more flexible. Unibap makes the robot see, which is the most powerful sensor (compared to our senses). The robot can detect safety issues and more with the vision system. Unibap are working on implementing the description of the work task directly into the CAD programs which removes all the steps of robot programming that currently are required. They are initially developing a plug-in for the CAD program Solidworks and will develop a plug-in for other CAD programs such as Catia and Creo later. Unibap’s system is self-adjustable which means if a mobile platform is used their system can handle variations in the environment. Unibap’s system have an accuracy of 2 micrometers due to the use of a stereo camera that is self-calibrating. Their system calibrates itself by a few references, for example three walls. By looking at the walls, the correct coordinates are located. The tool cannot be seen by the vision system since it is located under the camera, but by adding a mirror the camera can even locate the tools coordinates when looking into the mirror and then measuring the location of the tool, this method is an approved patent. According to Unibap the biggest challenges about automation is to reduce the requirement of large development resources such as programming and preconceptions about automation. Modern production is requiring more and more flexible automation. All kinds of tasks can be automated, and the low hanging fruits will be taken first.
4.5.2 ABB Robotics

ABB Robotics sells industrial robots, where the smallest robot has a pay load of 0.5 kg and the largest 800 kg. They are mainly used in industrial environments. With the introduction of force control, it is possible for a robot to feel pressure and torque which enables many more work tasks to be automated. Previously, work tasks such as post processing of parts, such as grinding, and assembly tasks were hard to automate. Force control makes it possible for an industrial robot to perform such tasks, where parts need to be handled with a certain amount of pressure and torque. According to ABB Robotics, safety is a challenge and have always been. The space in a factory is limited and costly and reducing the robot cells require less safety devices. The main challenges of today are short product cycles, digitalization, low volume and many change overs. All companies are calculating the return on investment (ROI) of automation and to see if it is beneficial. Nothing is impossible, it is more of a financial issue, than a technological. ABB Robotics believes that the electronic industry will become much more automated due to collaborative robots. The pharmaceutical industry is highly automated with high volume with a low variation of products but since the market is changing automation will be more robot oriented than machine oriented which is the same for the food industry. A new trend with automation is to move around machines and robots for enabling it to perform more work tasks because of low volume and high product variation. One challenge with mobile robots and machine is electric cables. Automation becomes cheaper for every year and the degree of automation is constantly increasing.

4.5.3 Trimble Solutions Sweden AB (BIM Expertise)

One of Trimble Solutions Sweden AB’s, strengths are their BIM expertise. Trimble Solutions Sweden AB is developing BIM software for the construction sector and they have competence for the entire chain, from project planning to maintaining the completed building. Together with Microsoft they have developed holographic software for the construction industry which produces an augmented reality right in front the operator’s eyes using a Microsoft HoloLens. The augmented reality is based on the BIM-model. In this augmented reality, an operator can walk around the BIM-model and the model stays completely still, no matter how much the operator moves. The HoloLens is also certified for protective eyewear which makes it suitable for usage on construction sites. The Swedish market is very conservative, but some companies such as Smederna AB, which was also interviewed for this thesis, are ahead with their work with BIM. One of the biggest challenges with BIM and automation is, according to Trimble, the dynamic environment that the construction industry works in. Benefits with robots are that they can help with some heavy lifting tasks. In the future BIM will be able to communicate between external program and sensors with real-time data.

4.5.4 Company A (Designs buildings with BIM)

Company A designs buildings to several contractors and use the BIM program Revit from Autodesk to create a digital model. Challenges that Company A needs to handle are which details must be in the digital model since some can be difficult to create in the digital model. The communication between Company A and their customers is often demanding since it is hard to know what the customer desires. A major challenge is that the contractor usually starts the construction before Company A is finished with the digital model. The digital model that Company A creates is not used by any contractor since they only require paper
drawings. Company A also use BIM to extract coordinates for piles which can be generated for all piles in a table.

4.5.5 Build-r

Build-r is developing a mobile industrial robot for mounting drywalls at construction sites. The reason for selecting this specific work task is that it is heavy work and it is used frequently. The robot which is a IRB 4600 from ABB will lift the drywalls with a vacuum tool and place it against the wall and screw it into the stud with an electric screwdriver. This particular screwdriver is used in other industrial settings and was chosen because of its high screw capacity and for its reliability. The robot takes a new drywall sheet and mounts it next to the first one. The robot will be mounted on a mobile platform which will consists of all the parts necessary to mount the drywalls. The platform will be driven by omni directional wheels which makes the platform able to drive in sideways in all directions. The compressor for the vacuum tool will also be mounted on the platform along computers and batteries. The robot has a cameras and laser scanners for navigation and stud finding. A full-scale prototype of the drywall robot is currently being developed and will be tested at a construction site in the summer of 2018. A goal that Build-r has is that the robot that they are developing can be operational during the night 24 hours per day. Build-r is working with ABB and the construction company NCC and they are receiving funds from Smart Built Environment. Challenges for Build-r was to design the mobile platform so that is stable since industrial robots are heavy. In figure 2 a CAD model of Build-r’s drywall installation robot is shown.

![Figure 2: Build-r drywall installation robot](image)

4.5.6 FANUC

FANUC is a manufacturer of industrial robots. FANUCs robots have vision integrated into this controller which makes vision easy and more affordable to install as an add-in. A picture can be taken from above to aid the robot to find tools and material which works as a guide for the robot. When the material and tools are placed it is not necessary to place them exactly as in the picture, the robot will find them anyway with high guidance. FANUCs robots are connected to a global network where they share and learn different tasks from each other. A few years ago, Fanuc produced around 5000 robots per year and now their goal is to produce 11000 robots per year due to increased demand. In Sweden Fanuc has in two years
doubled their sales. Collaborative robots are increasing in sales since it is possible for human to work together with them. These robots must be bolted into the ground because the collaborative function does not work if they are mobile. Collaborative robots do not have as high speed as regular ones. Challenges in automation according to Fanuc is safety which is a large part. Challenges on a construction site could be the environment such as the cold which can cause problems for the electronics in their industrial robots. In order for automation on a construction site to be successful the installation should be smooth and self-adjusting with calibrations procedures and fit inside a container. To make the end-user satisfied it should be simple to use, program and calibrate and it is important to include the end-user when discussing automation.

4.5.7 byBrick Interface AB

byBrick Interface are into augmented reality, augmented reality, mixed reality and more, they have large knowledge about making different programs communicate with each other. They use BIM for real-estate and are working together with a real-estate firm to create a virtual reality for customers to see and walk around in before the building is complete and before the construction begins. byBrick technology can reduce adjustments in the future by walking around inside a virtual building in the project planning phase. byBrick Interface receives 3D-data form their customers, which can be in BIM, 3DsMax etc, depending on what type of information should be shown in the virtual world. The 3D-data contains large amount of unnecessary data that must be reduced in order to run smoothly. byBrick Interface believes that Microsoft’s HoloLens technology is old even though it has not been publicly released in Sweden because of the fast technology development in augmented and virtual reality. byBrick Interface believes that the technology for controlling robots with machine vision is available. A large challenge with robots is people’s attitudes towards robots such as the mind-set that robots are taking our jobs.

4.5.8 Smederna AB

Smederna build steel constructions and use BIM for automating some of their production. The key to Smedernas success is that they have spent a lot their resources in designing the steel construction with effective and simple solutions. Since a lot of work is made in advance the assembly is quick and no need to rework anything. Their goal is to spend more time in the beginning phase and design everything in detail. Every part in the construction, large and small, have a unique number that have a specific location in the constructions in which they are to be used. When the construction elements are to be assembled all the holes are predrilled, all the beams are cut to the exact lengths within accepted tolerances, and there are premade markings for weld placements. Smederna says that their success comes from more than just automation, where they give most credit to their way of focusing a lot of work hours on the processes before the physical processing of the incoming material. This means that their drawings and work instructions are very well thought out as to avoid confusion and mistakes in later processes, such as physical handling and machining in the workshop, be it manual or automated. Smederna says that the work tasks which includes handling of heavy materials and the tasks which are time demanding are the tasks worth automating. Their ambition is also to stray from using regular paper drawings and move to using 3D models and drawings on handheld electronic devices, on which the entire BIM model can be referred to and explored in real time, further avoiding misinterpretations and eliminate the need for massive storages of physical paper sheets. When working with steel Smederna needs tolerances of one millimeter.
4.5.9 Company B (Wall prefabricator)

In the production at this prefabricator the level of automation was zero and the reason was that production of walls had a high variety of dimensions only a few walls where the same. The prefabricator has their focus on smart solutions instead of automation since automation have a high investment cost and the uncertainty of success. In their production, they produced different kind of walls such as sandwich walls which is the main focus in this report. The Sandwich walls consists of concrete on the outside, cellular plastic on the inside, rebars in different dimensions, a wire for lifting the wall, plastic pipes at the bottom for attaching the wall to the concrete foundation and sometimes electric cables. This prefabricator had several different concrete-mixes and all was tested before a wall was cast. A problem that sometimes occurred with the concrete-mix was that is become viscous which made it hard to flow out of the overhead concrete dispenser. There is some heavy lifting with the rebars and the posture was not ergonomic when lashing together the rebars.

4.5.10 Company C (Prefabricator of villas)

This prefabricator builds villas and have a low volume and high variation product mix. All villas are uniquely built since they are designed by the prefabricator together with the customer. The walls and trusses are assembled manually on large tables that are placed horizontally and when one side is complete the wall and truss are turned with the help of a bridge crane for the completion of the other side. Some wooden parts are precut in a semiautomatic saw machine before they are used in the assembly. The wooden parts are loaded into the machine manually, one by one. The machine saw the part in specific lengths and angles and are unloaded manually and placed together with all the wooden parts for the specific villa. The machine receives the dimensions and cutting information from BIM. The saw machine was implemented in 2016 for the purpose of reducing the heavy work task in lifting up the saw blade for every cut which was repetitive and not ergonomic. The personnel are open to implementing aid that ease the measuring and assembly task but persist that fully automatic solutions could reduce their high quality and difficult to implement. At this prefabricator, the tolerances usually lie within five millimeters, but around window the tolerances need to be narrower, within one millimeter.
### 4.5.11 Summary of the results from the interview study

A summary of the results from the interview study can be seen in Table 4. Due to the companies’ different business areas, all companies could not or did not have the knowledge to answer all questions.

*Table 4: Summary of the result from the interview study*

<table>
<thead>
<tr>
<th>Company</th>
<th>Key area of business</th>
<th>Possible to automate in construction</th>
<th>Automation challenges in construction</th>
<th>Automation benefits in construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unibap AB</td>
<td>Developing vision and artificial intelligence for robotics in manufacturing industries and space applications</td>
<td>Finding materials and coordinates</td>
<td>Large development resources and preconception about automation</td>
<td>Flexibility, higher accuracy</td>
</tr>
<tr>
<td>ABB Robotics</td>
<td>Manufacturing industrial robots</td>
<td>Industrial robots have become more flexible due to collaborative robots which enables more work tasks to be automated</td>
<td>Safety, electric cables, financial, short product cycle, digitalization, low volume and many change overs</td>
<td>Becomes cheaper every year, flexibility</td>
</tr>
<tr>
<td>Trimble Solutions Sweden AB</td>
<td>Selling and developing BIM program.</td>
<td>-</td>
<td>Dynamic environment</td>
<td>Reduce heavy lifting for humans</td>
</tr>
<tr>
<td>Company A</td>
<td>Project planning consulting, focus on constructing BIM models</td>
<td>-</td>
<td>Paper drawings, not utilizing a digital model</td>
<td>-</td>
</tr>
<tr>
<td>Build-r AB</td>
<td>Automation in construction</td>
<td>Heavy lifting, screwing, stud finding and transporting material</td>
<td>High weight of industrial robots</td>
<td>Operational all day and night, reduce heavy lifting and repetitive tasks</td>
</tr>
<tr>
<td>FANUC Nordic AB</td>
<td>Manufacturing industrial robots</td>
<td>Work tasks that requires locating for example materials with the help of a vision system</td>
<td>Safety, environmental factor such as cold</td>
<td>Flexibility</td>
</tr>
<tr>
<td>byBrick Interface AB</td>
<td>Developing cross reality interfaces for marketing and industries</td>
<td>-</td>
<td>Preconception about industrial robots</td>
<td>-</td>
</tr>
<tr>
<td>Smederna Sverige AB</td>
<td>BIM, design, automation</td>
<td>-</td>
<td>-</td>
<td>High accuracy, less rework, reduce heavy lifting, less storage of physical papers</td>
</tr>
<tr>
<td>Company B</td>
<td>Building prefabricated walls</td>
<td>-</td>
<td>Uncertainty of success and high investment cost</td>
<td>-</td>
</tr>
<tr>
<td>Company C</td>
<td>Building complete villas, focus on prefabrication</td>
<td>Cutting wood</td>
<td>Lower quality and difficult to implement</td>
<td>Reducing heavy repetitive work tasks</td>
</tr>
</tbody>
</table>
4.6 Conferences

Two conferences were attended and both of them were about digitalization. The following two subsections reports the findings from these conferences.

4.6.1 Utblick med BIM Alliance 2018

The conference Utblick med BIM Alliance 2018 was about digitalization in the construction industry and expert in different fields were invited to speak. There was a general consensus that the construction industry is behind the manufacturing industry in many ways, lacks data, the buildings does not become as-built, there is low standardization, slow innovation rate and a low utilization of digital tools. All the companies that spoke agrees that the construction industry have potential and could be better in utilizing available technology to increase productivity, reduce errors, making the building as-built and utilize BIM, AI and other digital tools through the entire supply chain. The conference goal was to mediate how the construction industry can become digital through different tools, methods and collaboration. Companies and the subject of which spoke of can be seen in Table 5.

*Table 5: Utblick med BIM Alliance Conference Speakers*

<table>
<thead>
<tr>
<th>Company</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formas</td>
<td>National investment on digitalization in community building from an innovation and research perspective</td>
</tr>
<tr>
<td>AI consultant</td>
<td>Opportunities with AI</td>
</tr>
<tr>
<td>Alimak Group</td>
<td>Digitalization and innovation</td>
</tr>
<tr>
<td>Maestro Design &amp; Management</td>
<td>Manufacturing and design in world class</td>
</tr>
<tr>
<td>Datscha</td>
<td>Proptech and BIM</td>
</tr>
<tr>
<td>ESS</td>
<td>Product lifecycle management</td>
</tr>
<tr>
<td>Tikab</td>
<td>True digital model based construction documents deliveries – the project Slussen</td>
</tr>
<tr>
<td>Skanska</td>
<td>Digital tools in production</td>
</tr>
<tr>
<td>Akademiska Hus, Zynka BIM</td>
<td>From real-estate data to new business opportunities</td>
</tr>
<tr>
<td>Tyréns</td>
<td>Parametric design and productization</td>
</tr>
<tr>
<td>Linköpings University</td>
<td>Connecting the construction sites</td>
</tr>
<tr>
<td>Svensk Betong and Skanska</td>
<td>Lifecycle perspective</td>
</tr>
<tr>
<td>Linköping University</td>
<td>Master’s degree in BIM</td>
</tr>
<tr>
<td>Plan B</td>
<td>National guidelines for BIM</td>
</tr>
<tr>
<td>Serneke</td>
<td>How to drive changes in organizations with the effects of digitalization</td>
</tr>
</tbody>
</table>
4.6.2 ABB Automation Scandinavia 2018

The ABBs Automation Scandinavia 2018 conference was about digitalization and how digital technologies can be used to increase quality, availability and productivity. In the manufacturing industry the digitalization is generally on a high level and this conference was how companies can become even more digital through the use of new tools that are available, AI and collaboration between different companies. The manufacturing industry is becoming more automated since industrial robots have become more flexible and collaborative and the potential to increase the level of automation is extremely high.

Table 6: ABB Automation Scandinavia 2018 speakers and subjects

<table>
<thead>
<tr>
<th>Title</th>
<th>Company</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chief Digital Officer</td>
<td>ABB Group</td>
<td>How ABB can make your company more successful</td>
</tr>
<tr>
<td>Project leader</td>
<td>Mälarenergi</td>
<td>Mälarenergi’s digital strategy journey to “the city’s control room”</td>
</tr>
<tr>
<td>Division manager</td>
<td>Borås Energi och Miljö</td>
<td>A hyper modern control room</td>
</tr>
<tr>
<td>Professor in computer science</td>
<td>KTH</td>
<td>AI and robotics – state of the art and challenges</td>
</tr>
<tr>
<td>Chief Automation Officer</td>
<td>Northvolt AB</td>
<td>Northvolt builds Europe’s largest factory for lithium batteries</td>
</tr>
<tr>
<td>Digital Lead</td>
<td>ABB Sweden</td>
<td>Collaboration, speed and innovation increase the rate in the digital transformation</td>
</tr>
<tr>
<td>Sales manager and CEO</td>
<td>Sales manager Robotics and B&amp;R Sweden</td>
<td>Journey to the future manufacturing industry</td>
</tr>
</tbody>
</table>
5 ANALYSIS

In this chapter, the three research questions are analyzed and the example concept case, built upon existing technologies, is described.

5.1 Research Question 1 – What Is Possible to Automate on the Construction Site with Today’s Technologies?

With today’s technology automating processes in the construction industry have been done in numerous ways in several parts of the world. Generally, monotonous and repetitive tasks are the most suited tasks for automation implementations, as supported by Chu et al. (2013), Build-r (2018), Panda et al. (2017) and Usmanov et al. (2017). ABB claims that with the introduction with collaborative robots, automation becomes more flexible and more business areas can be automated. Today there are few areas which cannot be automated according to the company Unibap and ABB Robotics, which claims that automation possibilities are more of a financial question than technical possibilities. The construction industry has a slow innovation rate (Bock 2015; Bogue 2018; Wu et al. 2016). There are however several ways that the construction industry is utilizing new technologies such as drones which 61 % of the construction industry uses in the U.S according to Tatum & Liu (2017) and 12 % in the U.K according to Bouge, (2018). Skanska begun to use augmented reality in some projects and looking into a full scale automated rebar station.

The examples of successful automation in the construction industry and upcoming are plenty; the companies Fastbrick and Construction Robotics have automated bricklaying in the construction industry on-site and research of robotized bricklaying is done by Usmanov et al., (2017). The company MX3D are currently constructing a steel bridge in Amsterdam through additive manufacturing in a factory, Gosselin et al., (2016) used an industrial robot to 3D print concrete, Labonnote et al., (2016) research shows that 3D printing can be implemented for large-scale structures. According to Anna Kochan (2000) have Stefan Moser developed an automatic manipulator for spraying concrete on to a surface. ETH Zürich are building a house, called DFAB House, with different types of automated processes where García de Soto et al., (2018) used an industrial robot to build a complex concrete wall. Komatsu are developing autonomous construction vehicles for use on-site and research of autonomous vehicles and robots guided by vision system are done by Lundeen et al., (2017), Feng et al., (2015), Chu et al., (2013), Almawayhi et al., (2017). The company Unibap have developed a vision system to guide and make robots more flexible. The company Odico are using robots for cutting complex shapes and Usmanov et al., (2017) use an industrial robot to cut bricks. The company Smederna has automated their steel beam manufacturing processes with the help of BIM where Chu et al., (2013) have developed a robotic beam assembly system for on-site. The company nLink draws information from BIM to drill holes with a robot on-site and the company Build-r are using a robot to install drywalls on-site. Both Teizer et al., (2017) and Kochovski & Stankovski, (2018) researched in collect real-time data utilizing IoT devises in the construction industry.

Robot systems have become more advanced which makes them able to work in unstructured environments and in several diverse fields (Bock, 2015). Based on research, the current state-of-the-art implementations of automation in the construction industries and the interviews conducted for this report, it is possible to automate countless work tasks in construction such as drilling, bricklaying, autonomous guiding of construction vehicles and
robots, 3D printing of steel, cutting, drywall mounting, spraying concrete, additive manufacture of steel walls and timber assembly. Tasks which are advantageous for automating are those that are monotonous, repetitive and entails poor worker ergonomics.

In the concept case when building sandwich walls a worker performs several tasks which are lifting, sawing, cutting, bending, spraying concrete and scraping with the tools: saw, brick trowel, finishing trowel, cutting plier and a rebar tie tool. For implementing automation on-site using industrial robots to build sandwich walls, which is rather complex, it is recommended by Davies, (2012) that a vision system should be installed. The industrial robot must also be able to move around on-site. Digital information will be utilized from the BIM model.

In order to get a better overview of what is possible to automate on-site with today’s technology, with the concept case as an example, the theory and empirical results are summarized in Table 7.

**Table 7: Concept case, potential robot tasks and corresponding theories and empirics**

<table>
<thead>
<tr>
<th>Concept case: Possible robot tasks and digital technologies</th>
<th>Corresponding Theories</th>
<th>Corresponding Empirics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifting and placing</td>
<td>(García de Soto et al., 2018), (Usmanov et al., 2017)</td>
<td>Build-r, FANUC, ABB Robotics, ETH Zürich, Fastbrick, Construction Robotics</td>
</tr>
<tr>
<td>Cutting</td>
<td>(Usmanov et al., 2017)</td>
<td>Odico</td>
</tr>
<tr>
<td>Lashing</td>
<td><em>Not found</em></td>
<td>Robotic Rebar Station (Skanska and Robotdalen)</td>
</tr>
<tr>
<td>Spraying concrete</td>
<td>(Wu et al., 2016), (Gosselin et al., 2016), (Anna Kochan, 2000), (Labonnote et al., 2016), (García de Soto et al., 2018)</td>
<td>ETH Zürich</td>
</tr>
<tr>
<td>Scraping</td>
<td>(Usmanov et al., 2017)</td>
<td><em>Not found</em></td>
</tr>
<tr>
<td>Finding materials and coordinates</td>
<td>(Lundeen et al., 2017), (Feng et al., 2015), (Chu et al., 2013), (Usmanov et al., 2017)</td>
<td>Unibap, FANUC</td>
</tr>
<tr>
<td>Movability</td>
<td>(García de Soto et al., 2018), (Almawyahi et al., 2017)</td>
<td>Komatsu, Build-r, Unibap</td>
</tr>
<tr>
<td>Utilizing BIM</td>
<td>(Lundeen et al., 2017), (Usmanov et al., 2017)</td>
<td>Smederna</td>
</tr>
</tbody>
</table>

Sawing and cutting could possibly be removed from the work tasks since the polystyrene blocks are smaller than the traditional polystyrene plates which will be illustrated in section 5.5.7.
5.2 Research Question 2 – What Are the Benefits of Automation on the Construction Site?

There are several benefits with automation such as increased safety according to Sharma, (2011) and Lundeen, (2017) said that industrial robots could increase safety in the construction industry which is agreed by the companies Fastbrick, Komatsu, Construction Robotics and according to Frohm et al., (2006) could be due to the fact that operators are kept out of the automation system and thereby are humans protected. Safety could also be increased by using IoT devises according to Kochovski & Stankovski, (2018). Higher productivity in automation could be due to the fact that automation often leads to faster results according to Sharma (2011), shorten project lead time according to Lundeen, (2017), García de Soto et al. (2018) found that automation led to higher productivity when building complex walls. Robots can work around the clock without a break and can be used for repetitive and heavy lifting tasks which increases ergonomics for workers, according to Usmanov et al. (2017). The following companies all agrees in some way that productivity is increased by robotics and automation, Fastbrick, nLink, Build-r, ETH Zürich, Komatsu, Construction Robotics, Odico and Smederna AB. Both Sharma, (2011), Lundeen (2017), Frohm et al. (2006), Chu et al. (2013) agrees that quality is an aspect that will increase with automation. Both nLink’s drilling robot and Fastbricks bricklaying robot increase accuracy which yields a higher quality which is also concurred by the company Unibap. According to Bonev et al. (2015), methods and concepts from the automotive industry have for some time tried to be implemented into research in construction to reach higher productivity.

The use of IIoT can find and correct problems faster than humans which saves time and money (Buyya & Dastjerdi, 2016). According to Tomita et al. (2017) UAV can be used for automated measurements, of satisfactory accuracy, which is less time consuming and presents less risk of injury for workers. Industrial robots are vital to increase the level of flexibility and automation in modern production system (Bolmsjö, 2006). Automation in the construction industry has the potential to return substantial operational, environmental and economic benefits (Bouge, 2018). According to Eastman (2008) utilizing BIM in the construction industry has major advantages such as reduce conflicts and errors and the planning process becomes smoother. According to Company E, benefits with robots are that they can help with some heavy lifting tasks. According to Skanska, building rebar cages manually on-site is heavy and not ergonomic and is therefore an optimal work task to automate in the construction industry.

Reasons for the increase of productivity in manufacturing could be due to the benefits from automation. As identified by Frohm et al. (2006), benefits from automation in manufacturing are efficiency improvements, cost reductions and enhanced competitiveness and productivity.
5.3 Research Question 3 – What are the challenges for implementing automation on the construction site?

Several researchers claim that the construction industry have a low innovation rate both Bock, (2015), Bogue (2018) and Wu et al. (2016). This low innovation rate could be because of a low research and development according to Bock, (2015), Smith & Tardif, (2009) adds that the worldwide construction industry has achieved little in technological advancement. Implementation of industrial robots in the construction is challenging due to high variety of tasks performed and are encircled by disorganized materials (Chu, et al., 2013; Papaioannou et al. 2017). The challenge of a dynamic environment is confirmed by ABB Robotics and the challege of high variety of tasks is confirmed by Trimble Solutions Sweden AB.

Digital technology provides data for automated manufacturing technologies (Eastman et al., 2008). One of the biggest challenges with BIM and automation is, according to Trimble Solutions Sweden AB, the dynamic environment that the construction industry works in. According to Skanska BIM is mainly used for winning building contracts and construction companies have to fight for contracts in a design-bid-build method. According to (Eastman et al., 2008) is the design-bid-build method a challenge since valuable collaboration cannot start before a contract is won. Safety is one main challenge in automation and it is confirmed by the companies FANUC and ABB Robotics.

When a building is complete it is based on the digital model and there are many modifications in the actual building which means that the digital and the actual building will have variations, meaning that an important part of the digital model is lost. This is confirmed by Company A which state that the digital model they create will not be as-built when the construction is complete. According to Albinsson (2018), new technologies that will arise to the construction sites that cannot be fully implemented today since there is a lack of drawing documentations and digital substrates.

Smederna follows their BIM model fully but they emphasis allocating resources to the beginning of the project so that the steel construction can be assembled efficiently later. Build-r has challenges with integrating the various parts together and to design the mobile platform so that is stable since industrial robots are heavy. Main challenges today in the manufacturing industry according to ABB Robotics are short product cycles, digitalization, low volume and many change overs. In the past, flexibility was a challenge according to Bolmsjö, (2006). All companies are, according to ABB Robotics, calculating the return on investment (ROI) of automation which means that it is an important measurement for the planning of automation investments. One challenge with mobile robots and machine is electric cables according to ABB Robotics. Challenges according to the company Unibap are the requirement of large development resources and preconceptions about automation. byBrick Interface also emphases preconceptions about automation where it is not uncommon for it to be seen as a means to replace workers, which creates an opposition against automation. Autor (2015) mentions that the types of jobs available, as well as what they pay, indeed changes due to automation. However, Autor (2015) also stresses that, in the past two centuries, human labor has not been made obsolete by automation or technological advancements, even though automation is typically intended to substitute for labor. One of the reasons is that it also complements labor and foster higher demand for labor through increased production outputs.
The global analysis of the state-of-the-art implementations did not provide any challenges in their implementations, these companies only provided benefits. Therefore, no analysis can be drawn from challenges these companies might have been presented to.

5.4 Automation Concept Case

In this chapter, a concept case is presented in the purpose to examine what kind of technologies can be used to achieve the building of four sandwich walls on-site. These walls are utilizing a zigzag rebar technique in prefabricated blocks of polystyrene which, after the assembly, has rebar nets mounted on them and then gets sprayed with concrete on both sides of the wall.

5.4.1 Requirements

For this case, the concrete foundation for the villa is a prerequisite and is assumed to exist prior to the implementation of automation for this suggested case. Regarding materials, it is a prerequisite that they are pre-cut and supplied at the correct locations on-site, ready to be used for construction by the robots. In this case, the robots are not meant to be performing their tasks in real time collaborations with humans, due to the complex nature of such installments, it is therefore a requirement that no human workers enter the perimeter of the work site while robots and machines are operating.

5.4.2 Industrial robot

Build-r are in collaboration with ABB and selected an IRB 4600 for their operation since it has the capacity to lift drywalls, the reach is long enough, and their mobile platform can handle the weight of the robot. Build-r made a reasonable selection since selection of an industrial robot that have a low weight, long reach and a high payload is limited, therefore tradeoffs must be made. FANUC has a similar robot with regards to weight, reach and payload. The selection of an industrial robot to the concept case would be the IRB 4600 since it weighs less than M-710iC/45M.

5.4.3 Machine vision

According to Davies (2012) a vision system should be installed for complex task that will be carried out by a machine. The construction site is an ever-changing environment and few work tasks are identically performed at each occasion (Vähä, et al., 2013). Unibap’s vision system could be used for guiding the robot on-site since it is an ever-changing environment. For the concept case Unibap’s vision system would be selected since their system is self-calibrating and has a very high accuracy, which is important for success according to FANUC.
5.4.4 BIM

BIM has information about spatial relationships, geographical information, geometry, properties of building components, quantities etc. (Vähä, et al., 2013). Advantages with BIM is reduced project duration, lower cost and better-quality buildings (Eastman, et al., 2008). The research of BIM is growing and there is a rapid adoption and development in BIM technologies (Zou, et al., 2017). Unibap are developing a plug-in for the CAD program Solidworks and will develop a plug-in for Catia and Creo later. Perhaps it could be possible to develop a plug-in for BIM as well. BIM contains all the relevant information of a building, have several advantages and substantial research and adoption, is therefore the logical choice for the digital substrate in the concept case.

5.4.5 Mobile Platform

In order for the industrial robot to be able to move around a construction site it must be mounted onto a mobile platform, rails, gantry or portal. For our concept case, a mobile platform is selected because it needs no installation and it is easier to transport. Build-r will use a mobile platform with omni directional wheels, but the proposed concept will be working both inside and outside on-site with makes caterpillar treads a better choice. Alitrak DCT-450 is one mobile platform that could be selected to our concept, but one main disadvantage is the loading capacity at 450 kg since industrial robots generally has a low lifting capacity to weight ratio, which makes them very heavy. A lighter industrial robot could be mounted onto this platform for the purpose of performing a task that does not require such a high lifting capacity. However, a platform that supports a higher loading capacity for a heavier robot is needed since lifting a rebar net requires longer reach and higher lifting capacity. Selection of an existing platform that supports a heavier weight has not been, because a perfect fit could not be found. Instead, a mock up platform was modelled.

5.4.6 Execution

Materials could be placed outside or inside of the building in approximate places and with the help of the vision system the material can be located. Appropriate tools will be mounted on the robot and should be able to be switched by the robot, if necessary. There could be several robots in different sizes that performs different tasks and collaborates when necessary. Lifting and placing the polystyrene could be performed by a small or a large robot depending on the weight and size of these. Perhaps lifting a large heavy rebar net could be done in collaboration by two small robots instead of one large. Attaching the rebar with the polystyrene could be done by a large or small robot. Spraying concrete and the scraping of the walls for the last finish should be executed by a large one since a long reach could be vital.
5.4.7 Solidworks Layout

Below is the proposed example of a robotic construction case, modelled and rendered using Solidworks 2017-18. In the rendition, the robots are outfitted with Unibap’s Intelligent Vision System 70 (IVS-70). The placement of the IVS-70 is likely to be changed to achieve optimal functionality. Additional renditions can be found in appendix.

![Figure 3: Example of an on-site robotic construction layout](image)

5.4.8 Safety

Safety is one of the greatest challenges with automation according to several companies in this report and should not be taken lightly. The industrial robot will perform its tasks without human intervention while operating. Safety devices such as scanners or sensor plates could be set up so that when a human enters the robot working area it will instantly come to a stop. Humans could oversee the robot from a safe distance and provide supplements and support when needed.

5.4.9 Automation concept regarding the RQs

As a synthesis of the data collected for this thesis, the automation concept represents a possible near-future implementation of robotic on-site construction. The concept’s feasibility is supported by findings from the data collections conducted by the authors, where work tasks, similar to those in the concept, have been successfully automated in other settings, such as lifting, cutting and drilling. While it therefore can be considered a possible implementation, there are still challenges to acknowledge. As the data also suggests, the construction sites are far from isolated laboratory environments, implying that the concept requires advanced digital technology in order to function as intended. This is because the robots and their equipment will be subject to both changing weather conditions and changing work conditions with uncleanness, such as dirt, and most likely scattered building material in assorted sizes. This, in addition to the fact that some of the building material is imprecise, compared to the often submillimeter tolerances of the manufacturing industry, leads to the need for self-adjusting and self-calibrating machines. This challenge can be tackled with the use of digital databases together with BIM and
vision systems, such as Unibap’s. Another challenge is that there are currently not any construction robots established on the market, which limits the choices of suitable robots capable of performing heavy lifting while still being mobile enough to move about the typical construction site. In this case ABB’s robot IRB 4600 were chosen to illustrate the robotic application. With an automation implementation such as this, there are several possible benefits which can be gained. As discovered through the data collection, the potentials of automation are indeed many, such as productivity increases, cost reductions and increased worker safety, where the automation solutions should do the heavy lifting and strenuous tasks so that the workers do not have to.
6 DISCUSSION AND CONCLUSIONS

The purpose of this report is to investigate technologies that could be used to automate on-site construction operations via the use of digital technologies. Both small start-up companies and huge companies from many corners of the world are looking to automation to increase production and safety in the construction industries. The world of automation has grown rapidly for the last four decades as computers are constantly becoming more advanced and versatile which enables for more and more work tasks to be automated. In recent years more and more, automated solutions have been implemented in our society such as self-driving cars, trucks and heavy vehicles, AGVs, UAVs and more.

The construction on-site is a highly dynamic environment according to Papaioannou et al., (2017) which have made automated solutions problematic. However, in recent years, sensors, vision and other new technologies are enabling robots to be more versatile and safer to implement in the construction industry. There are robots available that are fenceless and safe to work together with humans that are not confined in one single place.

Many companies have begun to collaborate with different companies from other business areas, resulting in mutual benefits. Collaboration between companies that are specialized in different business areas are seen as a key to success by many and there are several examples of collaboration in this report. According to Kochovski & Stankovski, (2018) IoT can be used to support collaboration in the construction industry. Adopting BIM can enable close collaboration with construction and design teams (Eastman et al., 2008; Krygiel & Nies, 2008). Collaboration is seen as an aspect that can improve productivity in the construction industry. Close collaboration of construction and design teams is possible when adopting BIM, which will make construction deliveries more reliable, less costly, reduces errors and enables faster processes. (Fulford & Standing, 2014). Skanska have begun to collaborate with ABB, Volvo CE, Robotdalen, Trimble and is funding the research project ARRAY. Other companies that are in collaboration are: Fastbrick and Caterpillar, which have signed a MOU, Build-r are collaborating with their innovation together with ABB and NCC, MX3D are in collaboration with several companies, ETH Zürich are collaborating with numerous companies to build the DFAB House, Komatsu have signed partnership with NVIDIA for making construction vehicles autonomous.

The manufacturing industry have had several automation challenges in the past which has been overcome through the use of technology and information. The construction industry could possibly face the same, or similar, challenges but they have the chance to learn from history which could ease difficulty of the implementation of automation. In many manufacturing plants the production can run 24 hours per day and 365 days per year. In the construction industry in Sweden, of the 24-hour available the construction projects are only active in two-thirds of these. Build-r’s vision is to increase production in the construction industry by utilizing the night shift since there are no operations done at this time.

The industrial robots are heavy and have a low lifting capacity compared to its own weight. In the construction industry an industrial robot has working condition of loose tolerances, imperfect measurement and large workpiece uncertainties (Lundeen, et al., 2017). The reason behind the high weight is because the robot is required to work fast and accurate in manufacturing. The construction industry does not require as high accuracy as the manufacturing industry since working with wood the tolerances that are necessary are one to five millimeters and with steel about one millimeter. In the manufacturing industries, the
industrial robots do many repetitive tasks for many thousands of products which require speed. This lowered accuracy requirement could be paired with a vision system to make sure that the robot compensates for already installed elements.

A dedicated construction robot (CR) should be able to have a reduced weight if adjusted solely for the construction industry since precision and speed can be slightly reduced. A CR must be able to move around in an unstructured environment both inside and outside which sets requirements on the weight. A CR should perform several work tasks instead of many repetitive such in the manufacturing industry. A CR must be built to withstand the harsh environment inside and outside of the building. nLink have combined an industrial robot with hydraulics with a scissor lift which reduced the need for a large and heavy robot that could drill the holes. Based on how different companies have previously handled the issue of movability of a robot in the construction industry, with respect to the fact that it is an everchanging environment and variable terrain, a mobile platform has been a choice by many. This is because it that can handle variations in the terrain, rain and dust but also be stable when the robot is moving. Stabilizers that unfolds when the platform is stationary could increase stability if a heavy industrial robot is mounted into the mobile platform.

It is a vital aspect to begin to use BIM as a live model since it can be used for a basis in automation tasks and also for digitalization of the construction site. The Microsoft HoloLens can already be used in the construction industry as an aid for construction workers on-site, which is possible by the use of BIM. Furthering the usages of BIM more extensively throughout the construction industries could have huge benefits in the future when automating work tasks with the help of BIM is implemented.

There is much to gain from automating work tasks on the construction site. Productivity and safety aspects are one good motive to develop automation solutions which can be implemented at a construction site, since it has the potential to increase speed, lower the occurrence of accidents and also to free the workers from repetitive and strenuous work tasks. In addition to the safety concerns at a typical construction site, manual labor, in contrast to automation, also leads to inexact results, unnecessary waste of build material and long lead times for the completion of tasks. These are all problems that can be tackled using automation, provided that the technologies needed for implementing such solutions is accessible.

**RQ 1 – What is possible to automate on the construction site with existing technologies?**

Companies in this report have utilized industrial robots and machines to automate operations in the construction industry. Some of these companies are in the beginning stage, some are in the testing stage and others are implemented at various stages in the construction industry. It is possible to automate numerous work task in the construction industry since industrial robots have become more flexible and vision system have become more advanced.

It is possible to automate task that are installation of drywalls, drilling, cutting, spraying of concrete, timber assembly, bricklaying, additive manufacturing of steel walls and autonomous guiding of vehicles. Generally, monotonous and repetitive task are the work task that should be automated first.
RQ 2 – What are the benefits of automation on the construction site?
Automation in the construction industry have been implemented by several companies in different ways and at various stages and benefits that will come from these solutions are, higher production, increased safety, lower costs, better accuracy, fewer errors, faster completion and better ergonomics.

RQ 3 – What are the challenges for implementing automation on the construction site?
Challenges for implementing automation on the construction site are several and could experience the same challenges that the manufacturing industry had in the past which is a great opportunity to learn how they tackled those challenges. Challenges that are facing the construction industry today are a dynamic and ever-changing environment, low research and development budget, reluctance in new strategies, safety, preconception about automation, allocating more resources in the start of the project, continuous updating of the digital model and safety, the design-bid-build method that hinders collaboration.

Thesis Purpose
In this thesis, several existing and emerging automation solutions for automating on-site construction operations, with the use of digital technologies, has been reported. The three research questions have been answered where this thesis describes the possibilities, benefits and challenges with automation. To reach this goal, the authors sought data through literature, interviews, global analysis and conference attendances, which all gave similar results, pointing towards a future with possibilities for increased automation, bringing forth important benefits. Key enablers for this to happen is increased collaboration between companies and members of the operations’ supply chains, as well as an increased level of digitalization.

Future Research
This thesis evaluates the current level of digitalization and automation in the construction industry, but not how to increase those aspects. Therefore, important topics for future research could be regarding how to best increase the digitalization and automation levels in the construction industry. Further research could also be about how to standardize digital methods to increase co-operability between construction companies and their involved parties, since collaboration often proves to be a great strategy for rapid development. Lastly, research regarding the development of automation equipment tailor made for the construction industry would most likely be of great benefit, and enabler, for reaching increased automation levels. Research on integrating hydraulics on industrial robots in creating a CR could be of interest for the axis with the highest torque to reduce the weight, the speed and accuracy could be compensated by the other axis.
7 REFERENCES


### 7.1 Global Analysis References


APPENDIX – Additional Renditions of Concept Case

Figure 4: Additional render of concept case - no.1

Figure 5: Additional render of concept case - no.2